DEVELOPING METHODS TO REDUCE BIRD MORTALITY IN THE ALTAMONT PASS WIND RESOURCE AREA

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Governor

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- FINAL REPORT -

PIER-EA Contract No. 500-01-019

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PREFACE

The Public Interest Energy Research (PIER) Program managed by the California Energy Commission (Commission) supports public interest energy research and development that will help to improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. The PIER Program annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions. PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
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- Renewable Energy
- Environmentally Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

What follows is the final report to the California Energy Commission for Contract Number 500-019-01, conducted by BioResource Consultants of Ojai, California, as a contribution to the Energy-Related Environmental Research Program. For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Publications Unit at 916-654-5200.

REPORT ORGANIZATION

Chapter 1, *Understanding the Problem*, reviews the hypotheses and speculations of the causal factors of bird mortality at wind farms. Beginning in Chapter 1, the term "wind farm" is used throughout. A wind farm consists of more than one wind turbine and the related infrastructure needed to collect the generated power. It presents a framework and terminology for discussion of the problem, as well as the experimental and analytical approaches used in this study, and why they were used. This chapter also describes the objectives and the study area.

Chapter 2, *Cause of Death and Locations of Bird Carcasses in the APWRA*, presents a summary of the causes of death attributed to carcasses found in the APWRA, and it analyzes the distances of carcasses found from wind turbines. The mortality estimates presented in Chapter 4 are adjusted based on an analysis of the distances that carcasses were found away from the wind turbines.

Chapter 3, *Bird Mortality in the Altamont Pass Wind Resource Area*, presents the fatality search methods and the mortality estimates. These estimates were adjusted by search effort and searcher deficiencies such as the limitations of the search radius, removal of carcasses by scavengers, and searcher detection rates. Mortality is estimated and compared inter-annually, as well as summarized for the study period with low and high estimate values for mortality per species.

Chapter 4, *Impacts to Birds Caused by Wind Energy Generation*, integrates standardized estimates of bird mortality among those wind energy facilities from which estimates have been reported. This chapter places the bird mortality of the APWRA in context with other wind energy facilities. It compares bird mortality and bird activity levels in the APWRA among studies that reported these metrics from the early 1990s through the present study nearly a decade later.

Chapter 5, *Range Management and Ecological Relationships in the APWRA*, summarizes ecological patterns observed in the APWRA and how they relate to rodent control, physiography, elevation, and other measured variables. This chapter examines vegetation height, cattle grazing intensity, the abundance of certain raptor prey species, and speculates on how each might relate to the wind turbine-caused mortality of various bird species.

Chapter 6, *Distribution and Abundance of Fossorial Animal Burrows in the APWRA and the Effects of Rodent Control on Bird Mortality*, presents an analysis of how ground squirrels and pocket gophers responded to a rodent control program conducted in the APWRA, as well as to other measured variables, such as slope grade and elevation. The distribution and abundance of ground squirrels and pocket gophers is related to raptor mortality in this chapter, and the effectiveness of the rodent control program is evaluated.

Chapter 7, *Bird Fatality Associations and Predictive Models for the APWRA*, begins by reviewing hypothesized causes of bird collisions with wind turbines. It then provides details about the variables that were measured and the methods used to test for significance of associations between predictor variables and bird fatalities. All possible relationships between fatalities and measured variables were tested. The most meaningful results are presented and used to formulate indicators of threat posed by wind turbines to selected bird species in the APWRA. Maps of predicted levels of threat are presented for future planning purposes (e.g., turbine siting).

Chapter 8, *Bird Behaviors in the Altamont Pass Wind Resource Area,* presents the experimental and analytical methods used to study bird activity levels and behaviors in the APWRA. Significant and meaningful associations between measured predictor variables and behaviors are summarized.

Chapter 9, *Conclusions and Recommendations*, identifies mitigation measures that follow from the research results and that will most effectively reduce bird mortality caused by the continued operation of the existing wind turbines in the APWRA. This chapter also prioritizes the recommended mitigation measures, and recommends discontinuing some that remain in use.

Appendix A is a paper entitled, *Measuring Impacts to Birds Caused by Wind Turbines*. The standard measurement of mortality currently being used by researchers is the number of fatalities per wind turbine per year. This paper presents a new metric for reporting bird mortality at energy generation facilities, including wind energy facilities. This metric, the number of deaths per megawatt of power generation per year, standardizes comparisons of impacts among wind farms composed of very different wind turbine models, as well as between wind power generation and other forms of power generation. The term will be easier for the public to comprehend because it is one simple step away from presenting the impacts on a per capita or a per household basis. This chapter, and this metric, provides much of the foundation for data presented in Chapter 4.

Additional technical appendices (B, C, and D) are provided in the order in which they are referenced in the report.

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EXECUTIVE SUMMARY

For decades, research has shown that wind turbines in the Altamont Pass Wind Resource Area (APWRA) kill many birds, including raptors, which are protected by the Migratory Bird Treaty Act, the Bald and Golden Eagle Protection Act, and/or state and federal Endangered Species Acts. Each violation of these acts can result in fines and/or criminal convictions.

Early research in the APWRA on these bird fatalities mainly attempted to identify the extent of the problem. However, in 1998, the National Renewable Energy Laboratory (NREL) initiated research to address the causal relationships between wind turbines and bird mortality. The Public Interest Energy Research Environmental Area (PIER-EA) of the California Energy Commission funded a project by BioResource Consultants to build upon and expand those previous endeavors and determine whether measures could be implemented to reduce bird collisions with wind turbines in the APWRA.

Two factors heighten the urgency and importance of resolving this issue. First, one goal of California's renewable portfolio standard (RPS) is meeting 20% of the State's electricity needs through renewable energy sources by 2010. Second, Alameda County placed a moratorium on issuing permits to increase electrical production capacity in the APWRA beyond the existing 580 MW permitted capacity until there is demonstrable progress toward significantly reducing bird mortality.

With more than 2,000 megawatts (MW) of installed generating capacity in California, wind turbines provide up to 3.5 billion kilowatt-hours (kWh) of emissions-free electricity for the state annually. By identifying and implementing new methods and technologies to reduce or resolve bird mortality in the APWRA, power producers may be able to increase wind turbine electricity production at the site and apply the mortality-reduction methods at other sites around the state and country.

It is the mission of PIER-EA to develop cost-effective approaches to evaluating and resolving environmental effects of energy production, delivery, and use in California. In addition, an objective of the PIER Renewable Area is to expand renewable distributed generation technologies to help provide electricity generation in high-demand, high-congestion areas. By addressing bird mortality issues in the APWRA, the PIER-EA is helping to alleviate the most important environmental issue being associated with wind power generation, while also supporting the development of renewable energy generation in the State.

Objectives

This four-year research effort involving more than 4,000 wind turbines was aimed at better understanding bird mortality at the world's largest wind farm—the Altamont Pass Wind Resource Area (APWRA) in central California. Electricity-generating wind turbines installed in the APWRA kill large numbers of birds of many different species, including many raptors. Researchers studied bird behaviors, raptor prey availability, wind turbine/tower design, inter-turbine distribution, landscape attributes, and range management practices in their effort to explain the variation in bird mortality with the goal of developing predictive models that could be useful for future planning decisions in the APWRA.

The primary objectives of this research were to: (1) quantify bird use, including characterizing and quantifying perching and flying behaviors exhibited by individual birds around wind turbines; (2) evaluate the flying behaviors and the environmental and topographic conditions associated with flight behaviors; (3) identify possible relationships between bird mortality and bird behaviors, wind tower design and operations, landscape attributes, and prey availability; and (4) develop predictive, empirical models that identify areas or conditions that are associated with high vulnerability.

Approach

Other studies have evaluated bird mortality in the APWRA. For this study, researchers adopted the following approaches to help improve accuracy and the usability of the resulting data. For example, the researchers:

- conducted searches at 2,548 wind turbines in addition to the 1,526 wind turbines they had studied previously,
- adjusted mortality estimates to account for errors in detection rates and the rates of removal of carcasses by scavengers,
- used the number of fatalities per MW per year as the mortality metric, thereby avoiding the potentially false appearance that larger wind turbines kill more birds, and
- presented mortality estimates as ranges, where the lower end of the range was the mortality adjusted for fatalities that were likely missed beyond the 50-m search radius, and the upper end was the mortality adjusted for fatalities missed due to undetected carcass removal by scavengers.

Outcomes

Researchers found that at least three years of carcass searches are needed before the sample of wind turbines sufficiently stabilizes in the percentage of non-zero mortality values. Using a monitoring duration less than three years may yield unreliable estimates of mortality.

Researchers explored the relationship between the time each bird species spent close to wind turbines and the number of fatalities. They found that:

- inter-specific variation in mortality could not be explained by variation in the number of flights within close proximity to wind turbines, and
- some bird species spent more time flying within 50 meters (m) of wind turbines than expected, and they spent less time within 51–100 m or 101–300 m, which indicated that those species were attracted to the areas near to wind turbines,
- most flights by golden eagles, red-tailed hawks, American kestrels and all raptors combined were at heights at or below the rotor planes existing wind turbines in the APWRA.

Unique suites of attributes are related to mortality of each species, so the researchers conducted species-specific analyses to understand the factors that underlie wind turbine-caused fatalities. They found the following:

- Golden eagles are killed more frequently than expected by chance alone at wind turbines located in areas in the APWRA characterized as canyons.
- Higher mortality of a number of species within part of the APWRA was related to rock piles that were produced during wind tower installation. This correlation could be a result of desert cottontails and ground squirrels (prey species for large raptors) inhabiting these rock piles.
- The degree of clustering by pocket gophers around wind towers was associated with red-tailed hawk mortality, and the degree of clustering of gophers appeared greatest on steeper slopes where laydown areas and access roads were cut. The degree of clustering of pocket gophers and desert cottontails was also greatest where rodent control measures were applied.

In terms of bird fatalities attributable to turbine designs or arrangements, researchers found the following:

- Turbines mounted on tubular towers killed disproportionately more red-tailed hawks and other raptors—as did wind turbines on taller towers, those with larger rotor diameter, and those with slower to intermediate blade tip speeds.
- Perching on wind turbines or their towers is a less important factor contributing to mortality than previously suspected.
- Wind turbines installed in wind wall configurations[1] are safer for birds, as are wind turbines within dense clusters of turbines and those forming the interior of wind turbine strings.
- Wind turbines were most dangerous at the ends of turbine strings, at the edges of gaps in strings, and at the edges of clusters of wind turbines.
- The most isolated wind turbines killed disproportionately more birds.

Researchers also observed seasonal variations:

- Winter and summer were the two seasons of the year when disproportionately larger numbers of birds were killed, although there were species-specific differences.

The study estimated that between 881 and 1,300 raptors are killed annually in the APWRA. For all birds combined, that number is estimated at between 1,766 and 4,721. These estimates translate to 1.5 to 2.2 raptor fatalities/MW/year and 3.0 to 8.1 bird fatalities/MW/year. Over 40 different bird species are represented in the fatalities. Among these, researchers estimate that the APWRA wind turbines are annually killing 75 to 116 golden eagles, 209 to 300 red-tailed hawks, 73 to 333 American kestrels, and 99 to 380 burrowing owls.

[1] A *wind wall configuration* consists of parallel rows of wind turbines closely aligned to each other but with alternating tower heights.

Over the past 15 years, the risk to birds of turbine-caused fatalities increased substantially in the APWRA. The number of raptors observed per hour declined while mortality remained steady, so the ratio of the number of deaths per MW to the number of raptors seen per hour increased.

To assert that the APWRA is anomalous in its bird mortality may be misleading when comparing it to other wind energy facilities. While a relatively large number of raptors are killed per annum in the APWRA, the ratio of the number killed to the number seen during behavior observations is similar among wind farms where both rates of observation have been reported. It appears, based on the research reports reviewed for this project, that when comparing wind energy facilities birds tend to be killed at rates that are proportional to their relative abundance among wind farms.

For the development of the predictive models, researchers performed tests that accounted for differential search efforts among groups of wind turbines, and examined test results for associations that were both statistically and biologically sound. The models ranged in predictive power from 37% to 82% correct classification, and projected that of the 4,075 wind turbines in the sample, 6% to 67% posed greater threat levels, depending on the bird species considered. To demonstrate the utility of the modeling approach, the report focused on four raptors species, even though the fatality associations used for model development were also estimated for multiple other species. The modeling results were more reliable for golden eagles and burrowing owls than they were for red-tailed hawks and American kestrels.

Conclusions, Recommendations, and Benefits to California

The researchers conclude that many of the bird collisions with wind turbines are associated with factors that could not be understood within the scope of this project, or that may simply be random. Most of the variation for some species may be explained by factors not addressed in this study. However, the findings are sufficiently robust for the wind industry to begin repowering with larger turbines according to recommended guidelines, or implementing a series of mitigation measures that will avoid, reduce, and offset impacts caused by existing and future wind turbines in the APWRA.

The researchers conclude that the most effective solution to reduce bird mortality would be to replace the numerous small turbines currently installed with fewer, larger turbines. A repowering program is beginning in the APWRA that replaces many of the existing turbines at a ratio of approximately seven to twelve older, smaller turbines with one newer, larger turbine. The effect that the repowering program will have on bird mortality is unknown; however, the research presented in this report suggests that repowering may reduce mortality, especially if turbines are installed on the tallest practicable towers. Also, these research results should aid the siting process of any new turbines with a primary goal being to install new turbines in locations and in arrangements that will result in fewer bird kills than in the past.

If the wind turbine owners fail to repower with larger turbines, then the report provides the foundation for the aggressive implementation of management strategies that will most likely

promote a partial reduction in bird mortality. To help alleviate bird mortality in the APWRA, the project researchers recommend implementing the following mitigation measures:

- Cease the rodent control program
- Relocate selected, highly dangerous wind turbines
- Move rock piles away from wind turbines
- Retrofit tower pads to prevent under-burrowing by small mammals
- Remove broken and non-operating wind turbines
- Install wind turbine designs beneficial to the APWRA bird fatality issue
- Implement the means to effectively monitor the output of each wind turbine
- Retrofit, using APLIC guidelines (minimum), noncompliant power poles

The following measures would be appropriately applied experimentally, due to the degree of uncertainty in their likely effectiveness. However, these measures could also be applied universally, but with the understanding that they might not substantially reduce bird mortality.

- Reduce vertical and lateral edge in slope cuts and nearby roads
- Exclude cattle from around wind turbines
- Install flight diverters
- Paint blades using the Hodos et al. scheme
- Experiment with devices that will identify when to operate problem wind turbines with the least effect on birds.

Researchers also recommend that certain measures be abandoned by the owner/operators as options for reducing bird mortality in the APWRA:

- Rodent control program
- Installing perch guards on wind turbines
- Providing alternative perches
- Barricading the rotor planes of turbines

If all mitigation measures supported by this project's findings were implemented, mortality might be reduced by up to 20–40%, depending on the species, and perhaps as high as 40–50% should the mitigation measures act synergistically to reduce mortality. The remaining, random portion of the mortality would likely continue in the APWRA for as long as the existing wind turbines operate at or above the current output capacity. To compensate suitably for these continuing and unavoidable losses of birds, off-site mitigation directed to protecting regionally important wildlife habitat may be warranted.

Benefits to California will accrue if there is a demonstrable reduction of bird mortality in the APWRA. Doing so will encourage more energy capacity to be permitted by Alameda and Contra Costa counties. By repowering with fewer, larger wind turbines mounted on the tallest practicable towers, and/or implementing some or all of the recommended mitigation measures identified in this report, the owner/operators of the APWRA can expect to achieve improved compliance with state and federal laws and regulations protecting birds.

ABSTRACT

Wind turbines in the Altamont Pass Wind Resource Area (APWRA) provide on average 1.1 billion kilowatt-hours (kWh) of emissions-free electricity annually, enough to power almost 200,000 average households per annum, but these turbines also kill birds that are legally protected, and have been doing so for decades.

This five-year research effort focused on better understanding the causes of bird mortality at the world's largest wind farm. Researchers studied 2,548 wind turbines and combined their data with results from 1,526 wind turbines they had studied previously. They sought to: (1) quantify bird use, including characterizing and quantifying perching and flying behaviors of individual birds around wind turbines; (2) evaluate flight behaviors and the environmental and topographic conditions associated with them; (3) identify possible relationships between bird mortality and bird behaviors, wind tower design and operations, landscape attributes, and prey availability; and (4) develop predictive, empirical models that identify turbine or environmental conditions that are associated with high vulnerability.

Researchers concluded that bird fatalities at the APWRA result from various attributes of wind turbine configuration and placement, and that species-specific behavior plays a large role in how each contributory factor affects mortality. The report details numerous specific observations.

Researchers identified and evaluated possible measures to mitigate bird mortality in the APWRA. They offer recommendations to discontinue or modify some current management actions, to implement new ones immediately, and to experiment with others. Data presented in the report support these recommendations. The results suggest that repowering with carefully placed, modern wind turbines mounted on taller towers may be the preferable means to substantially reduce bird mortality.

CHAPTER 1

UNDERSTANDING THE PROBLEM

1.1 INTRODUCTION

Beginning in 1989, researchers have consistently documented that wind turbines in the Altamont Pass Wind Resource Area (APWRA) kill large numbers of birds—especially raptors (Orloff and Flannery 1992, 1996; Howell 1997; Howell and DiDonato 1991). Early researchers mainly focused on locating fatalities and quantifying bird mortality. Though they hypothesized various causes and mechanisms associated with wind turbine-caused fatalities, this early research was directed mainly at identifying the extent of the problem, not at the underlying causes.

In March 1998, the National Renewable Energy Laboratory (NREL) initiated research to address certain complex questions: What is the full extent of bird mortality in the APWRA? What are the underlying causes of the mortality? What role do bird behaviors play in mortality at wind turbines? Is mortality predictable at wind turbines with certain suites of characteristics? If it is, then can management strategies be developed to reduce mortality?

To help understand the complexity underlying these questions, and some of the terminology associated with them, we present the following framework for addressing and interpreting factors related to bird mortality in the APWRA.

Step 1	Natural behaviors, geographic distributions, and ecological relationships that predispose wildlife to harm due to wind turbines	→	**Susceptibility**
Step 2	Placement and operation of wind farm structures and related management activities that pose threats to wildlife	→	**Vulnerability**
Step 3	Mortality due to wind farm operations	→	**Impacts**
Step 4	Reliably predicting impacts from indicators of susceptibility and vulnerability	→	**Solutions**

Within this framework, it is the integration of Steps 1 through 3 that leads to Step 4 and its solutions. An empirical model developed in Step 4 can be broadly applied to predict *impacts* using quantitative measurements of factors that relate to *susceptibility* and *vulnerability*—terms that are drawn from the ecological indicators framework (Rapport et al. 1985; Cairns and McCormick 1992; O'Neill et al. 1994; Rotmans et al. 1994; Schulze et al. 1994; USDA 1994; Battaglin and Goolsby 1995; Wilcox et al. 2003; for examples see Zhang et al. 1998, 2003) and defined below. Step 4, which is the focus of this study, was funded by the California Energy Commission beginning in late

fall of 2001 and continuing in the field until May 2003. This research was an extension of work already begun under NREL funding from 1998 into 2001 (Smallwood and Thelander, In review). That effort primarily focused on identifying bird behaviors and attributes of wind turbines, the landscape, and range management practices that associated with fatalities caused by bird collisions with wind turbines. For this report, we have combined the data from both research efforts.

1.1.1 Natural Behaviors and Ecological Relationships: Susceptibility

Natural behaviors and ecological relationships of birds contribute to their inherent susceptibility to wind turbines. Birds die in the APWRA attempting to pass through the rotor plane of operating wind turbines, or when flying into guy wires, or when perching atop electrical distribution poles that service the wind farm, and for other reasons. A bird attempting to fly through the rotor plane is an expression of natural behaviors, but in an artificial context, where the rotor plane has been introduced along with all of the other land uses and structures that typify wind farms. Because each species of bird exhibits unique suites of behaviors, geographic distributions, and ecological relationships, each also possesses unique susceptibilities to wind farms. For example, golden eagles (*Aquila chysaetos*) may spend most of their foraging time in canyons, making them likely to be more susceptible to wind turbines installed in canyons.

Red-tailed hawks (*Buteo jamaicensis*) may be less susceptible to wind turbine placement in canyons, but perhaps more susceptible to wind turbines placed on ridgelines, especially if ridgelines are where they fly most frequently. Burrowing owls (*Athene cunicularia*) might be most susceptible to wind turbines installed where the owls perform their courtship displays, or where their dispersal flights take them into the altitudes of the moving turbine blades. Thus, susceptibility is estimated by measuring and comparing behaviors that could cause individual species to collide with wind turbines as these behaviors continue to be expressed, unaltered, following the installation of wind turbines.

Orloff and Flannery (1996) suggested that some birds inadvertently enter the rotor plane because they simply cannot see moving wind turbine blades. More specifically, they suggested that raptors enter the rotor plane unwittingly when they are fixated on a distant perch or prey item while the blades are in their foreground. Raptors may identify a perch and continuously observe it until they land on it, or they may detect a prey item and continuously observe it until they capture it. If the raptor's target is located behind the moving blades of a wind turbine, then the raptor may not see the blades, or may see them only when it is too late to avoid them.

The relative effects of motion smear (Hodos et al. 2001) versus fixed focus on prey items remains unknown, as does the degree to which these two factors might interact. But the frequent fatalities of non-raptorial birds summarized in this report indicates that fixed focus on prey items or perches are not the only reasons birds attempt to pass through the rotor plane.

Certain flight behaviors might influence a species' susceptibility to wind turbines, such as their long-distance flight behaviors during migration and their use of declivity winds (i.e., strong winds passing over ridge crests as winds are forced upslope). Perching patterns might connote various levels of susceptibility, if, for example, certain birds are prone to perching on wind towers because

these towers simulate trees with which the species are familiar. Certain mating behaviors might distract individuals regardless of whether wind turbines are operating nearby. Nocturnal predators may or may not be more susceptible than diurnal predators, due to differences in sensory perception relied upon by animals during the night versus during the day. Last, some bird species that occur in relatively large numbers in the study area may only fly at heights well above the rotor blades, thus indicating low susceptibility to the wind turbines presently in use. Future upgrades involving larger and taller wind turbines might alter the susceptibility of these bird species. For these and other potential interspecific differences in susceptibility associated with flight behaviors, future changes in wind turbine design, operation, and placement might yield different mortalities among bird species in the APWRA.

The preferred approach to estimating susceptibility is to implement a *before-after control impact* (BACI) design with replication of impact and control treatments (Anderson et al. 1999). However, we could not implement such a design, because we were assigned wind turbines that were put into operation prior to the initiation of our study. Uninformed about bird behaviors in the APWRA prior to wind turbine operations, we made what inferences we could about susceptibility of bird species to the placement and operation of wind turbines (see Chapter 8).

1.1.2 Exposure to Wind Farm Operations: Vulnerability

The placement and operation of wind turbines can make birds vulnerable to wind turbine collisions when and where birds are already susceptible to wind turbines due to the birds' relative abundance, behaviors, and ecological relationships (e.g., predator-prey interactions). *Vulnerability* is a relative term that requires the measurement of susceptibility and impact across ranges of environmental conditions within a study area.

Quantifying vulnerability requires the comparisons of bird activity near wind turbines and bird deaths to the availability of wind turbines within the environmental elements of interest, such as types of physical relief, seasons, and proximity to particular prey species, as examples. Measures of vulnerability can be based on relative abundance near wind turbines and/or on the relative mortality of bird species at wind turbines with particular attributes. In either case, use-and-availability analysis using chi-square test statistics is an effective means of testing whether particular levels of vulnerability are significant.

As an example of applying use-and-availability analysis, relative abundance can be measured as the proportion of the sampling periods that each bird species is observed flying over landscape element *i*, and this proportion of flight time is related to the proportion of landscape element *i* occurring within the study area. Bird mortality can be measured as the proportion of the sample of individuals killed at wind turbines of a particular type or environmental setting relative to the proportion of those types or settings in which all of the wind turbines in the study area occur. Vulnerability due to placement of wind turbines on certain landscape elements (as an example of any environmental element that one wishes to measure) can be expressed by the following model:

$$\frac{\chi^2\ Observed}{\chi^2\ Expected} = \frac{n_i}{N\,p_i},$$

where, in the case of measuring use of the areas near wind turbines, n = flight time of a particular species nearby wind turbines on landscape element i, N = total flight time of the species on the sampled landscape; and where, in the case of measuring mortality, n_i = number of individuals of the species killed at wind turbines on landscape element i, and N = total number of the species killed within the landscape area being sampled; and in both cases, p_i = proportion of the sampled landscape composed of landscape element i. In summary, part of our study attempts to identify the vulnerability of bird species to strikes with wind turbines based on our weighted measurements of susceptibility and impacts.

1.1.3 Measuring Effects on Birds: Impacts

Bird mortality studies conducted at wind resource areas have produced a variety of mortality estimates. Howell and DiDonato (1991) sampled wind turbines in the APWRA during 1988–1989 and reported 0.05 deaths per wind turbine per year (n = 17 fatalities). Orloff and Flannery (1996) conservatively estimated that 39 golden eagles were killed during a one-year period in the APWRA. They also estimated raptor mortality to range from 0.02–0.05 deaths/turbine/year. During a one-year period, Howell (1997) confirmed 72 wind turbine-caused fatalities during an 18-month period at two wind resource areas: the APWRA and the Montezuma Hills WRA. Bird fatalities consisted of 44 raptors and 28 non-raptors, with a mean raptor mortality of 0.03 deaths/turbine/year.

There are two fundamental perspectives from which one can interpret the effects of wind turbine operations on birds: legal and biological. From a legal perspective, individual fatalities can be considered significant effects and subject to civil or criminal penalties. Federal laws that specifically protect raptors include the Migratory Bird Treaty Act (MBTA), the Bald and Golden Eagle Protection Act, and the Endangered Species Act. Raptors are also protected under California Fish and Game Code 3503.5, which makes it illegal to take, possess, or destroy any bird in the Order Falconiformes or Strigiformes.

The MBTA prohibits killing any bird species designated as fully protected. The U.S. Fish and Wildlife Service (USFWS) considers any injury or fatality of any raptor from a collision with a wind turbine or ancillary facilities in the APWRA to be a "take," and therefore a violation of the MBTA (S. Pearson, USFWS, pers. comm.). Bird fatalities attributable to wind turbine operations are significant effects, from a legal perspective, because they violate the MBTA. The MBTA constitutes a decision that any additional human-caused losses of individuals of raptor species covered by the MBTA are legally significant.

Comparing the wind turbine-caused mortality to both the natural mortality and the recruitment rate of each affected species would effectively measure the biological importance of wind turbine-caused fatalities. Doing so would yield estimates of the degree to which wind turbines adversely affect a species' population size, stability, and distribution. However, to do so would require extensive information about the distribution and demographic structure of populations occurring at and around the APWRA. Simply counting living birds in the APWRA would be inadequate for this purpose, because for numerous species their numbers would change dramatically throughout the year due to migrations. The numerical estimates made in the APWRA would be, in multiple cases, contaminated by individuals that live most or part of their lives elsewhere.

The APWRA may directly affect many bird species that occur over a broad geographic area. Thus, the geographic scale required for estimating impacts to bird species would be much larger than the APWRA itself. The scope of the present study would not allow inferences of population-level or regional impact assessments to be made, but it is important to consider that these impacts are possible, and they are worthy of additional research.

Among the species of raptors killed in the APWRA, golden eagles and burrowing owls are probably the species of greatest concern, because they are California Species of Special Concern. No detailed studies have addressed impacts to burrowing owls, but a recent study of golden eagle mortality factors and population regulation over a broad geographic region specifically included the APWRA within its overall study area (Hunt 1994, 2002; Hunt and Culp 1997).

In recent years, numerous golden eagle deaths in the area have been attributed to wind turbines. Hunt (1994) and Hunt and Culp (1997) concluded that the additional effect of wind turbine-caused mortality might be contributing to a long-term decline in the local golden eagle population, but Hunt (2002) later concluded the local population might be stable. However, Hunt's study was too brief to reliably estimate multi-generational trends in golden eagle numerical abundance and demography (see Smallwood and Schonewald 1998; Hunt 2002). Hunt suggested that continuous monitoring would be needed and that recruitment was critical if the population was to maintain stability. Also, a high mortality of golden eagles might not change the number of individuals in the population so long as recruitment keeps pace with mortality, but a high rate of ill-fated recruitment might very well deplete golden eagle numbers in source areas (Smallwood 2002; Hunt 1998; Hunt 2002).

Until more rigorous research efforts are conducted in the APWRA for each bird species affected there, the full environmental impact of the APWRA will remain unknown. We will not know how the localized killing of individual birds affects their regional populations. In lieu of more rigorous research on population-level impacts, effective management practices are needed that will demonstrably reduce the vulnerability of bird species in the APWRA.

1.1.4 Relating Impacts to Causal Variables: Predictions and Solutions

Holding aside effects of season, weather, and wind turbine design and operation, if individuals of one bird species were randomly killed at wind turbines among measured environmental elements in the APWRA, then the probability of an individual being killed by a wind turbine occurring on a particular environmental element would equal the proportion of the wind turbines associated with that environmental element multiplied by the total number of that species killed in the study area. For example, if 20% of the wind turbines in a study area occurred on southeast-facing slopes, then a random distribution of 100 red-tailed hawk fatalities at wind turbines should have included about 20 birds killed by wind turbines on southeast-facing slopes. This product of total number killed (N) and the incidence of wind turbines on the ith landscape element is an expected kill rate at the ith landscape element. The number of fatalities at the ith landscape element can then be compared to the expected number of fatalities. For example, had 40 red-tailed hawks been killed by wind turbines on southeast-facing slopes, this observed frequency was twice the frequency expected of a random or uniform distribution of fatalities.

When the observed and expected frequencies of fatalities are equal, then the observed frequency must be attributed statistically to the number of wind turbines. However, when the converse is true, an association exists between that environmental element and mortality. If the relationship is less than one, then there may be an avoidance of one environmental element and the possible selection of another. By identifying environmental elements where mortality exceeded expectations due to wind turbine numbers alone (i.e., observed ÷ expected >1), we are able to identify which environmental factors might have a causal relationship. It is through the application of this approach that we assess vulnerability.

At selected wind turbines in the APWRA, we compiled data separately for bird behaviors, wind turbine and tower characteristics, fatality searches, fatality search results, maps of rodent burrow systems, and various other physical and biological factors. This report summarizes the resulting integration of these data. In turn, this data integration process provided the opportunity to develop predictive models for bird mortality at wind turbines based on wind turbine location on the landscape, wind turbine location relative to other wind turbines, wind turbine design and operation, the distribution of raptor prey species near wind turbines, and other potential predictor variables.

1.2 OBJECTIVES

The primary objectives of this research were to: (1) quantify bird use, including characterizing and quantifying perching and flying behaviors exhibited by individual birds around wind turbines, (2) evaluate the flying behaviors and the environmental and topographic conditions associated with flight behaviors, (3) identify possible relationships between bird mortality and bird behaviors, wind tower design and operations, landscape attributes, and prey availability, and (4) develop predictive, empirical models that identify areas or conditions that are associated with high vulnerability. Such models can be used to identify locations and conditions of high versus low vulnerability in the APWRA, or to reliably identify those wind turbines and landscape attributes that pose ongoing threats to birds.

We began the project by quantifying bird use and bird fatalities associated with that use. Only about 28% of the APWRA's total wind turbine population was included in the project initially, due to limitations placed on access to turbines. We quantified bird flight and perching behaviors at the various wind turbine types, and examined whether the frequencies of these behaviors at wind turbines were related to environmental factors such as weather, topography, habitat features, prey availability, and others.

As our study progressed, unexpected patterns prompted us to add certain focused subtasks and activities to complement the basic goals of the project. Such patterns included ground squirrel distribution and abundance not relating to raptor mortality; pocket gophers clustering near wind towers on steep ridgelines; and raptors generally avoiding perching upon wind towers while turbines operated. We added research on rodent distribution in relation to tower locations, bird use, and fatality locations. We also examined topographic and landscape features and related these to bird use and bird fatalities.

In general, the topics we examined fell into three broad categories: (1) bird flight behaviors; (2) wind turbine/tower design, placement, and operations; and, (3) raptor prey availability and distribution in relation to individual wind turbines and turbine strings. Wherever applicable, the methods used in our project adhere to guidelines developed and recommended for such studies by the Avian Subcommittee of the National Wind Coordinating Committee (Anderson et al. 1999).

1.3 STUDY AREA

The Altamont Pass Wind Resource Area is located in central California about 90 km east of San Francisco in eastern Alameda and southeastern Contra Costa counties (Figure 1-1). In the APWRA (which is the largest wind energy facility in the world), permits to install some 8,200 wind turbines were approved by the regulating authority, but about 5,400 were in place during our study (Alameda County 1998). The output capacity of the installed wind turbines is reported to be 580 megawatts (MW). The actual output may be 35%–40% of the rated capacity, depending on the hardware specifications (R. Thresher, NREL, pers. comm.). The turbines are distributed over approximately 150 km^2 (50,000 acres). Photos 1-1 through 1-8 depict aspects of the wind farm and various types of wind turbines.

Energy generation in the APWRA reached significant levels during the mid-1980s, when most of the wind turbines now at the site were installed. Wind turbines are generally grouped under common ownership. At least 13 different companies manage the energy that is produced in the APWRA, each using different tower/turbine configurations. Table 1-1 summarizes the wind turbine attributes of the wind turbines included in our sample in the APWRA.

The Altamont Pass region exhibits a complex topographic relief. Hilltop elevations range from 230 to 470 m (755 to 1,542 ft.) above sea level. Valley elevations range from about 78 to 188 m (256 to 617 ft.) above sea level. Livestock grazing constitutes the primary land use in the area.

Steady winds from the southwest blow across Altamont Pass during about April to October. Differential air temperatures form as the warmer Central Valley east of Altamont Pass draws in cooler, marine air from San Francisco Bay to the west. Winds are more erratic at other times of the year. They can originate from any direction. Wind speeds average 25–45 kilometers per hour (km/hr) between April and September, during which time the APWRA produces 70%–80% of its power. During the summer months, wind speeds are sufficient to operate the wind turbines beginning about mid-afternoon and increasing during the evening hours (Taylor 1998, pers. comm.). During winter, wind speeds average 15–25 km/hr. Dense fog can occur in the Altamont Pass during summer and winter. Winter fog conditions, known locally as “tule fog,” often linger for many consecutive days.

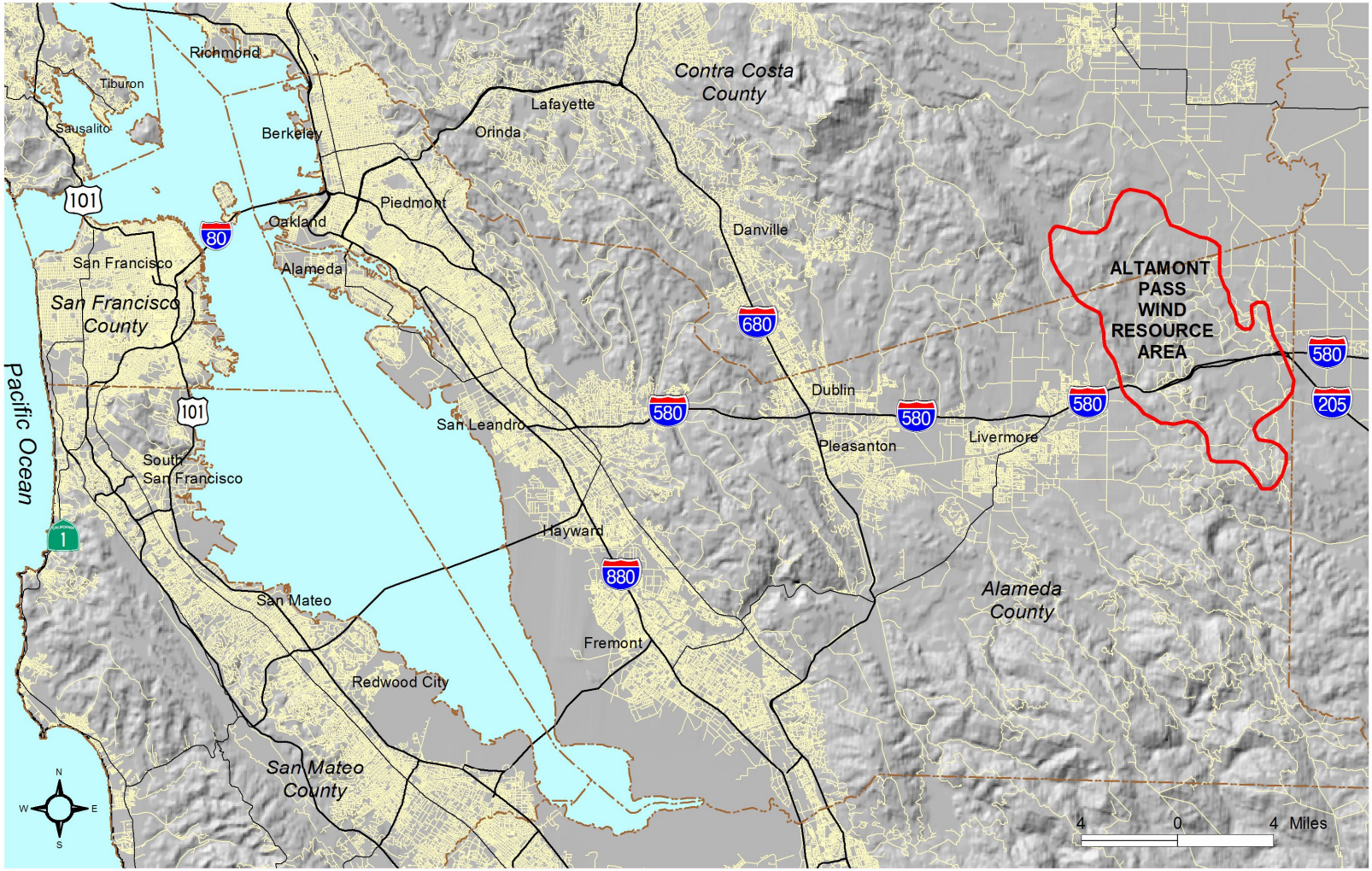


Figure 1-1. Location of the Altamont Pass Wind Resource Area (APWRA) in west-central California

Photo 1-1. Bonus 150-kW wind turbines mounted on tubular towers, plus Flowind 150-kW vertical axis wind turbines to the right

Photo 1-2. In the foreground are two Bonus wind turbines mounted on grey tubular towers. Downhill are five Danwin 110-kW wind turbines mounted on white tubular towers.

Photo 1-3. A string of Flowind 150-kW vertical axis turbines

Photo 1-4. Micon 65-kW wind turbines near Mountain House

Photo 1-5. KVS-33 turbines painted with stripes (experimentally) to increase their visibility to birds

Photo 1-6. An Enertech 40-kW wind turbine with two turkey vultures flying nearby

Photo 1-7. Example of a wind wall. KCS-56 turbines are mounted on two different tower heights to catch a larger height domain of the wind.

Photo 1-8. Windmatic 65-kW turbine adjacent to Old Altamont Pass Road

Table 1-1. Wind turbine models and associated attributes in the APWRA. Information provided by Altamont Infrastructure Company, Altamont Power Co., EnXco, SeaWest, and WindWorks.

Wind turbine manufacturer	Size (kW)	Tower type	Rotor diameter (m)	Tip Speed (kph)	Rated wind speed (kph)	Tower Height (m)	Percent time in operation	No.of blades
Bonus	120	Tubular	19.5	146.42	64.4	24.6	unknown	3
Bonus	150	Tubular	23.4	173.77	64.4	25.2	unknown	3
Danwind	110	Tubular	19.2	193.08	48.3	24.0	50 %	3
Enertech	40	Lattice	13.5	148.03	48.3	18.5	unknown	3
Flowind	150	Vertical axis	17.2	193.08	61.1	29.5	32 %	2
Flowind	250	Vertical axis	19.1	194.69	61.1	32.3	32 %	2
Howden	330	Tubular	31.4	239.74	43.4	24.6	unknown	3
Kenetech KCS-56	100	Horizontal lattice	17.8	246.18	46.7	14.0	39 %	3
Kenetech KCS-56	100	Horizontal lattice	17.8	246.18	46.7	18.5	39 %	3
Kenetech KCS-56	100	Horizontal lattice	17.8	246.18	46.7	24.6	39 %	3
Kenetech KCS-56	100	Lattice	17.8	246.18	46.7	43.1	39 %	3
Kenetech KVS-33 [a]	400	Lattice	33.2	180.21	43.0	24.6	69 %	3
Kenetech KVS-33 [a]	400	Lattice	33.2	180.21	43.0	36.9	69 %	3
Kenetech KVS-33 [a]	400	Tubular	33.2	180.21	43.0	24.6	69 %	3
Kenetech KVS-33 [a]	400	Tubular	33.2	180.21	43.0	36.9	69 %	3
Micon	65	Tubular	16.0	149.64	54.7	24.6	unknown	3
Nordtank	65	Tubular	16.0	143.20	54.7	24.6	unknown	3
Polenko	100	Tubular	18.2	149.64	49.9	24.6	unknown	3
Vestas	100	Lattice	17.2	167.34	67.6	unknown	unknown	3
W.E.G.	250	Tubular	25.2	212.39	48.3	24.6	52 %	3
Windmaster	200	Tubular	22.2	205.95	53.1	23.1	unknown	3
Windmaster	75	Tubular	22.2	205.95	32.2	23.1	unknown	3
Windmaster	250	Tubular	23.4	217.22	51.5	23.1	unknown	3
Windmaster	300	Tubular	25.2	234.91	54.7	23.1	unknown	3
Windmatic	65	Lattice	14.8	136.77	56.3	18.5	unknown	3

[a] The KVS-33 is a variable-speed wind turbine. The rotor speed at rated power (wind speed 26.7 mph) is 50 rotations per minute (rpm) and tip speed is 193.3 mph. The rotor speed at cut-in wind speed is 14 rpm and tip speed is 47.2 mph. The rotor speed in Altamont average winds (16 mph) is 29 rpm and tip speed is 112.1 mph (180.21 kph).

The vegetation is predominately nonnative annual grassland consisting of soft chess (*Bromus hordeaceus*), rip-gut brome (*Bromus diandrus*), foxtail barley (*Hordeum murinum ssp. leporinum*), Italian rye grass (*Lolium multiflorum*), and wild oats (*Avena fatua*). Common forbs include black mustard (*Brassica nigra*), fiddle-neck (*Amsinckia menziesii ssp. intermedia*), chick lupine (*Lupinus microcarpus var. densiflorus*), bush lupine (*Lupinus albifrons*), and wally baskets (*Triteleia laxa*). Grasses and forbs grow during the rainy months of January, February, and March; then die or go dormant by the beginning of June. The APWRA includes the following physiographic elements that harbor characteristic groups of species: annual grassland, alkali meadow, emergent marsh, riparian woodland and scrub, creeks and drainages, stock ponds, cultivated land, and rock outcrops.

At least 18 special-status wildlife species occur in the area, including: San Joaquin kit fox (*Vulpes macrotis mutica*), California red-legged frog (*Rana aurora draytonii*), San Joaquin pocket mouse (*Perognathus inornatus inornatus*), American badger (*Taxidea taxus*), Swainson's hawk (*Buteo swainsoni*), peregrine falcon (*Falco peregrinus anatum*), California tiger salamander (*Ambystoma californiense*), two species of fairy shrimp, and others. In addition, the area supports as many as 15 special-status plant species (Alameda County 1998).

Figures 1-2 through 1-7 help characterize the APWRA by illustrating the distribution of wind turbines classified by tower type (Figure 1-2), whether part of a wind wall (Figure 1-3), whether in or outside a "canyon" (Figure 1-4), the type of physical feature of the landscape the turbine was installed upon (Figure 1-5), the elevation at the turbine tower's base (Figure 1-6), and the level of intensity of rodent control practiced by the ranch owner, County of Alameda, and the turbine operators (Figure 1-7). Many other factors of the study area were also characterized numerically or categorically, and are described in the chapters that follow.

Within the APWRA study area, we performed focused studies involving smaller areas or select groups of wind turbines. One such study included observations of bird activities and behavior. This study involved about 1,500 wind turbines. Another focused study was of rodent species distributions around select strings or rows of wind turbines. Therefore, some of the chapters that follow require a somewhat different study area description from the one presented here.

The ecological relationships that have developed over time in the APWRA are in many ways analogous to those of an artificial undersea reef. Artificial reefs create lateral and vertical substrates where none existed before, and they attract a variety and abundance of organisms that would not be found there naturally. Similarly, the Altamont Hills once were covered largely by short-stature, annual grasses. Now those same grasslands provide an artificial substrate attractive to a variety of native terrestrial wildlife species, as well as non-native species whose numbers and distributions are artificial.

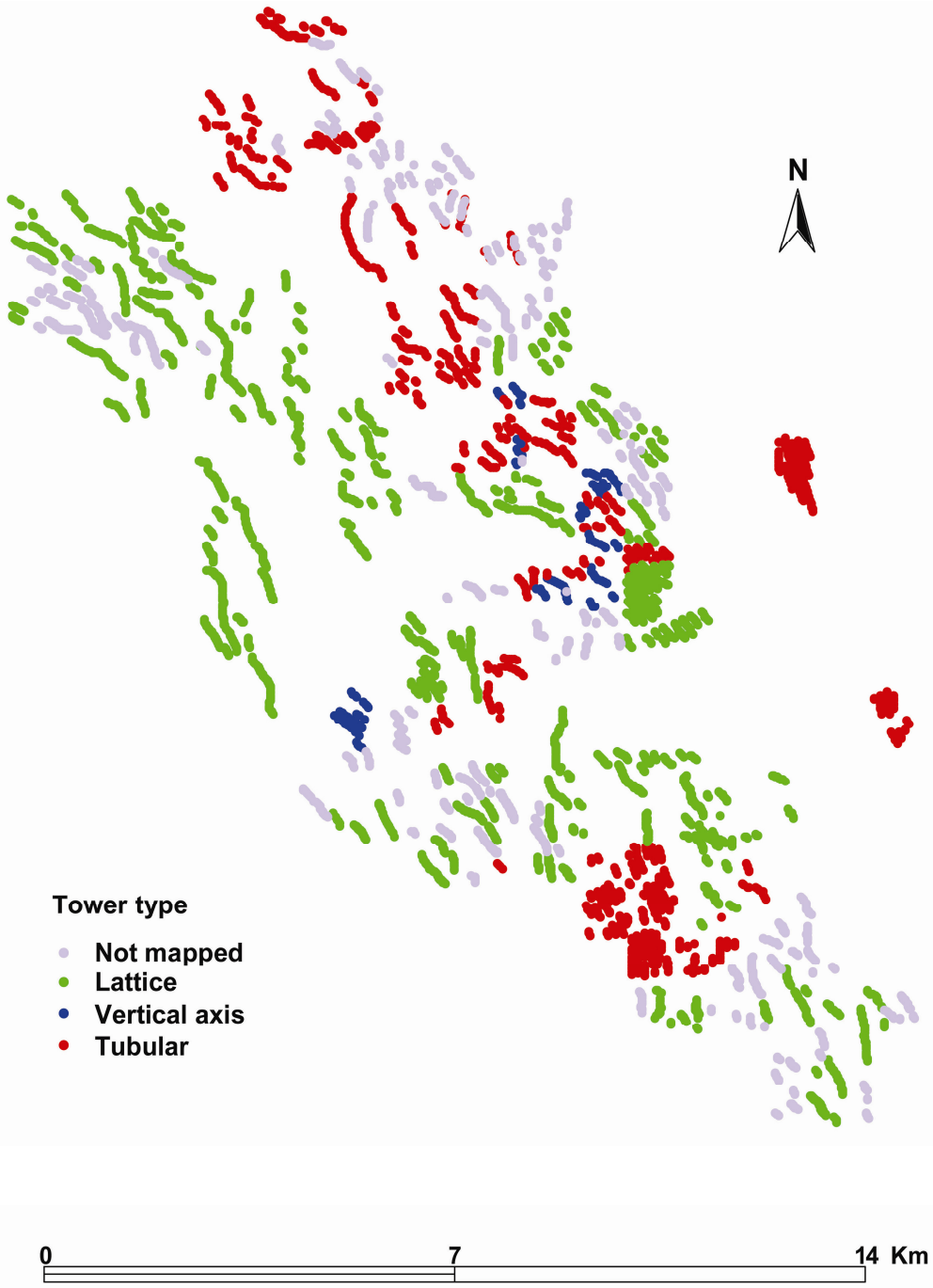


Figure 1-2. Distribution of wind tower types in the APWRA

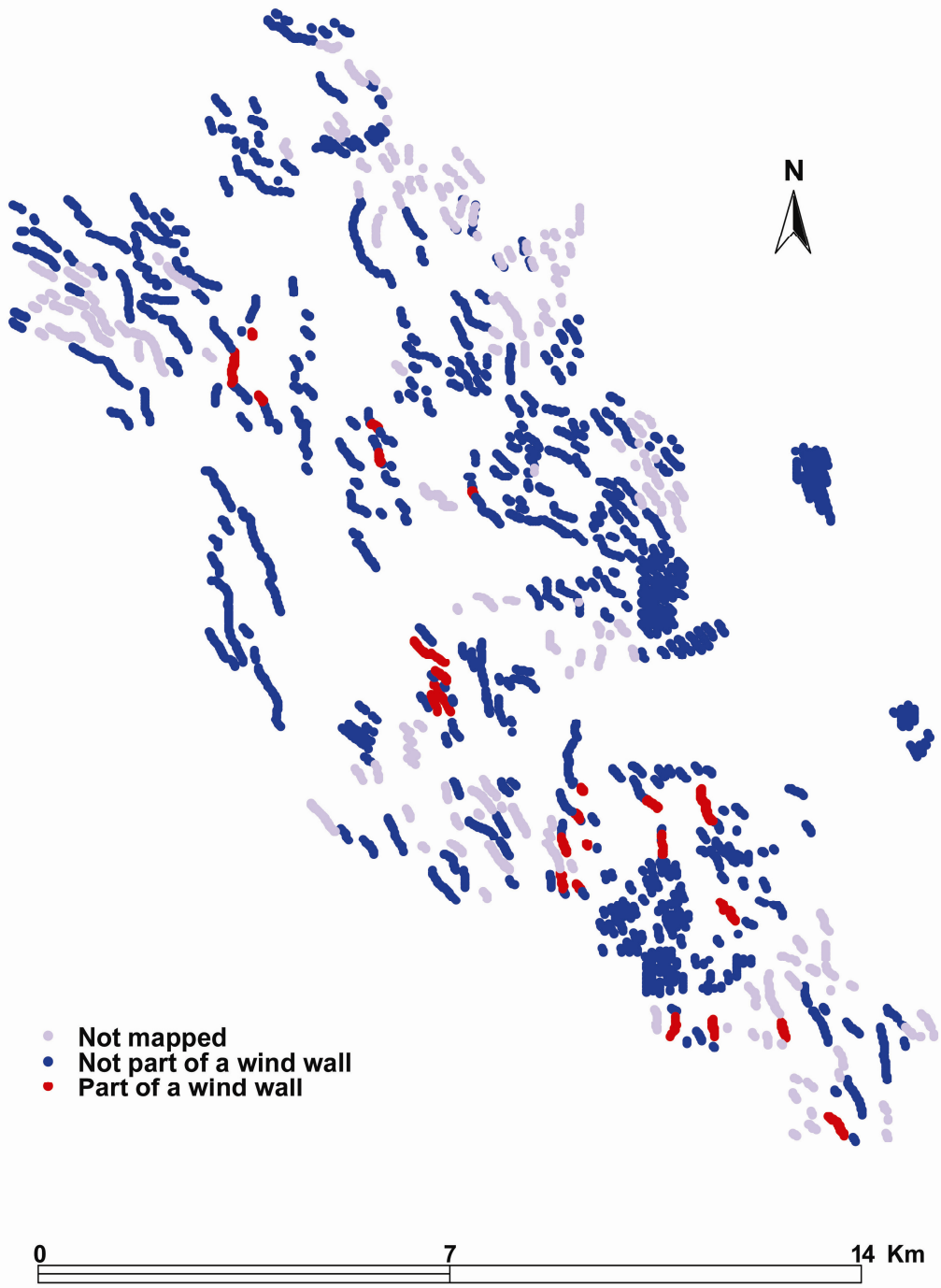


Figure 1-3. Distribution of wind walls in the APWRA. Wind walls are combinations of wind turbines on shorter and taller towers that are installed close to one another to capture a greater height domain of wind.

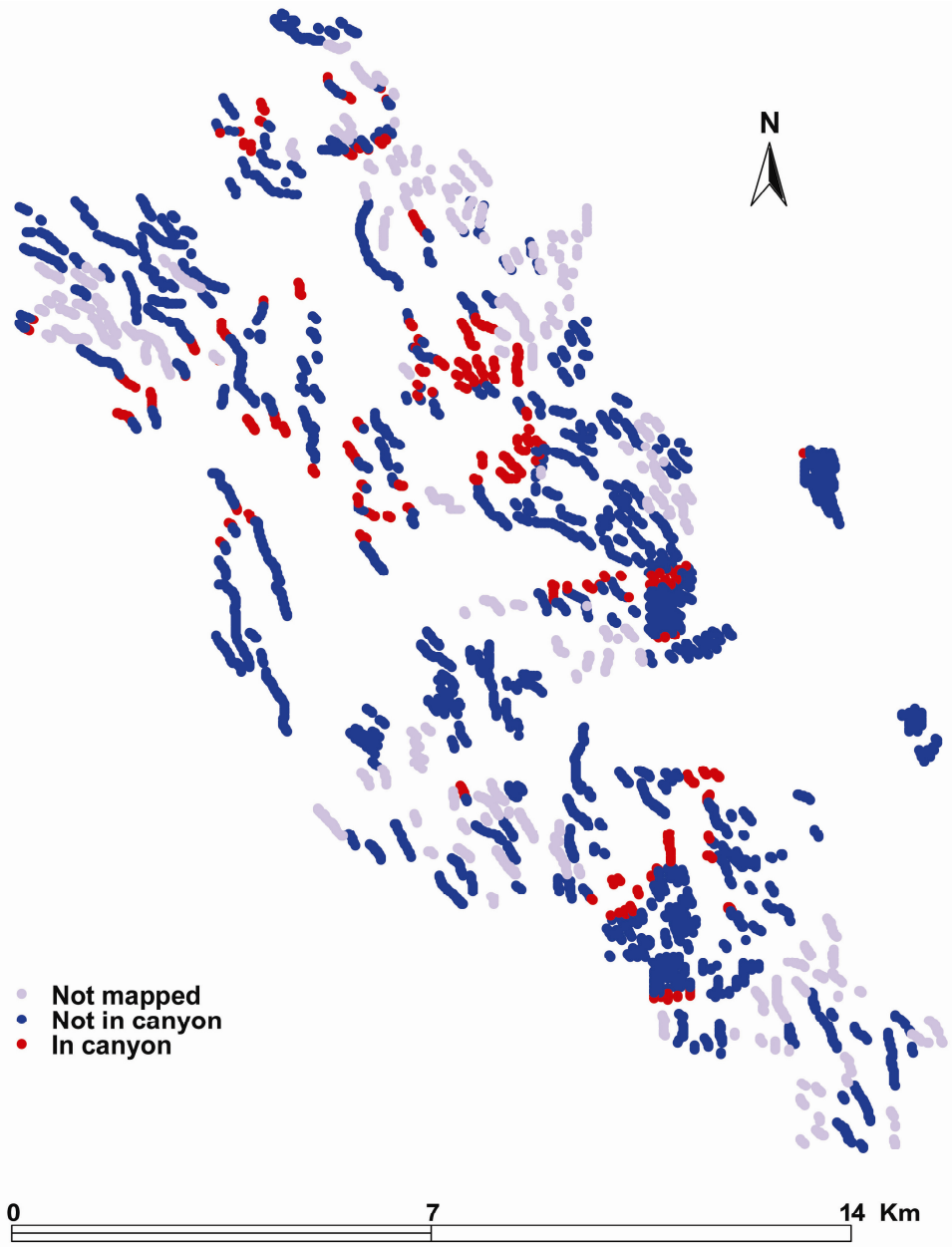


Figure 1-4. Distribution of wind turbines inside and outside of "canyons" in the APWRA

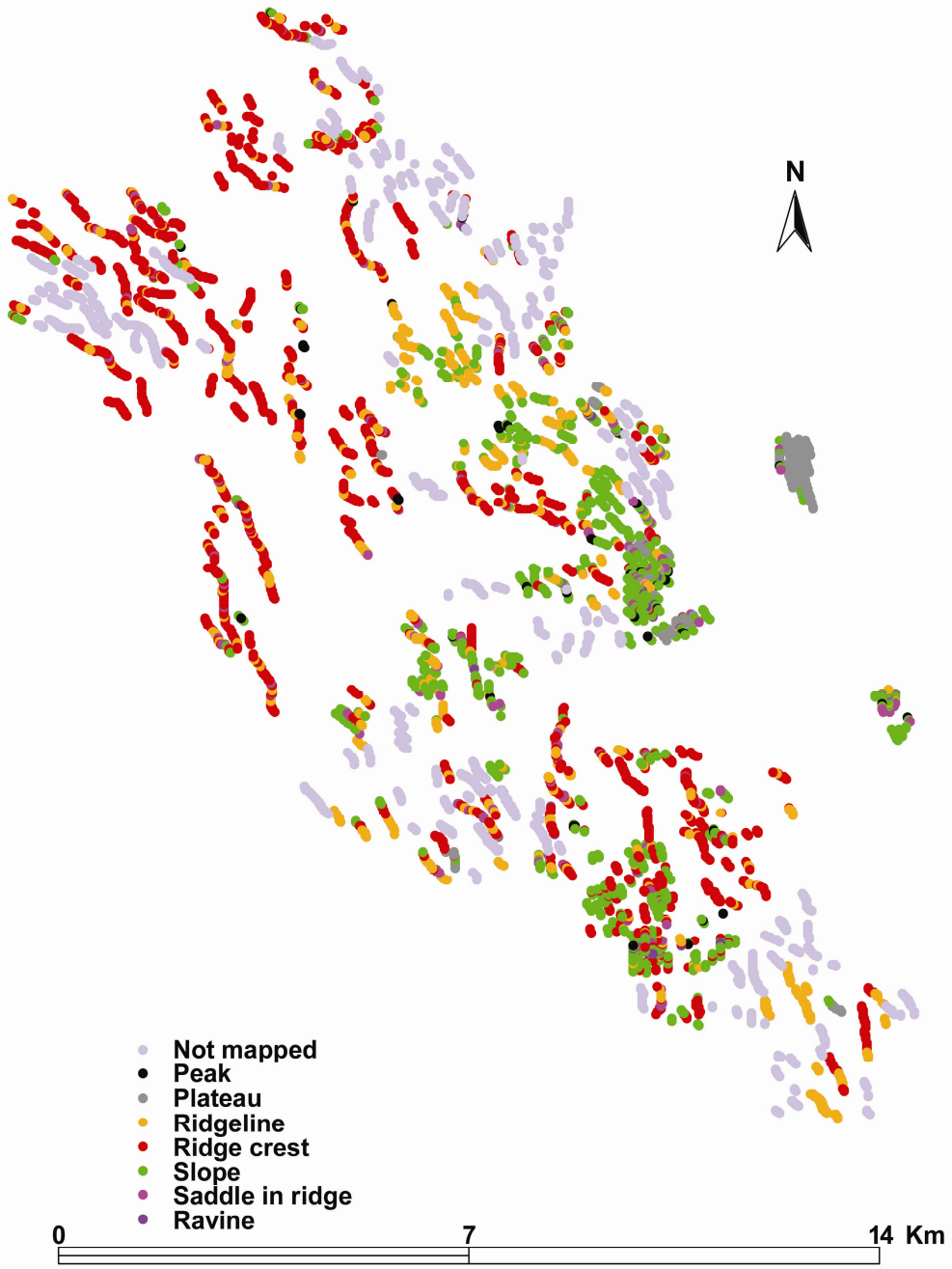


Figure 1-5. Distribution of wind turbines on various types of topographic features in the APWRA

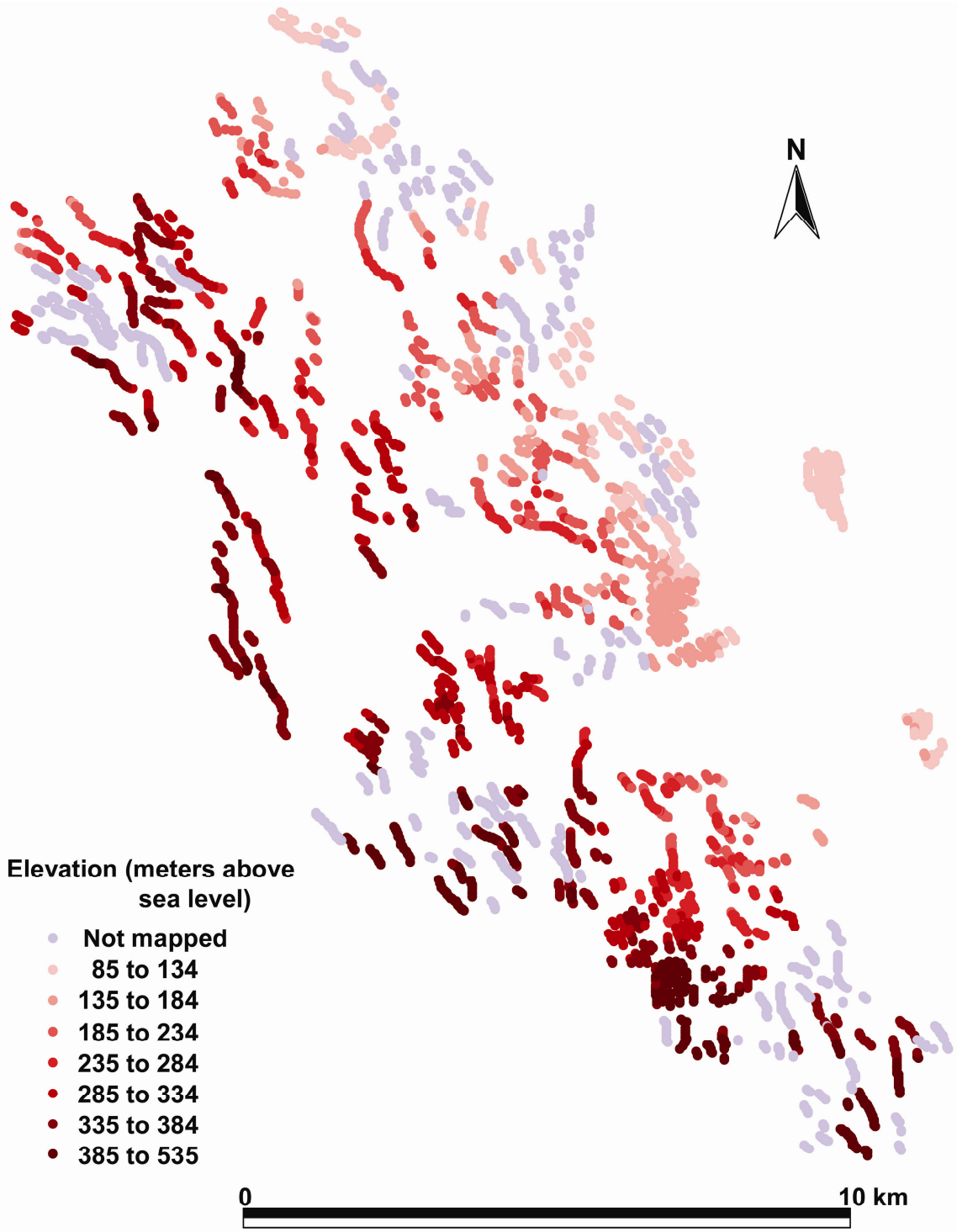


Figure 1-6. Distribution of wind turbines by elevation in the APWRA

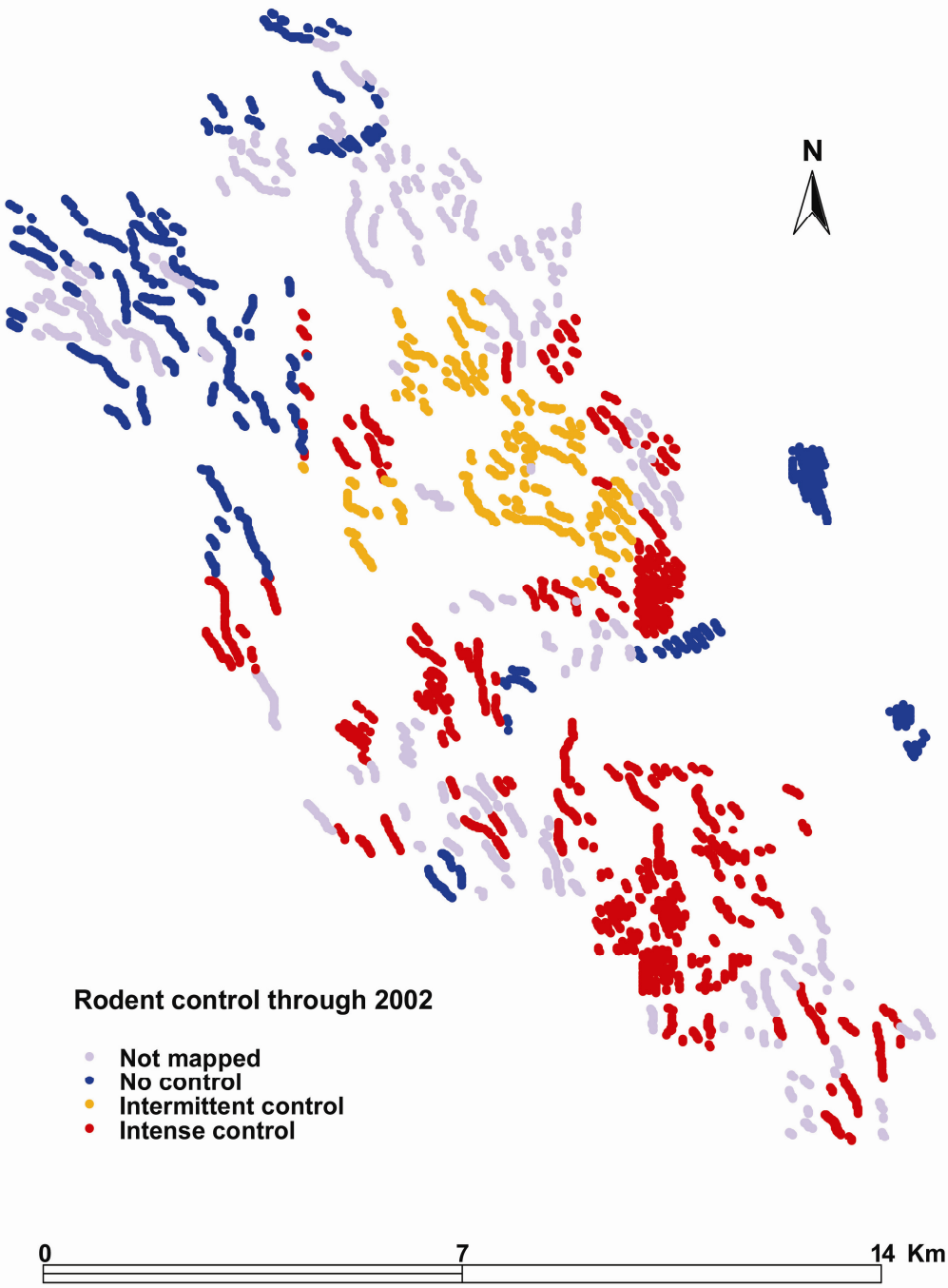


Figure 1-7. Distribution of wind turbines among levels of rodent control implemented in the APWRA during 1997–2002

Rodents and lagomorphs burrow under the wind tower pads where none existed before the APWRA was created. Rodents burrow into artificial berms created by access roads and into cut slopes. Lizards find shade and shelter under lattice towers. Cattle find shade and perhaps some other comfort near tubular towers. Where cattle spend their time, there will be more cattle pats and a greater foundation of a food web. Birds use the turbine towers as perching sites from which to loaf or hunt, and raptors hunt for prey that are attracted to the artificial substrate of the wind towers.

To uncover and understand the patterns of bird mortality at a wind farm one must first interpret the influences on wildlife ecology that are caused by wind turbines. They are artificial structures installed in an otherwise natural setting that can have a profound influence on how arrays of inter-related landscape components function. Pursuing just such an understanding became the basis for designing and conducting the research project described in this report.

CHAPTER 2

CAUSE OF DEATH AND LOCATIONS OF BIRD CARCASSES IN THE APWRA

2.1 INTRODUCTION

Our study of bird mortality and of fatality associations at wind turbines relied on finding carcasses and interpreting the condition of each to ascertain the circumstances of the bird's death. We also relied on a 50-m search radius around each wind turbine to include the majority of the carcasses resulting from collisions with wind turbines. In order to assess the efficiency of our search radius, we tested whether the distance of the carcass from the wind turbines related to the body size of the bird species, wind turbine attributes, season, and physiographic conditions. Understanding the factors that influence carcass search efficiency is important for interpreting our mortality estimates, as well as for designing future fatality monitoring programs at wind energy generating facilities around the world.

This aspect of our study was prompted by our discovery of carcasses beyond our search radius. Because we detected carcasses located beyond our search radius, we realized that some unknown proportion of the fatalities was not being detected because we were not systematically searching over a much larger area around each wind turbine. Also, we questioned the adequacy of our search radius as the repowering effort in the APWRA drew nearer. That program will result in the installation of a fewer number of much larger wind turbines on taller towers. We needed to know whether a greater search radius will be needed as part of the monitoring program following the repowering.

2.2 METHODS

The field methods used to find and record fatalities are described in Chapter 3. We identified each fatality by its associated carcass, or partial carcass, that was obviously independent of other evidence of fatalities in the area. We assumed that injured birds would eventually die as a result of their injuries, so they were also classified as carcasses, unless the injury was known to have healed and the bird returned to the wild.

Bird species were represented by typical body length (cm) as reported in National Geographic Society (1987), and were categorized as small (< 38 cm) or large (> 38 cm), the cutoff based on a natural break in a histogram of body length (Figure 2-1). We intended to factor in the slope of the hills downhill from each of the wind turbines, but we lacked sufficient funding to perform this step.

The statistical tests included mostly one-way analysis of variance (ANOVA) and least significant differences (LSD) between groups. All LSD tests reported below were associated with P-values < 0.05. We also estimated Pearson's correlation coefficient for the distance of the carcasses and elevation of the tower base.

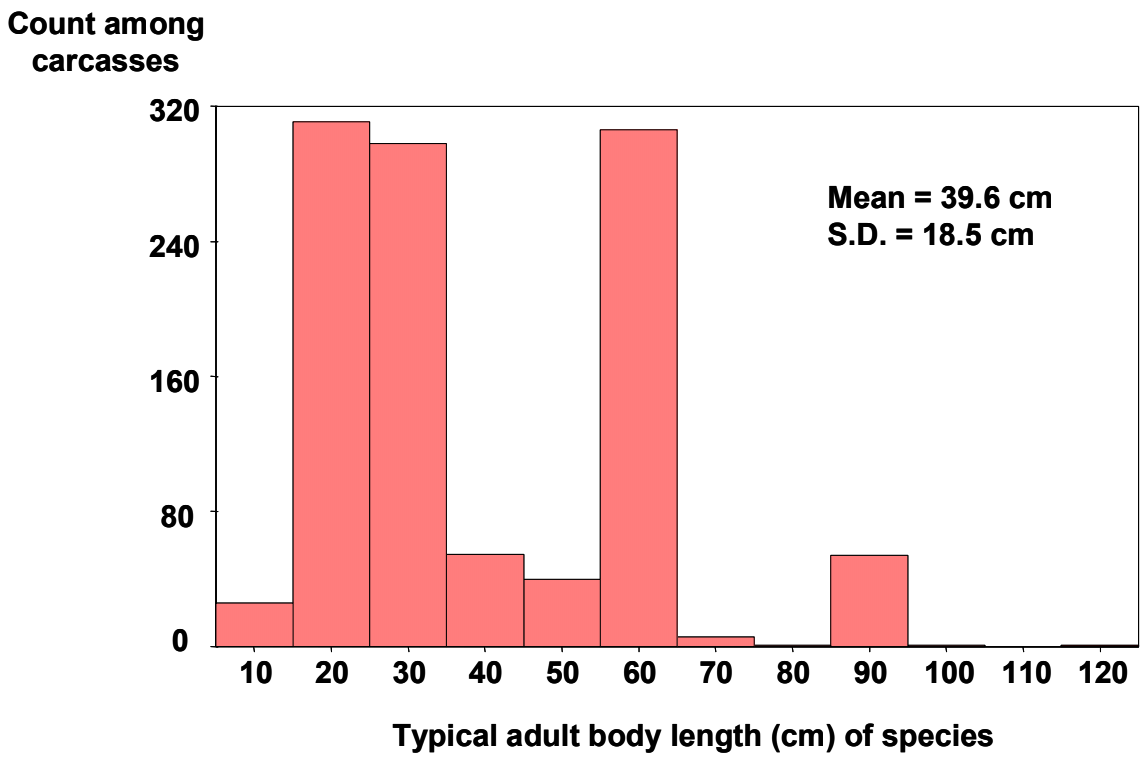


Figure 2-1. Frequency distribution of carcasses by typical body length of the species

2.3 RESULTS

2.3.1 Overview of Bird Fatalities in the APWRA

Most of the 1,189 carcasses we found in the study area were attributed to collisions with wind turbines, and the rest were attributed to predation, electrocution on electrical power distribution poles (e.g., Photo 2-1), collisions with wires and undetermined causes (Figure 2-2, Table 2-1). Broken and severed wings were the most common injuries noted, and decapitations, head injuries, and severe injuries to the torso were also common (Figure 2-3, e.g., Photos 2 through 5). However, many of the carcasses showed signs of multiple injuries, and these are not represented in Figure 2-3.

Age of the animal could not be estimated for most of the carcasses found, due to decomposition, and most of those that could be assigned an age category were adults, followed by immature birds (Figure 2-4). Most bird carcasses were discovered during summer and winter (Figure 2-5). Most were found near KCS-56 turbines on lattice towers and Bonus turbines on tubular towers (Figure 2-6), and most were estimated to have been killed within 30 days of discovery (Figure 2-7). Most were found in two ranges of elevation, between 115 and 225 m, and between 280 and 350 m (Figure 2-8).

We found evidence of 1,162 fatalities caused by collisions with wind turbines or their towers and by unknown causes (Table 2-1). Another 10 fatalities were caused by electrocution on electrical distribution poles and another two were caused by wire strikes. Two more carcasses were attributed to auto collisions as causes of death and 13 were due to predation.

Photo 2-1. A golden eagle electrocuted at an electrical distribution pole with riser elements

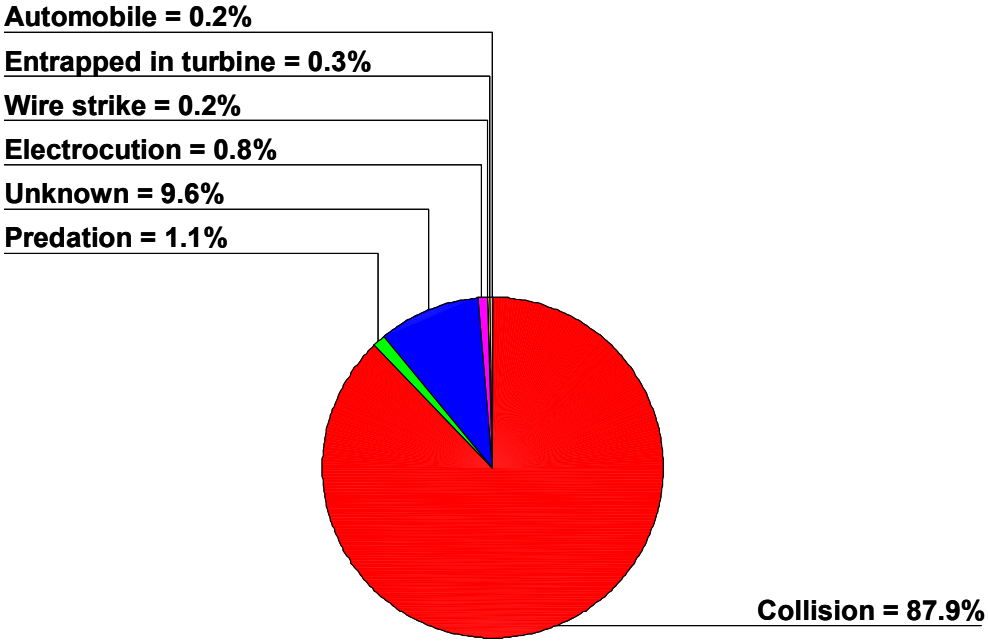


Figure 2-2. Pie-chart distribution of causes of fatalities attributed to carcasses found in the APWRA

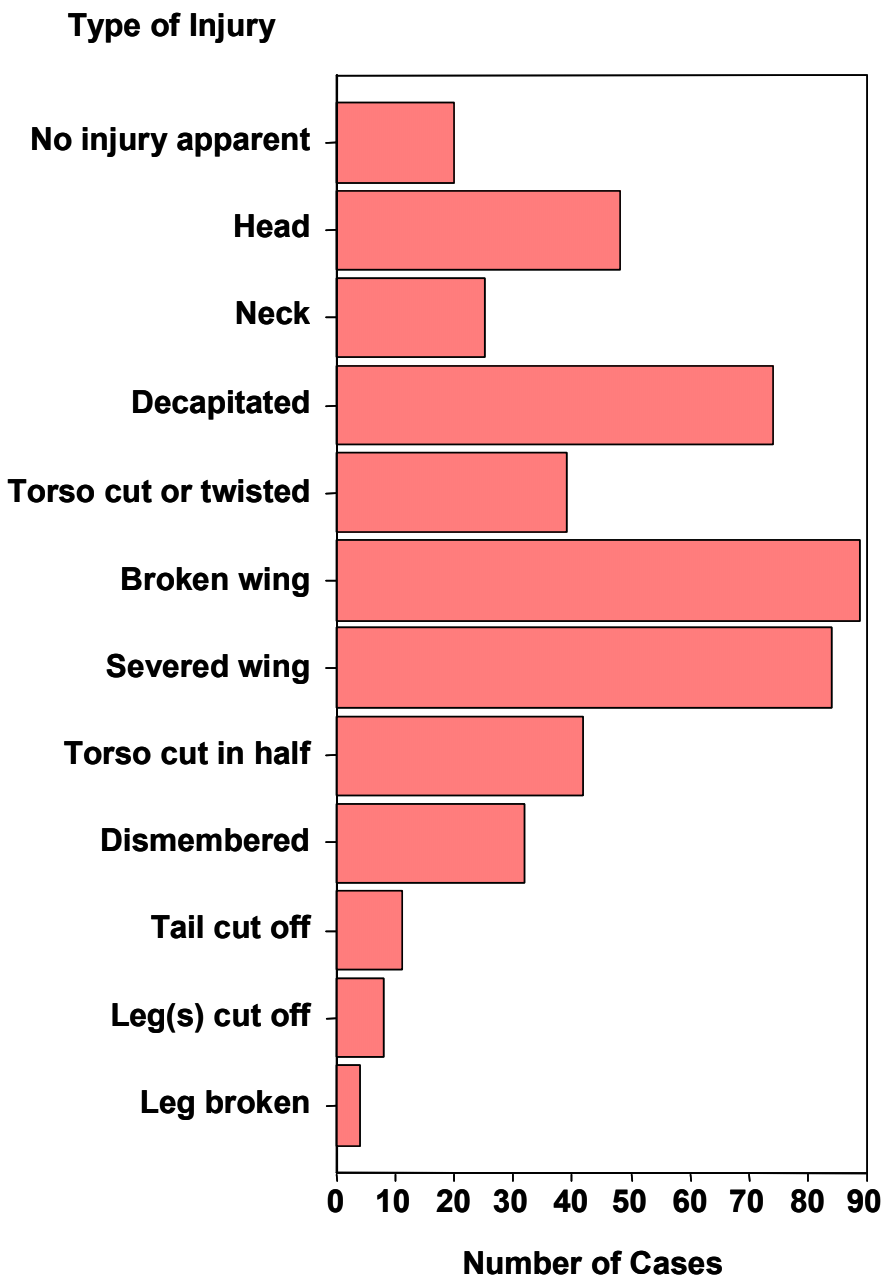


Figure 2-3. Frequency distribution of types of injury attributed to wind turbine-caused fatalities among birds found in the APWRA

Table 2-1. Summary of 1,189 bird (and bat) fatalities found in our study area from May 1998 through May 2003

Species/Group	Fatalities	Wind turbine collision	Electrocution	Wire strike
Golden Eagle	56	54	2	
Turkey Vulture	6	6		
Red-tailed Hawk	215	213	2	
Ferruginous Hawk	2	2		
Buteo sp.	24	24		
Northern Harrier	3	3		
White-tailed Kite	1	1		
Prairie Falcon	3	3		
American Kestrel	59	59		
Burrowing Owl	76	70		1
Barn Owl	52	50	1	1
Great Horned Owl	18	18		
Raptor	17	16	1	
Double-breasted Cormorant	1	1		
Cattle Egret	1	1		
Black-crowned Night Heron	2	2		
Lesser Yellowlegs	1	1		
American Avocet	3	3		
Mallard	36	35		
Ring-necked Duck	1	1		
Laridae sp. (gull)	18	18		
California Gull	7	7		
Ring-billed Gull	4	4		
Northern Flicker	6	6		
Mourning Dove	35	34		
Rock Dove	196	196		
Wild Turkey	1	1		
Northern Mockingbird	1	1		
Say's Phoebe	1	0		
Western Kingbird	1	1		
Pacific-slope Flycatcher	1	1		
Horned Lark	23	23		
Western Meadowlark	99	96		
Common Raven	12	12		
Tricolored Blackbird	1	1		
American Crow	7	5	2	
Brewer's Blackbird	13	13		
Red-winged Blackbird	12	12		
Brown-headed Cowbird	2	2		
Blackbird *(Icterinae sp.)*	1	1		
European Starling	67	67		

Table 2-1. (cont'd)

Species/Group	Fatalities	Wind turbine collision	Electrocution	Wire strike
Loggerhead Shrike	5	5		
Cliff Swallow	5	5		
Mountain Bluebird	5	5		
Violet-green Swallow	1	1		
Townsend's Warbler	1	0	1	
Black-throated Gray Warbler	1	0	1	
Yellow Warbler	1	1		
Savanna Sparrow	2	2		
House Finch	18	14		
House Sparrow	1	1		
Cockatiel	1	1		
Passerine	16	16		
Unknown	42	42		
Hoary Bat	4	3		
Totals	**1,189**	**1,162**	**10**	**2**

Photo 2-2. A decapitated American kestrel found under a wind turbine

Photo 2-3. A mallard cut in half by a wind turbine

Photo 2-4. The wing of a golden eagle found under a wind turbine

Photo 2-5. A golden eagle cut in half by a wind turbine

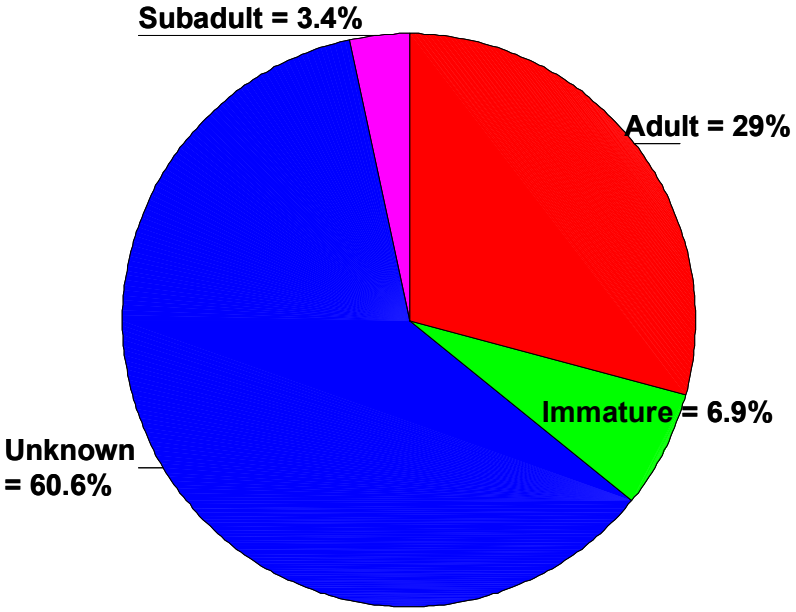


Figure 2-4. Pie-chart distribution of age classes of birds killed by wind turbines in the APWRA

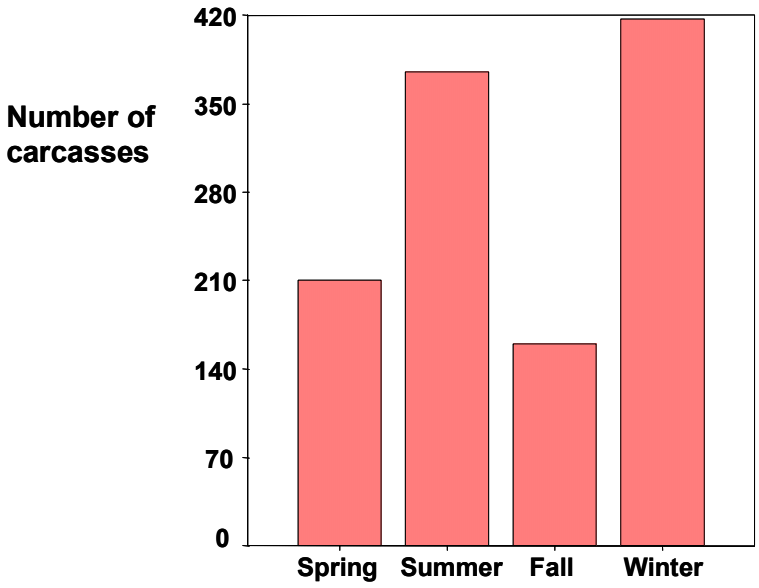


Figure 2-5. Number of bird fatalities found per season

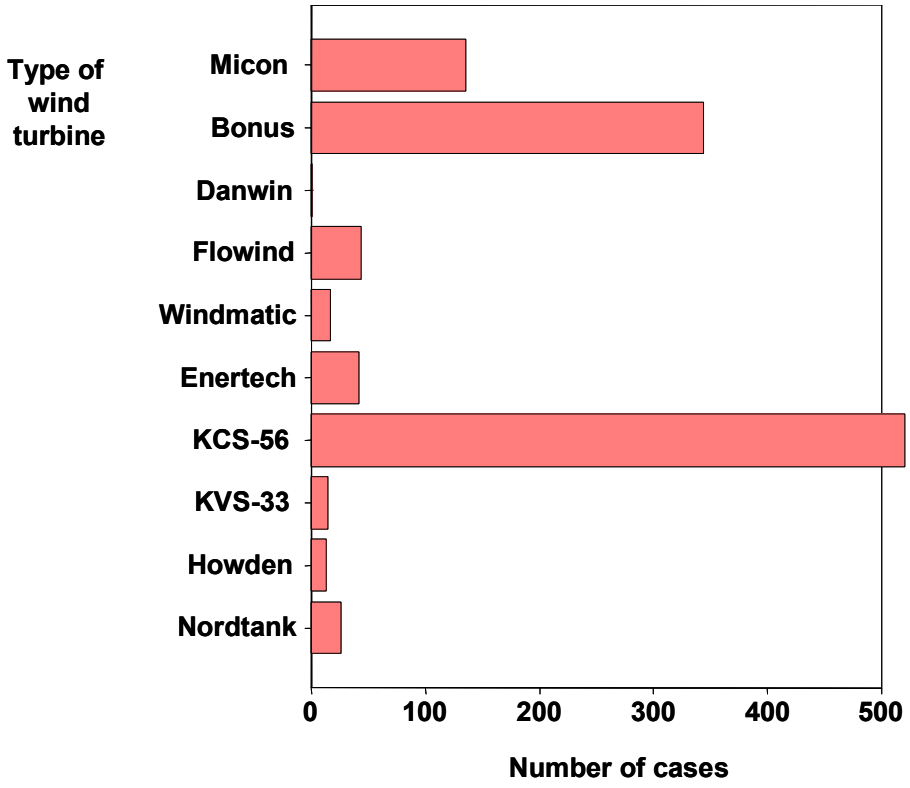


Figure 2-6. Number of bird carcasses found next to each wind turbine model surveyed in the APWRA

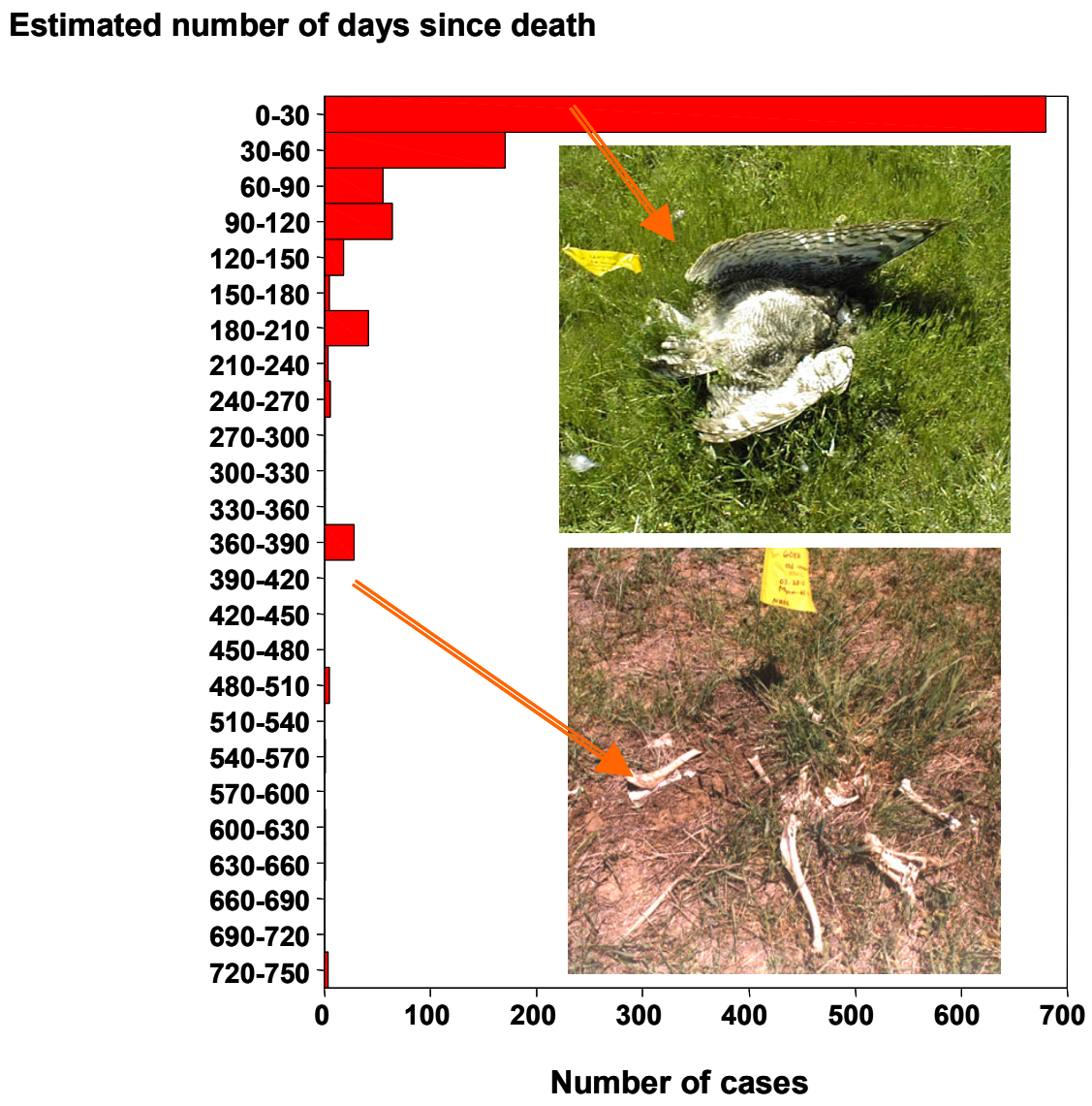


Figure 2-7. Frequency distribution of estimated number of days since death caused by wind turbines in the APWRA

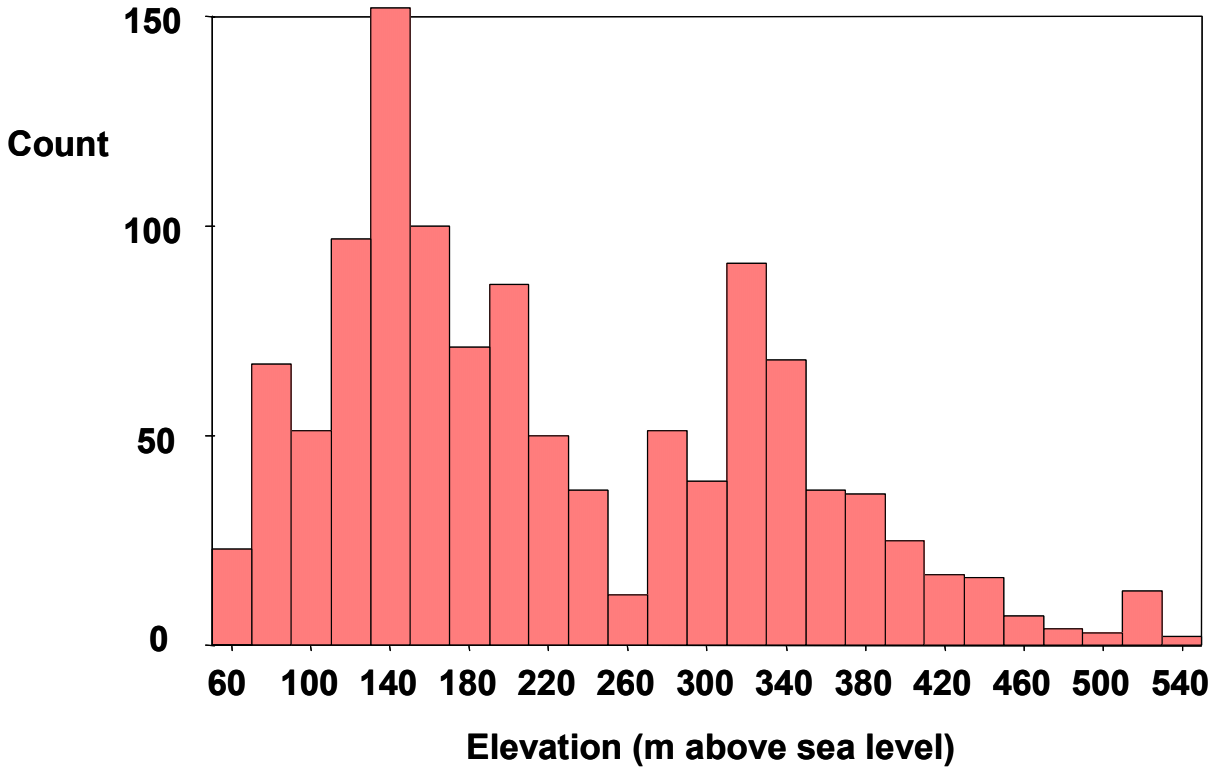


Figure 2-8. Frequency distribution of wind turbine-caused fatalities found in the APWRA (by elevation)

2.3.2 Distances of Bird Carcasses from Wind Turbines

Large-bodied Birds

Our search radius included 84.7% of the carcasses of large-bodied bird species determined to be killed by wind turbines or unknown causes (Figure 2-9A). Of these, 75% were located within 42 m of the tower. The mean and standard deviation of these 468 distances was 31.1 ± 30.0 m. Most carcasses were found northeast of the tower, and a considerable number were located southwest of the tower (Figure 2-10A).

Carcass locations of large-bodied bird species differed significantly by distance from wind turbines according to five ranges of tower heights (ANOVA F = 3.66; df = 4, 456; P = 0.006), and post-hoc LSD tests revealed that fatalities were located farther from 25-m and 32-m towers (means = 33 m and 57 m) than shorter towers (mean = 28 m for 14-m towers, and 26 m for 18.5-m towers) or 43-m towers (mean = 28 m). Distance from tower increased with tower height, according to linear regression analysis, although the precision of the model was poor (Figure 2-11A).

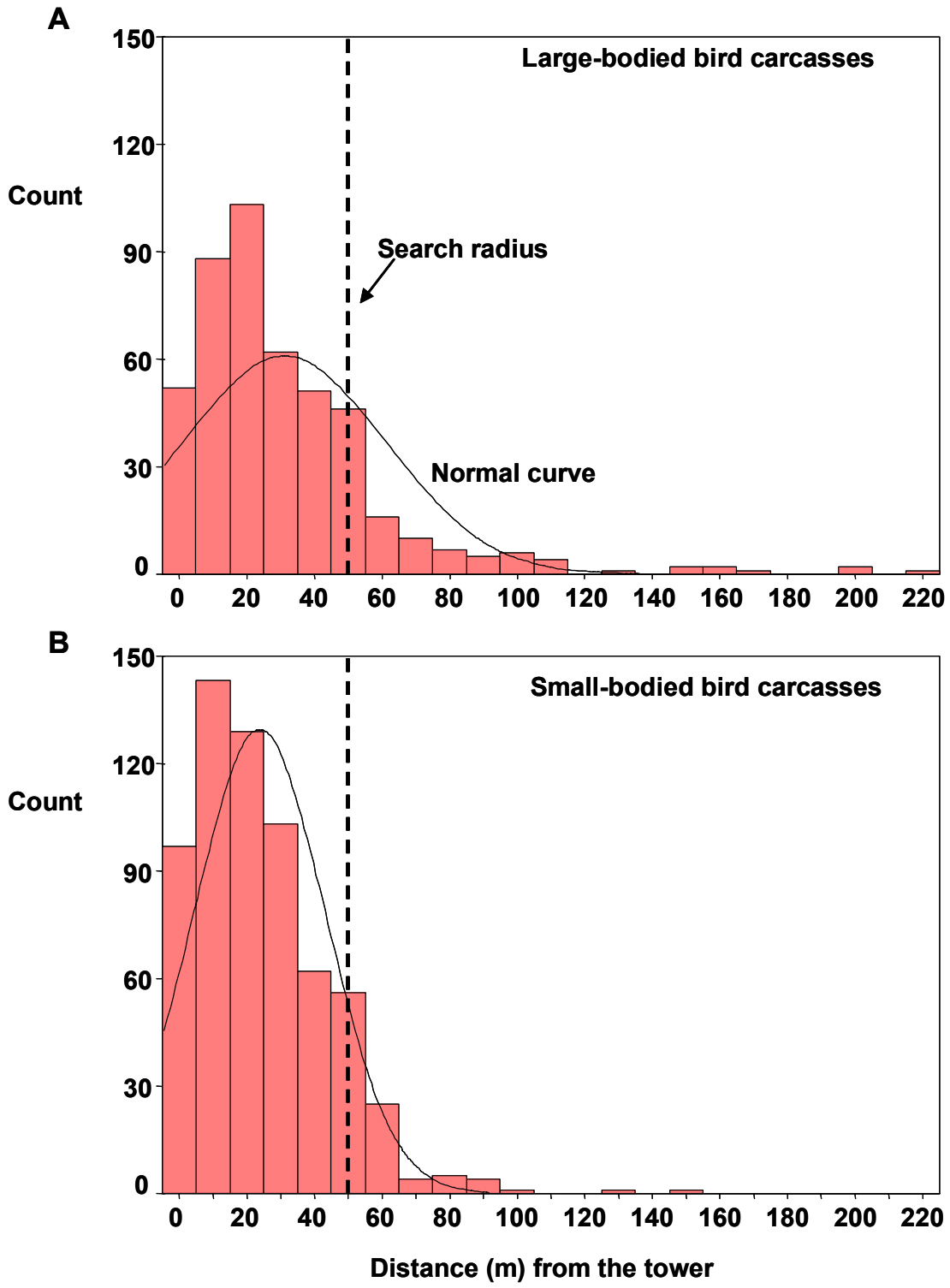


Figure 2-9. Frequency distributions of distance from the wind tower among carcasses of large-bodied (A) and small-bodied (B) bird species

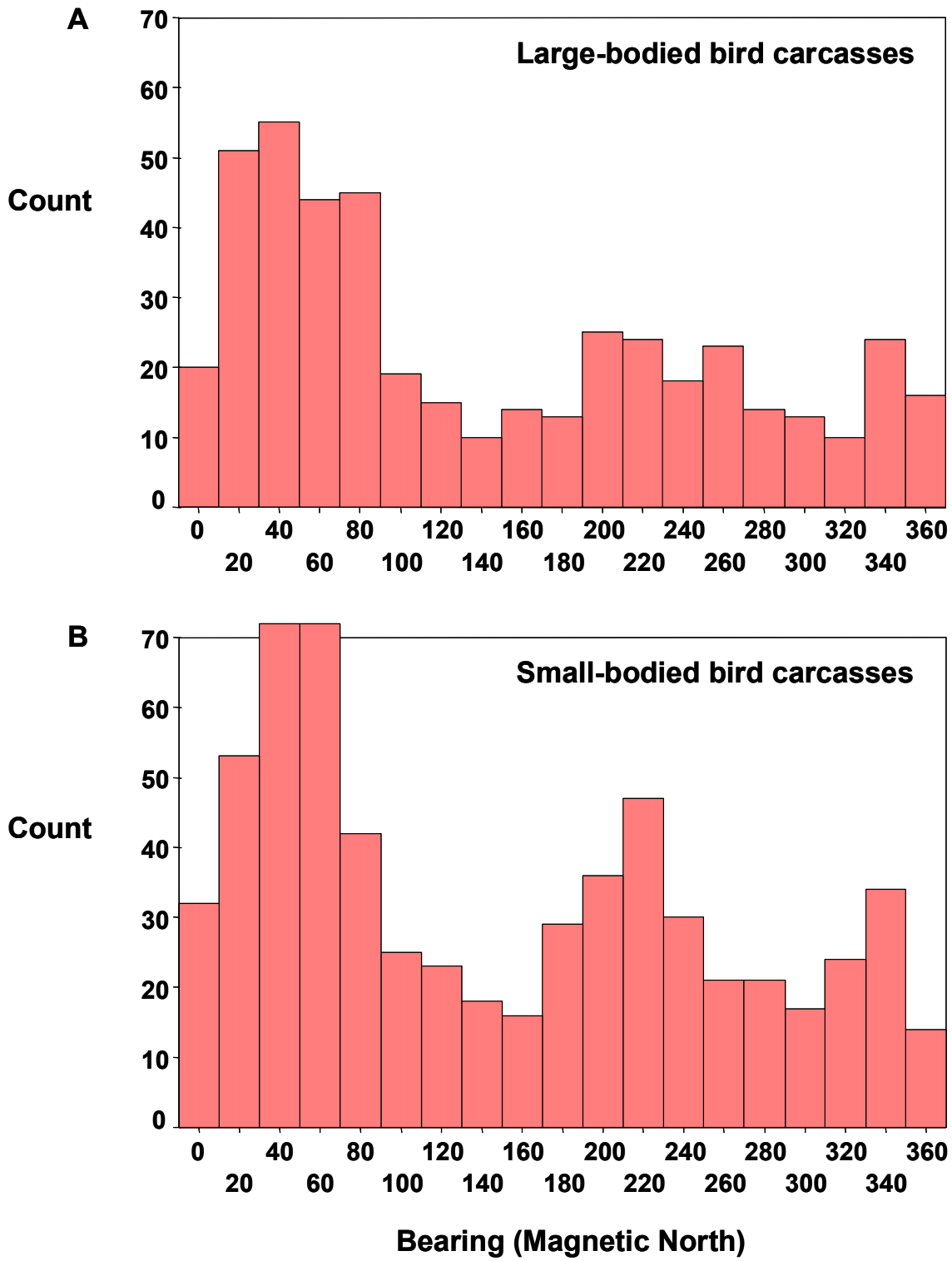


Figure 2-10. Frequency distributions of bearing from the wind tower among carcasses of large-bodied (A) and small-bodied (B) bird species

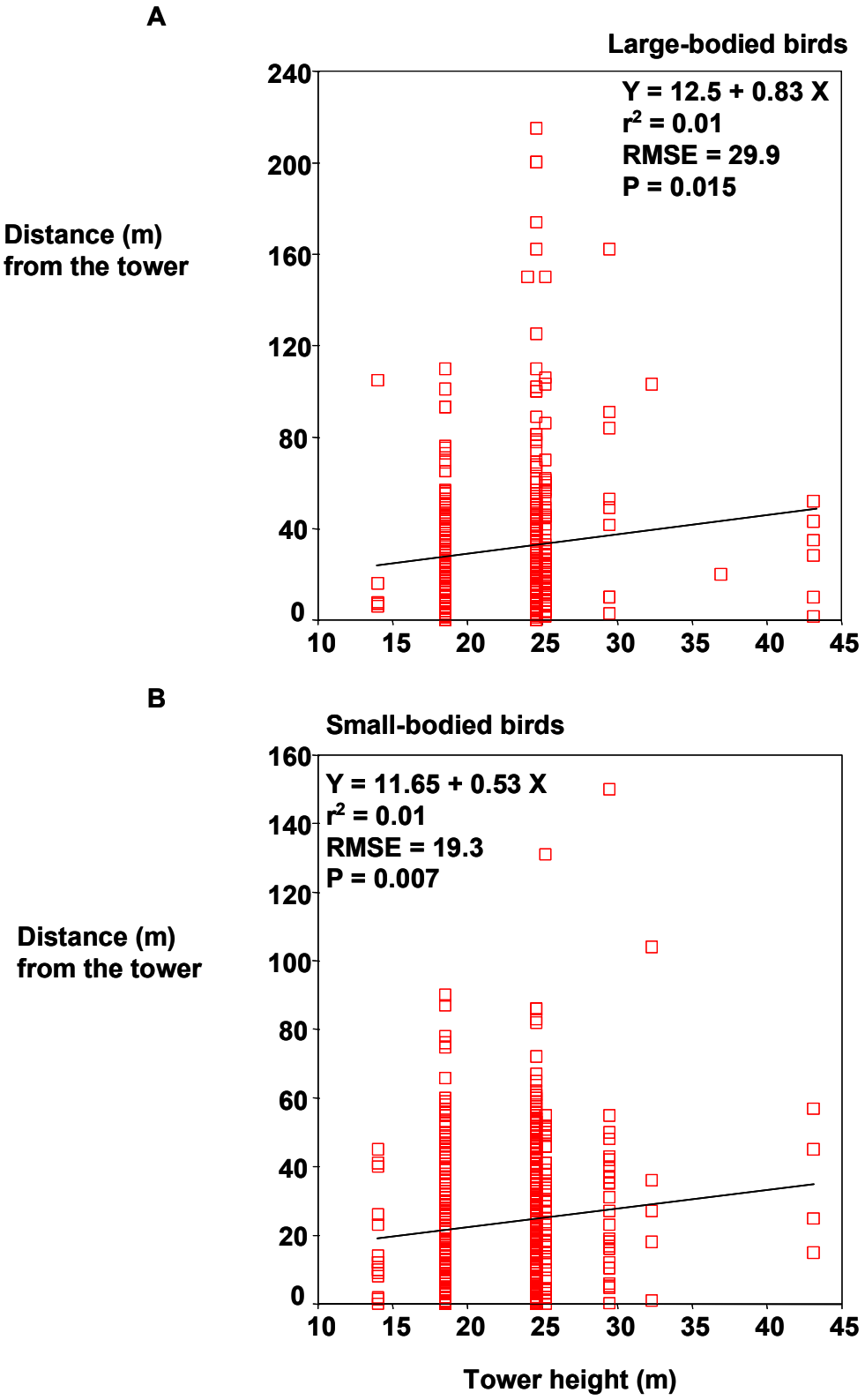


Figure 2-11. Distance of the carcass from the wind tower was a positive linear function of tower height for both large-bodied (A) and small-bodied (B) bird species.

We found that carcass distances from wind turbines differed significantly, based on blade tip speed (ANOVA F = 3.72; df = 9, 455; P < 0.001), although LSD tests revealed that the differences were only due to two turbine models operating at intermediate-fast speeds and otherwise there was no gradient from slow to fast speeds. The distance of the carcass location did not differ significantly by whether the rotor faces upwind or downwind (ANOVA F = 2.61; df = 1, 446; P = 0.107).

The distance of carcass locations from the wind turbines differed according to whether the wind turbine was located at the end, at a gap, or in the interior of a string of towers (ANOVA F = 11.11; df = 2, 455; P < 0.001), and post-hoc LSD tests found distances to be 13 m greater on average from end and edge of gap turbines, compared to interior turbines. Figure 2-13 illustrates the differences between mean distances.

Carcass distance from wind turbine did not differ by season of the year (ANOVA F = 0.75; df = 3, 458; P = 0. 524).

The distance of carcass locations from the wind turbines did not differ according to whether the wind turbine was located in a canyon (ANOVA F = 0.15; df = 2, 456; P = 0.862). It did not differ by four ranges of slope grade (ANOVA F = 1.25; df = 3, 456; P = 0.291), and it did not correlate significantly with elevation (r_p = -0.03, n = 457, P = 0.463).

Small-bodied Birds

Our search radius included 90.5% of the carcasses of small-bodied bird species (Figure 2-9B), of which 75% were located within 34 m of the tower. The mean and standard deviation of these 631 distances was 23.8 ± 19.4 m. Most carcasses were found northeast of the tower, and a considerable number were located southwest (Figure 2-10B), just as the large-bodied bird carcasses had been distributed.

Carcass distances from wind turbines tended to differ according to five ranges of tower height (ANOVA F = 2.24; df = 4, 628; P = 0.064), and post-hoc LSD tests indicated that carcasses were more distant from increasing taller towers through 32-m tower heights (mean distances at 14-, 18.5-, 25-, 32-, and 43-m heights were 17, 22, 24, 31, and 36 m, respectively). A linear regression slope was significant but imprecise (Figure 2-11B), and it predicted that for every meter increase in tower height, average distance of the carcass from the tower increased by half a meter.

Distance between carcass and tower did not differ significantly by wind turbine model (ANOVA F = 1.68; df = 8, 628; P = 0.101) (also see Figure 2-12B), or by blade tip speed (ANOVA F = 1.446; df = 10, 628; P = 0.156), or by whether the rotor faces upwind or downwind (ANOVA F = 0.98; df = 1, 596; P = 0.322).

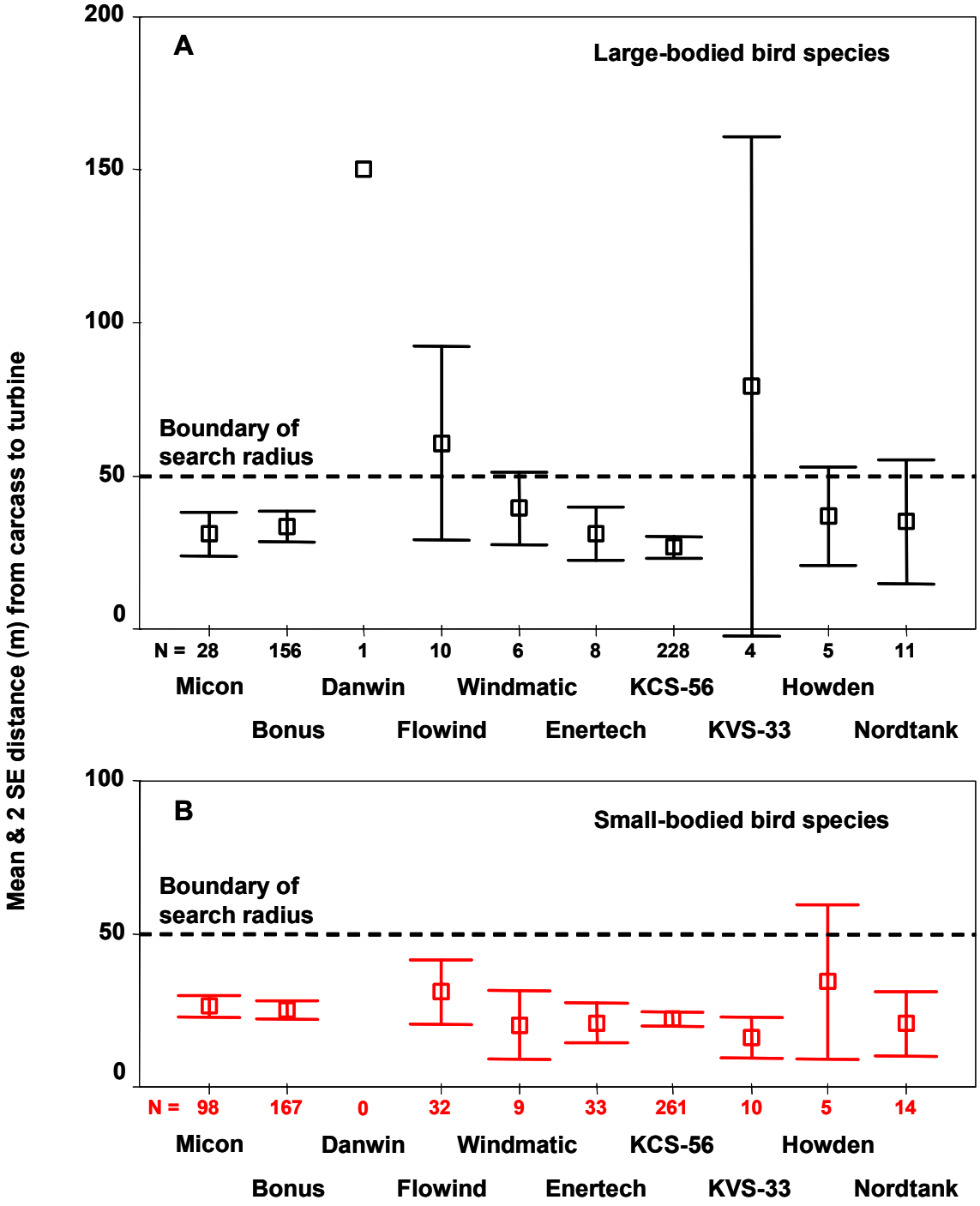


Figure 2-12. Mean distances from models of wind turbines for large-bodied (A) and small-bodied (B) bird species

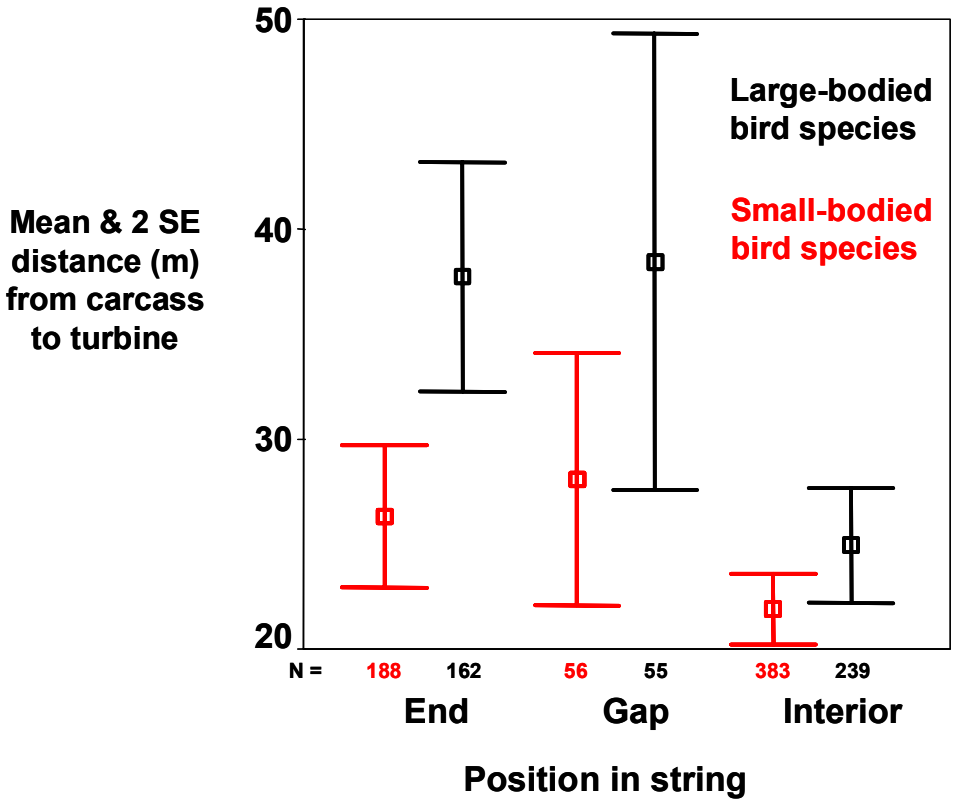


Figure 2-13. Mean distances of bird carcasses from wind turbines according to their positions in the string

Distance between carcass and tower differed significantly by position of the wind turbine in the string (ANOVA F = 4.79; df = 2, 626; P = 0.009), and post-hoc LSD tests revealed that the mean distances from end and edge-of-gap turbines were 4.4 m and 6.2 m greater, respectively, than from interior turbines.

Carcass distances from wind turbines differed significantly by season of the year (ANOVA F = 3.61; df = 3, 630; P = 0.013), and post-hoc LSD tests revealed that fatalities in spring were significantly closer to wind turbines (mean = 19.6 m) than were fatalities during summer (mean = 24.8 m), fall (mean = 28.1 m), and winter (mean = 23.5 m).

The distance of carcass locations from the wind turbines did not differ according to whether the wind turbine was located in a canyon (ANOVA F = 1.82; df = 2, 628; P = 0.164), or by four ranges of slope grade (ANOVA F = 0.237; df = 3, 628; P = 0.871). It correlated significantly and inversely with elevation, although the correlation coefficient was not large (r_p = -0.08, n = 628, P = 0.038).

2.4 DISCUSSION

We found birds beyond the 50-m search radius because the search crew members could sometimes see carcasses at these greater distances as they approached the 50-m termini of their transect segments. We found 15.3% of the carcasses of large-bodied species in our sample beyond the 50-m search radius, and 9.5% of our sample of small-bodied species was beyond our search radius. It appears that either larger-bodied bird carcasses were more readily seen at distances beyond the search radius or the majority of small-bodied birds truly fell within the 50-m search radius. We assume that we did not find an unknown proportion of the actual population of carcasses, due to carcasses located beyond our search radius.

Table 2-2 summarizes the results of our statistical tests of carcass distances related to measured variables. Taller towers knocked carcasses farther from the wind turbines, as did Flowind and KVS-33 wind turbines.

Table 2-2. Summary of significant test results related to distances of carcasses of large-bodied bird species from wind turbines

Variable	Large-bodied	Small-bodied
	Carcass distances greater at:	
Tower height	Taller towers	Taller towers
Turbine model	Flowind and KVS-33	---
Position in string	End and gap towers	End and gap towers

Although the position of the wind turbine in the string related significantly to the distance of carcass from the tower, the effect should be expected, simply because there is greater opportunity for carcasses to be located farther from the end tower. That is, if a bird is killed by an interior turbine, its carcass is likely to fall to either side and to be associated with the neighbor tower; whereas, the end tower only has one neighbor for such a mistaken association to be made. Still, the percentage of carcasses of large-bodied bird species found within 50 m of end turbines was 79%, which was 6% fewer than all the towers considered together and 11.4% fewer than the interior turbines alone. A greater search effort is needed for large-bodied bird species at end turbines; 100 m would include 94% of the carcasses we found.

A shortfall of our study was that we did not factor in the slope of the hills downhill from where the towers are located. The slope of the hills to each side of the wind turbines should be characterized and linked to the locations of the fatalities, so that measured distances from wind turbines can also be transformed into horizontal, planar distances by accounting for the degree of slope between the carcass and the tower. Many of the wind turbines at the ends of strings are located on precipices of very steep hills descending into ravines and canyons; they occur at the break of convex slopes. Birds can fall down these steep slopes, resulting in greater measured distances from the wind turbine. This potential effect needs to be considered in the future.

CHAPTER 3

BIRD MORTALITY IN THE ALTAMONT PASS WIND RESOURCE AREA

3.1 INTRODUCTION

The approximately 5,400 wind turbines operating in the APWRA generate about 580 MW of electricity, but they also kill birds that fly into the rotating blades. It is important for legal and biological reasons to estimate the impact of the APWRA on bird species. Impact estimates are needed to decide the extent, magnitude, and types of mitigation that should be implemented in the APWRA.

In this study we made impact estimates in terms of mortality, without regard to local species' populations. Mortality was expressed relative to megawatts of rated power generation and per year. We used MW in place of number of wind turbines for the reasons discussed in the Appendix A and elsewhere.

There are two fundamental ways to measure impacts to bird species. The simplest way is to express impact as the number of fatalities relative to the number of megawatts generated by the wind turbines and the time span over which the fatalities occurred. Another way is to compare the turbine-caused fatality rate to both the natural mortality and the recruitment rate of each species, thus estimating the degree to which the wind turbines adversely affect the numerical or demographic condition of each species. This latter way of expressing impacts enables risk assessments to be made, and is the preferred way of expressing impacts. However, this approach requires information of the numerical distribution and demographic constitution of populations occurring at and around the APWRA; the geographic scale of consideration should be much larger than the APWRA, because the APWRA may serve as an ecological sink for animal species affected by the wind turbines. That is because losing individuals from surrounding populations that disperse into the Altamont area and are killed could affect the overall numerical and demographic composition of the species throughout the region. It was beyond the scope of this project to estimate population size and to characterize the demography of all species in and around the APWRA; therefore, we employed the simpler means of estimating impact as the number of fatalities/MW/year.

To our knowledge, the simpler method of estimating impacts has been the only method used so far at this and other wind energy generating facilities. Howell and DiDonato (1991) reported 17 raptor fatalities for a rate of 0.05 deaths per turbine per year in the APWRA during 1988–1989. Orloff and Flannery (1996) conservatively estimated that 39 golden eagles were killed during a one-year period in the APWRA, with raptor fatality rates varying from 0.02 to 0.05 deaths per turbine per year. Howell (1997) identified 72 confirmed collision fatalities during an 18-month period at two wind resource areas: Altamont Pass and Montezuma Hills. Bird fatalities consisted of 44 raptors and 28 non-raptors with a mean raptor mortality of 0.029 birds per turbine per year. Outside the APWRA, raptor mortality estimates have ranged from 0 to 0.48 birds per turbine per year, and mortality estimates of all birds have ranged from 0 to 4.45 birds per turbine per year (Erickson et al. 2001). Erickson et al. (2001) did not report the mortality estimates of all birds in the APWRA because no scavenging or searcher efficiency studies were performed there. However, the error due to these factors would have rendered the estimates conservative, so not including them in Erickson et al.'s

review truncated the upper range of mortality estimates and underestimated the potential number of birds killed by wind turbine operations.

Among the species of raptors killed in the APWRA, the golden eagle has been the species of greatest concern and whose local population is most likely to be adversely affected (Hunt 1994, 2002). In addition to its low abundance relative to other raptors, the breeding and recruitment rates of golden eagles are naturally low, and reductions in golden eagle populations have been documented in other parts of the United States. The golden eagle is a species of special concern in California (California Fish and Game Department 1992) and receives special protection under the federal Bald Eagle Protection Act as amended in 1963.

In our final report to NREL (Smallwood and Thelander, in review), we reported mortality estimates based only on turbine strings that had been searched for carcasses for at least one year. We excluded many wind turbine strings that were searched for less than one year, and which would have generated much greater mortality estimates had they been used. In this study, these turbine strings were searched for an additional year, so they were included in our estimates of mortality.

Our purpose was to estimate mortality of each species so that comparisons could be made to other sites or to future monitoring results from the APWRA. Another objective was to compare mortality by wind turbine type, rodent control level, ownership of the wind turbines, and season of the year. Finally, we extrapolated our mortality estimates to the portion of the APWRA not sampled in order to characterize the range of likely project impacts per species and larger taxonomic groups.

3.2 METHODS

We sampled 1,526 individual wind turbine and tower configurations from March 1998 through September 2002, which we refer to as the first set of wind turbines. During the course of the project, we periodically added groups of wind turbines into this set as access to these turbines became available. By September 2002 the first set of wind turbines included 182 strings (i.e., rows of wind turbines). From November 2002 until May 2003 we sampled a second set of wind turbines, including 2,548 turbines arranged in 380 strings. Access to this second set of wind turbines was not granted until only six months remained in our study. In total, we sampled about 75% of the wind turbines in the APWRA.

Gauthreaux (1996) suggested that searches for bird fatalities should be circular around each wind turbine, the minimum radius to be determined by the height of the wind turbine. Because all wind turbines in our study area were arranged in strings, we searched them efficiently by walking strip transects along both sides and around the ends. Thus, we chose the string of turbines as one of our study units because searches were efficiently performed on them. All wind turbines composing a turbine string shared common search dates, frequency of searching, and time span during which the searches were performed. For reasons beyond our control, we were unable to search all turbine strings throughout the study or equally in frequency, so our fatality searches among turbine strings varied by time spans and seasonal representation. Most turbine strings were given roughly similar search effort over the time spans they were searched (Figures 3-1 and 3-2), averaging 7.2 searches per year.

Two people explored the ground around each string of wind towers, using one of two searching methods, one for level terrain and the second for hillsides (Figure 3-3). In either case, each person walked in line with the string, 50 m away from the first tower, and 50 m in the opposite direction away from the string centerline. Previous studies reported that about 77% of all carcasses were found within a 30–40 m radius from the wind towers (Orloff and Flannery 1992; Munsters et al. 1996; Howell 1997), and we recently found that 85%–88% of the carcasses occurred within 50 m of the wind towers (Smallwood and Thelander in review). Both searchers walked towards and outwards from the string of turbines in a zigzag pattern from wind tower to wind tower until they reached the last one in the string.

On hillsides or steep terrain, the searchers walked parallel to the string of wind turbines; whereas, on level terrain they walked perpendicular to it. The distance between each zigzag characterizes a different approach to this technique as compared with previous fatality search studies, such as Orloff and Flannery (1992). In this study, we kept a tight, closed, zigzag pattern, approximately four meters between each turn. The expected advantage of this ground-surveying technique was to increase the probability of detection of all bird remains, including small passerines.

The ground around each wind tower was searched in 8–10 minutes. Five hours per day was devoted to fatality searches, and two-person crews managed to search 30–40 wind turbines per day. With two to three people searching 120–150 wind turbines per week, 685 turbines could be sampled once every five to six weeks, thus completing approximately eight fatality search cycles in 12 months during 1998 through 1999, when we were limited to 685 turbines. Not all turbine strings were searched every month due to changes in field strategies or for reasons out of our control, such as fire hazards and flooded roads. As we were allowed to search around additional wind turbines, our search rotations took longer and our frequency of searches per year declined.

All carcasses or body parts, such as groups of flight feathers, head, wings, tarsi, and tail feathers, found during each search within a 50-m radius of the wind turbine were documented and flagged as fatalities. We carefully examined these to determine species, age, sex, and probable cause of death. The time since death was estimated by carefully analyzing the carcass condition (e.g., fresh, weathered, dry, bleached bones) and decomposition level (e.g., flesh color, presence of maggots, odor), using methods and standards described in the following paragraphs.

To determine the cause of death, we evaluated the general condition of intact carcasses. For dismembered or mutilated remains we evaluated carcass position, the distance and compass reading to the nearest wind turbine or electrical distribution pole or wire, and the type(s) of injury. Each fatality was classified as a “fresh kill” or as “old remains,” depending on the estimated time since death. Fatalities were considered fresh when carcasses and small remains were estimated < 90 days since death. Old remains included highly decomposed and dismembered carcasses with weathered and discolored feathers, missing flesh, and bleached, exposed bones. These carcass characteristics led observers to believe that the time since death was before the initiation of search rotations at the particular wind turbines. The above data, as well as the distance and angle to the wind turbine closest to the carcass, were recorded on a standard data sheet. Biologists photographed each fatality at the time of discovery.

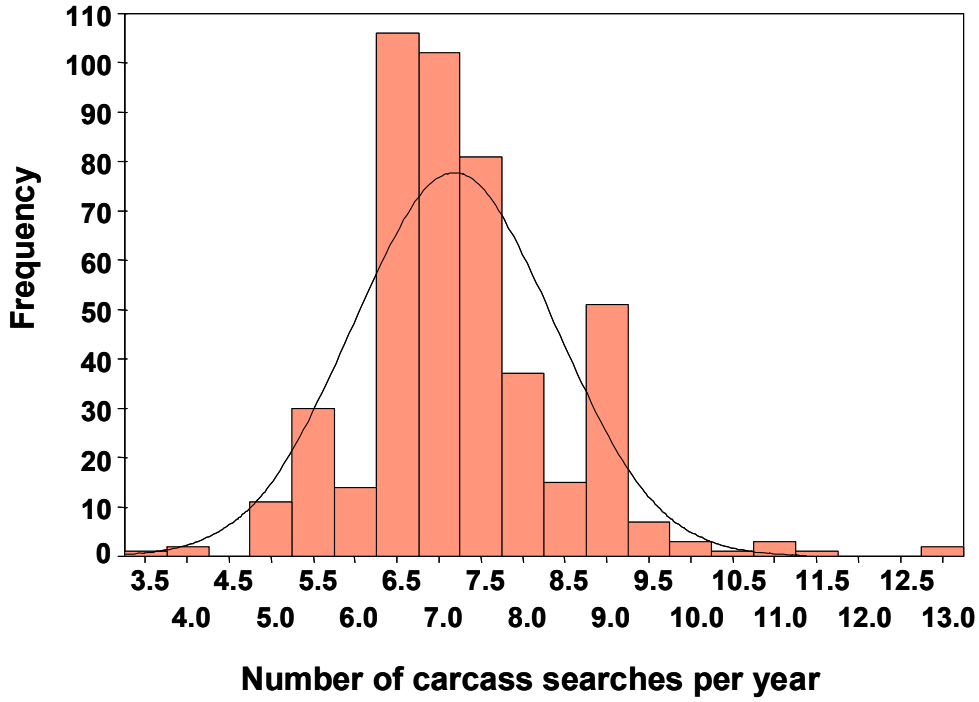


Figure 3-1. Frequency distribution of the annual number of carcass searches performed per wind turbine string during our study. Most turbine strings were searched between 6 and 9 times per year

We expressed mortality as the number of fatalities per MW per year (see Appendix A), where the MW were the sum of the rated power output of the wind turbines composing the string, and the number of years or fractions of a year were the time spans over which searches were performed at that string of wind turbines. To the number of years used in the mortality estimate, we added three months to every wind turbine string, to represent the time period when fresh carcasses could have accumulated prior to our first search. We assumed that the same number of fatalities would have been found during a given year regardless of whether twelve searches or eight searches were performed, but it is likely that reduced search frequency resulted in lower carcass detection rates, especially for smaller-bodied bird species. Old remains were not included in the calculations.

Searcher detection and scavenger removal rates were not studied, because it had already been established that mortality in the APWRA is much greater than experienced at other wind energy generating facilities. We were unconcerned with underestimating mortality, and in fact we acknowledge that we did so. We were more concerned with learning the factors related to fatalities so that we can recommend solutions to the wind turbine-caused bird mortality problem. Thus, we put our energy into finding bird carcasses rather than into estimating how many birds we were missing due to variation in physiographic conditions, scavenging, searcher biases, or other actions that may have resulted in carcasses being removed.

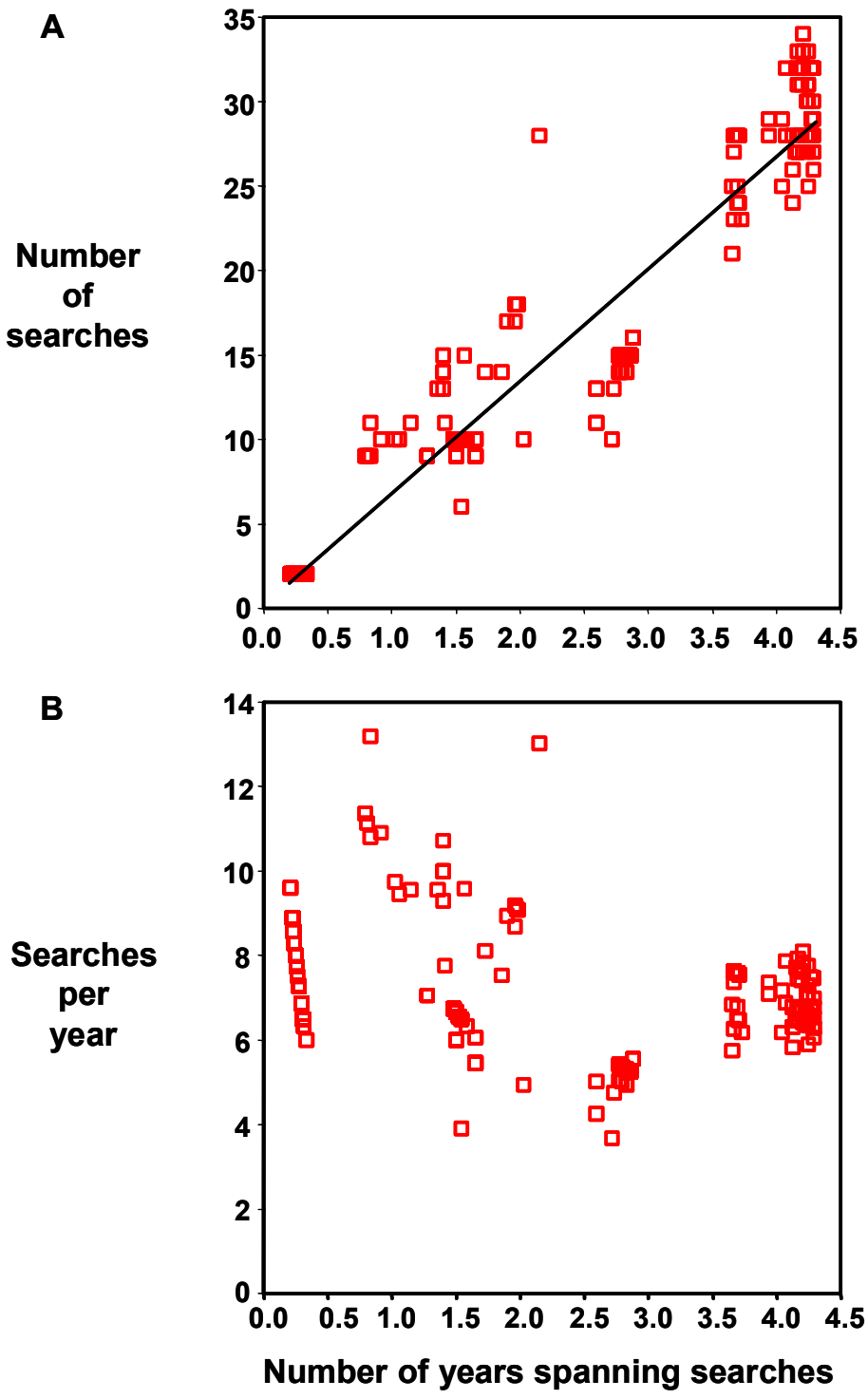


Figure 3-2. The number of carcass searches performed at each turbine string was a simple linear function of the span of time the searches were performed there (A). The searches per year decreased slightly with time span (B).

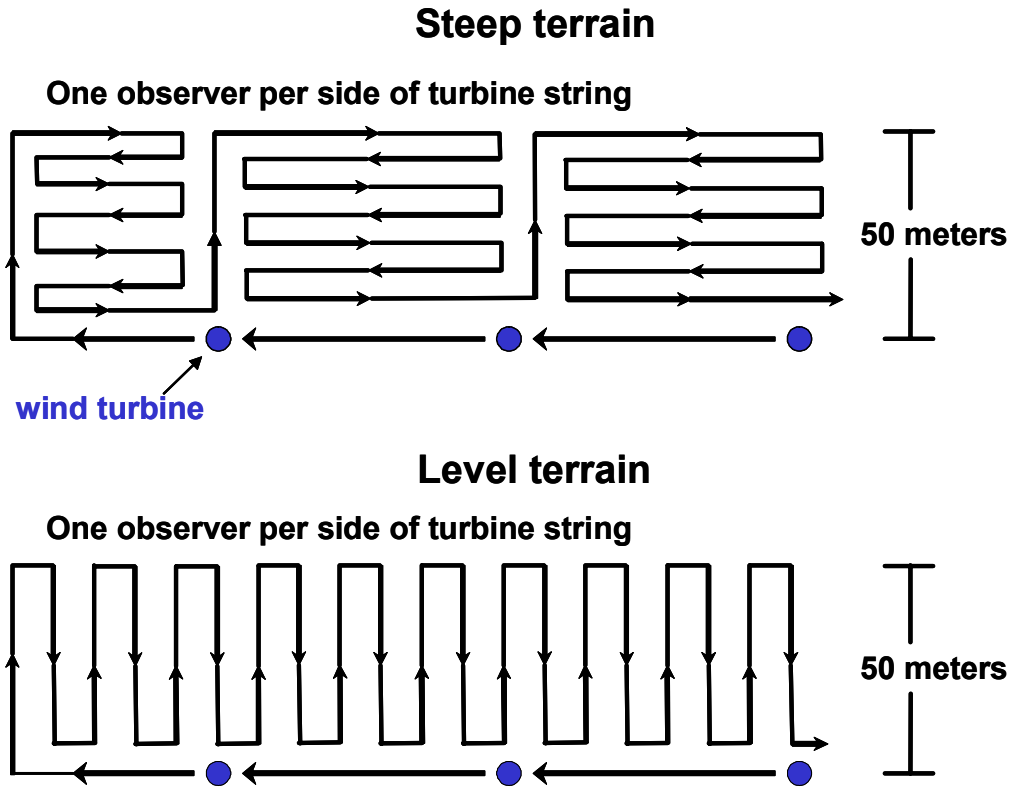


Figure 3-3. Fatality searches were performed in a regular pattern, which was adjusted to fit the terrain but that never compromised on the coverage of the 50-m search radius.

Because we did not perform trials to estimate searcher detection and scavenger removal rates, we relied on published estimates from other studies. Orloff and Flannery (1992) estimated searcher detection of 85% of raptor carcasses in the APWRA, so we used this value for raptors. For non-raptors, we used the mean between the Johnson et al. (2002) estimate of 38.7% and the Erickson et al. (2003) estimate of 43%, which was 40.85% and rounded to 41%. We divided raptor mortality by 0.85 and non-raptor mortality by 0.41. To these, we added the species/group-specific fraction of carcasses located > 50 m from wind turbines, assuming we missed detecting just as many outside our search radius. Adjustments for searcher detection rates were made prior to factoring in scavenger removal rates.

Erickson et al. (2003) estimated that after 40 days, 58.6% of carcasses of large-bodied species were removed on average, and that 80.2% of carcasses of small-bodied species were removed. Our average search interval was 53 ± 11.6 days for the first set of 1,526 wind turbines included in our first rotations, and 90 days for the second set of 2,548 wind turbines. Therefore, we adopted the carcass removal rates of Erickson et al. (2003) for the first set, assuming scavenger removal rates were similar between 40 days in their study and 53 days in ours, and we added 10% to these rates for the second set of 2,548 wind turbines, resulting in estimates of 68.6% of carcasses of large-bodied species removed

between searches and 90.2% of carcasses of small-bodied species. To adjust our mortality estimates so that they included the carcasses removed by scavengers and those that we did not detect, we divided the raw mortality estimates by the proportion of carcasses detected by Erickson et al. because the carcasses had not been removed yet by scavengers. For the first set of wind turbines searched, we divided mortality by 0.198 and 0.414 for small-bodied and large-bodied species, respectively. For the second set of wind turbines searched, we divided mortality by 0.098 and 0.314 for small-bodied and large-bodied species, respectively. Based on our experience with raptor carcasses in the APWRA, we did not believe that these scavenger removal rates were accurate for raptors, and we halved the removal rate estimates reported by Erickson et al. (2003). Mortality of small raptor species at the first set of wind turbines searched was divided by 0.396, and by 0.196 at the second set searched. Mortality of large raptor species at the first set of wind turbines searched was divided by 0.828, and by 0.628 at the second set.

After adjusting for searcher detection bias and the rates of carcass removal by scavengers, some error remains due to the WRRS (Wildlife Reporting and Response System) and other human actions. We found one raptor carcass buried under rocks and another stuffed in a ground squirrel burrow. One operator neglected to inform us when a golden eagle was removed as a part of the WRRS. Based on these experiences, it is possible that we missed other carcasses that were removed. For these reasons, our mortality estimates might be conservative.

3.3 RESULTS

We found 1,162 fatalities attributed to wind turbines, of which 198 were carcasses estimated to have been more than 90 days old and which were excluded from estimations of mortality (Table 3-1). These older carcasses were used for association analyses intended to identify factors related to turbine-caused mortality, and were used in the analysis of fatality associations reported in Chapter 6.

Most of the species represented by these wind turbine-caused fatalities are protected under the Migratory Bird Treaty Act (MBTA) and some have special status under other environmental laws (Table 3-2). At the string level of analysis, the frequency distributions of mortality were right-skewed, which means that most turbines killed no or few individuals during our four-year survey (Figure 3-4).

Golden eagle mortality did not change significantly between years of fatality searches in the APWRA, no matter which groups of turbine strings were compared (Tables 3-3 through 3-8); nor did the mortality of American kestrel and great horned owl. Red-tailed hawk mortality oscillated significantly between years (Table 3-3, Figures 3-5 and 3-6). Burrowing owl mortality increased from the first year through the third year of the study, according to the comparison including all turbine strings searched for at least one year (Table 3-3, Figure 3-7), but including only turbine strings searched all four years, it did not (Table 3-4, right columns). Barn owl mortality increased significantly between the first and second years, and then decreased through the rest of the study (Table 3-3, Figures 3-8 and 3-9).

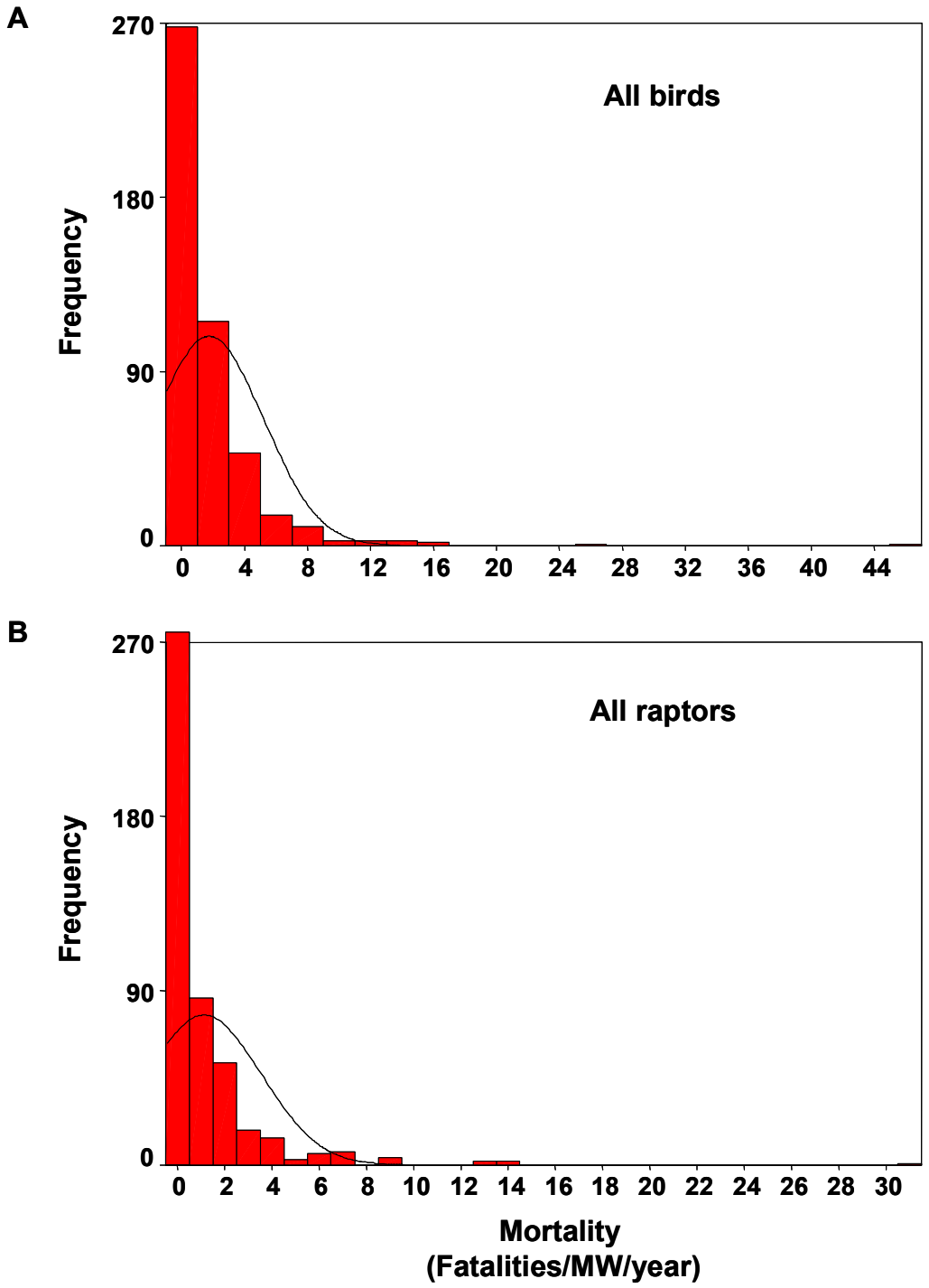


Figure 3-4. The frequency distributions of mortality estimates (unadjusted for the effects of search radius, searcher detection, and removal of carcasses by scavengers) were right skewed for all birds (A) and for raptors (B).

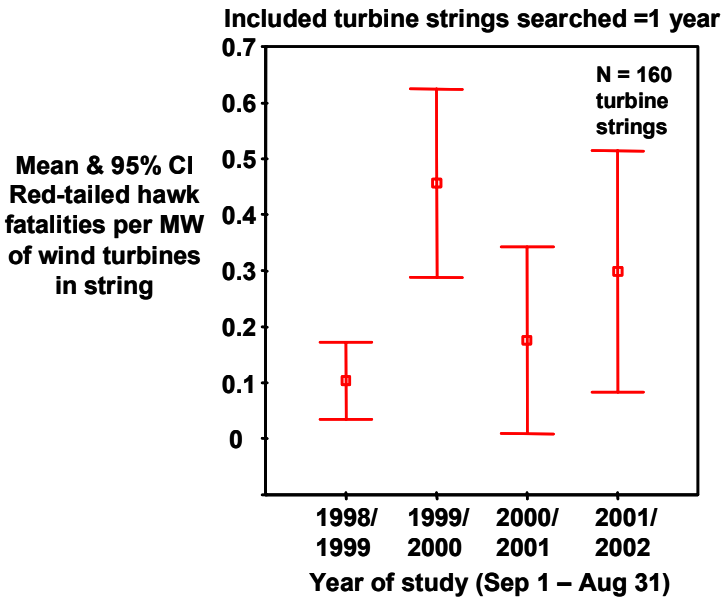


Figure 3-5. Inter-annual variation in mean mortality for red-tailed hawks, based on wind turbine strings searched for at least one year

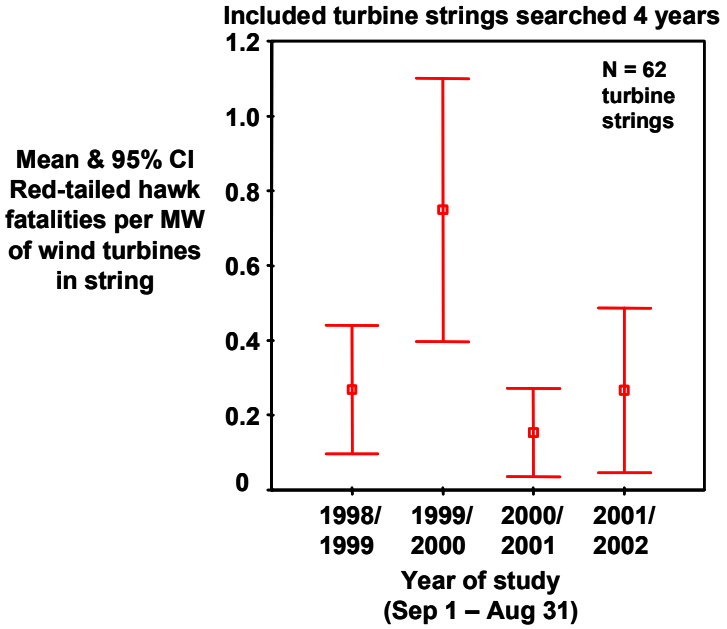


Figure 3-6. Inter-annual variation in mean mortality for red-tailed hawks, based on wind turbine string searched at least four years

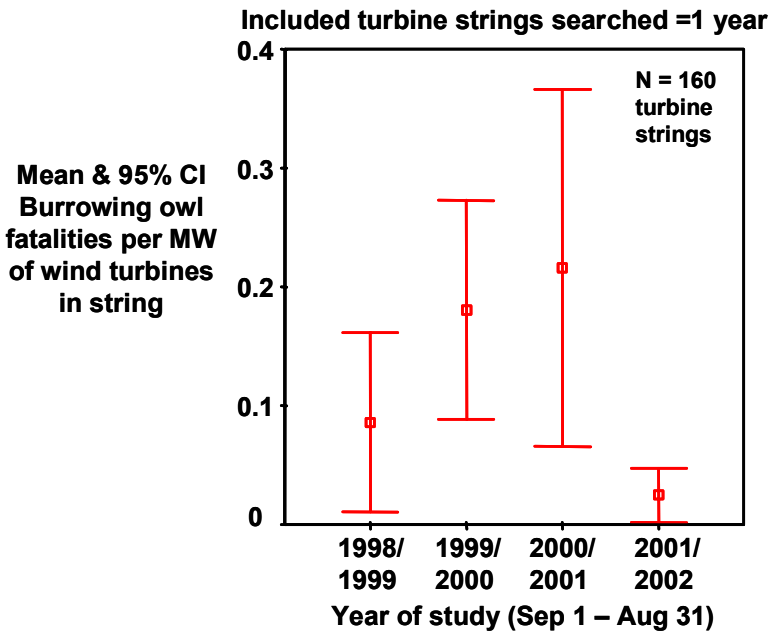


Figure 3-7. Inter-annual variation in mean mortality for burrowing owls, based on wind turbine strings searched for at least one year

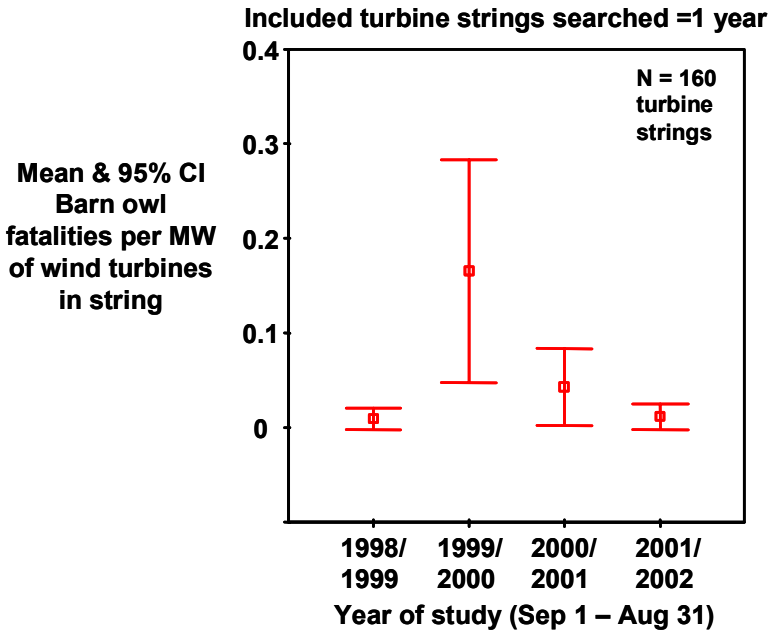


Figure 3-8. Inter-annual variation in mean mortality of barn owls, based on wind turbine strings searched at least one year

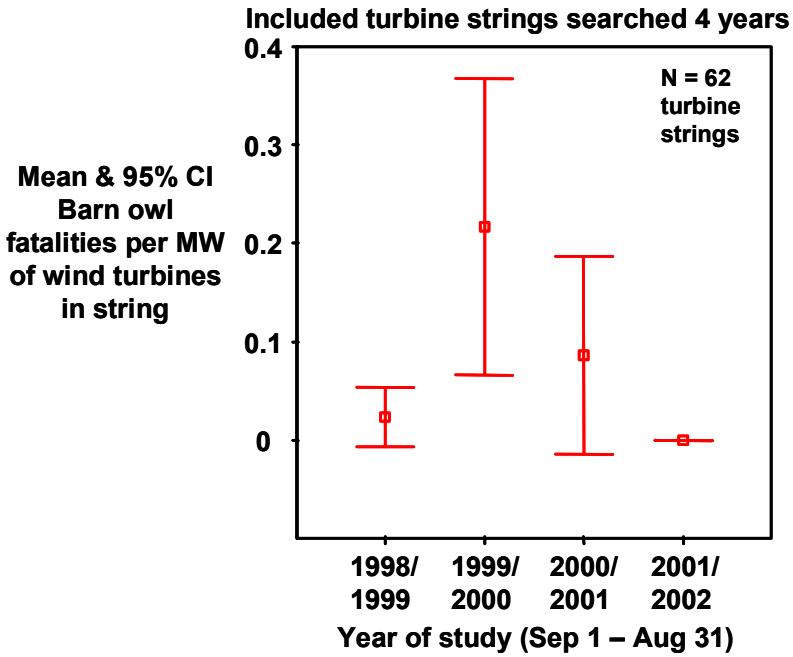


Figure 3-9. Inter-annual variation in mean mortality of barn owl, based on wind turbine strings searched at least four years

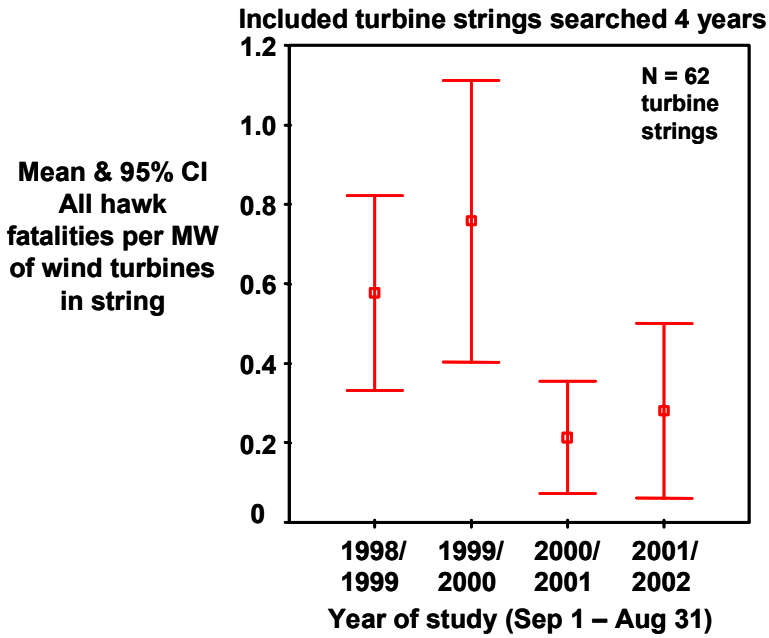


Figure 3-10. Inter-annual variation in mean mortality of all hawks, based on wind turbine strings searched at least four years

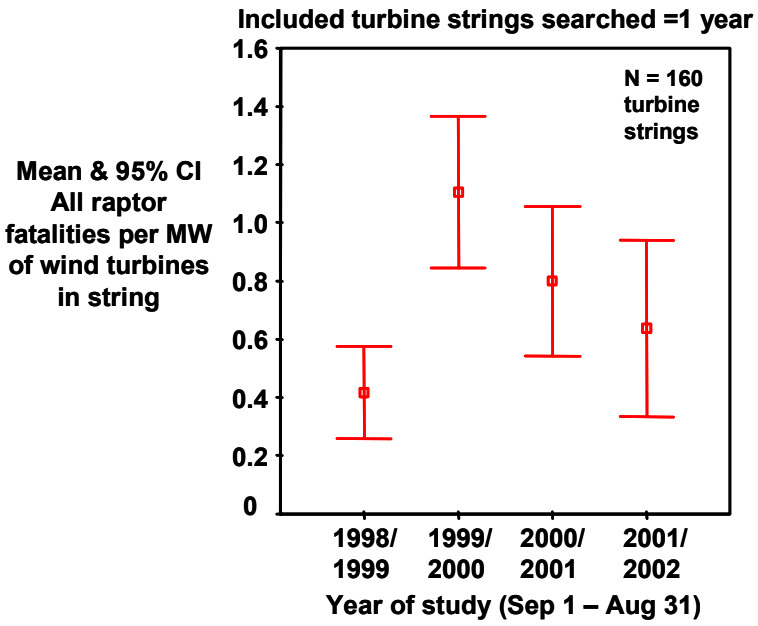


Figure 3-11. Inter-annual variation in mean mortality of all raptors, based on wind turbine strings searched at least one year

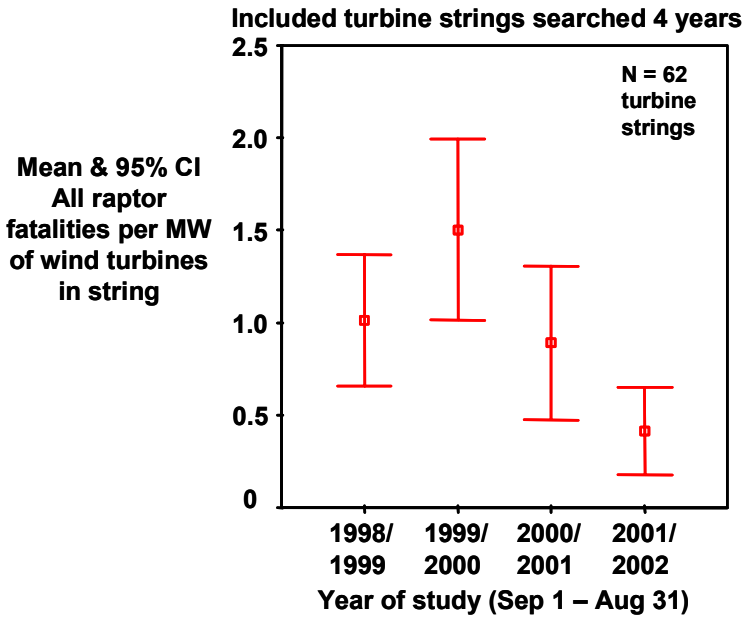


Figure 3-12. Inter-annual variation in mean mortality of all raptors, based on wind turbine strings searched at least four years

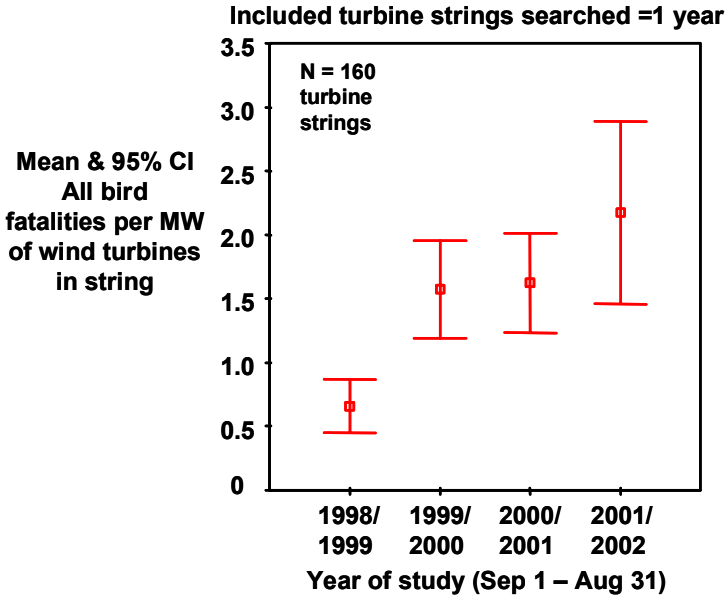


Figure 3-13. Inter-annual variation in mean mortality of all birds, based on wind turbine strings searched at least one year

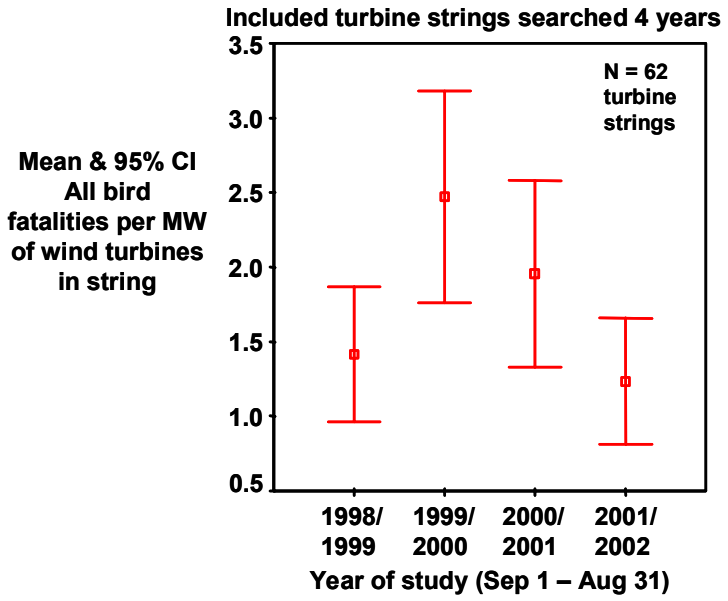


Figure 3-14. Inter-annual variation in mean mortality of all birds, based on wind turbine strings searched at least four years

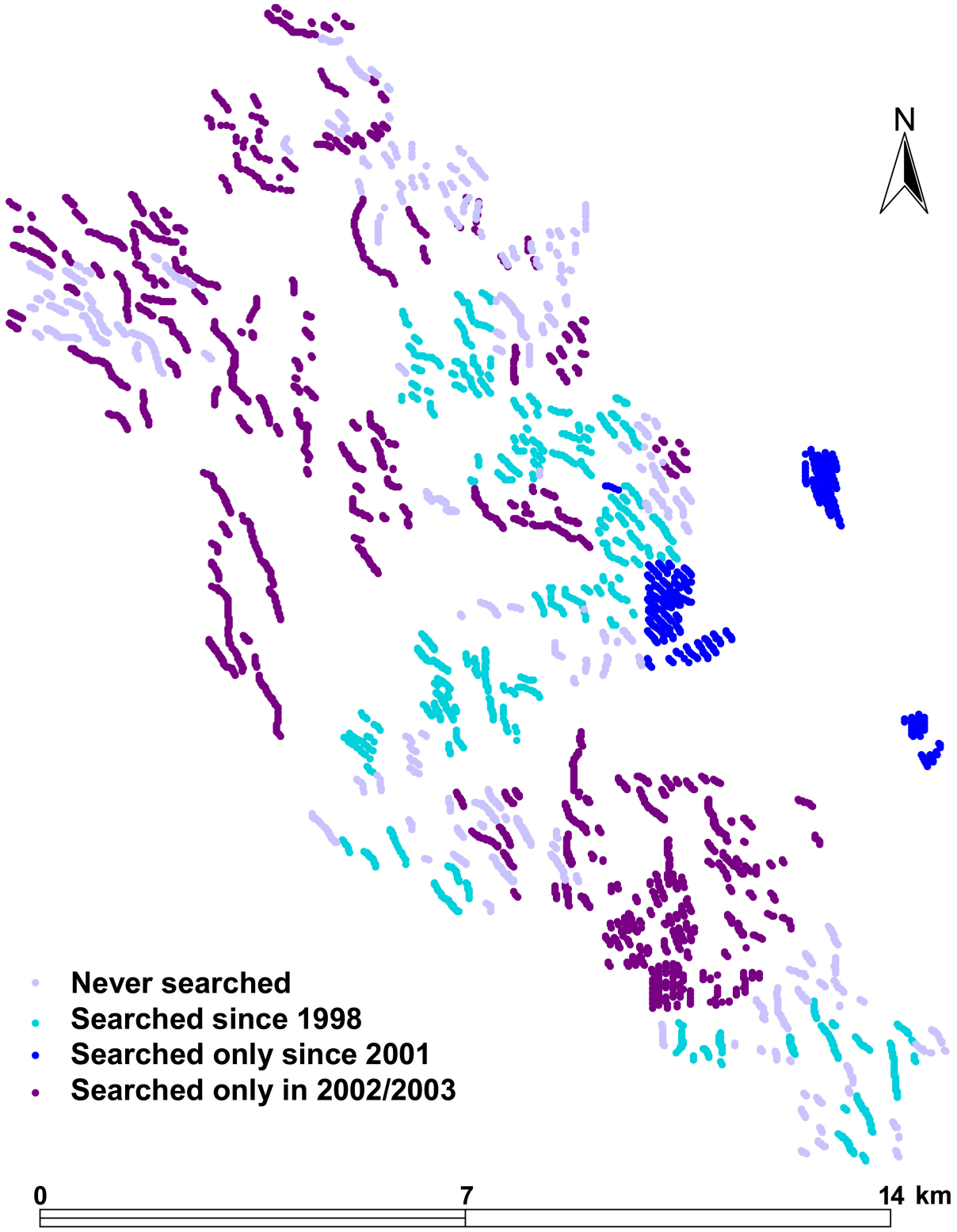


Figure 3-15. Relative search effort devoted to each wind turbine in the study, represented as year since carcass searches began

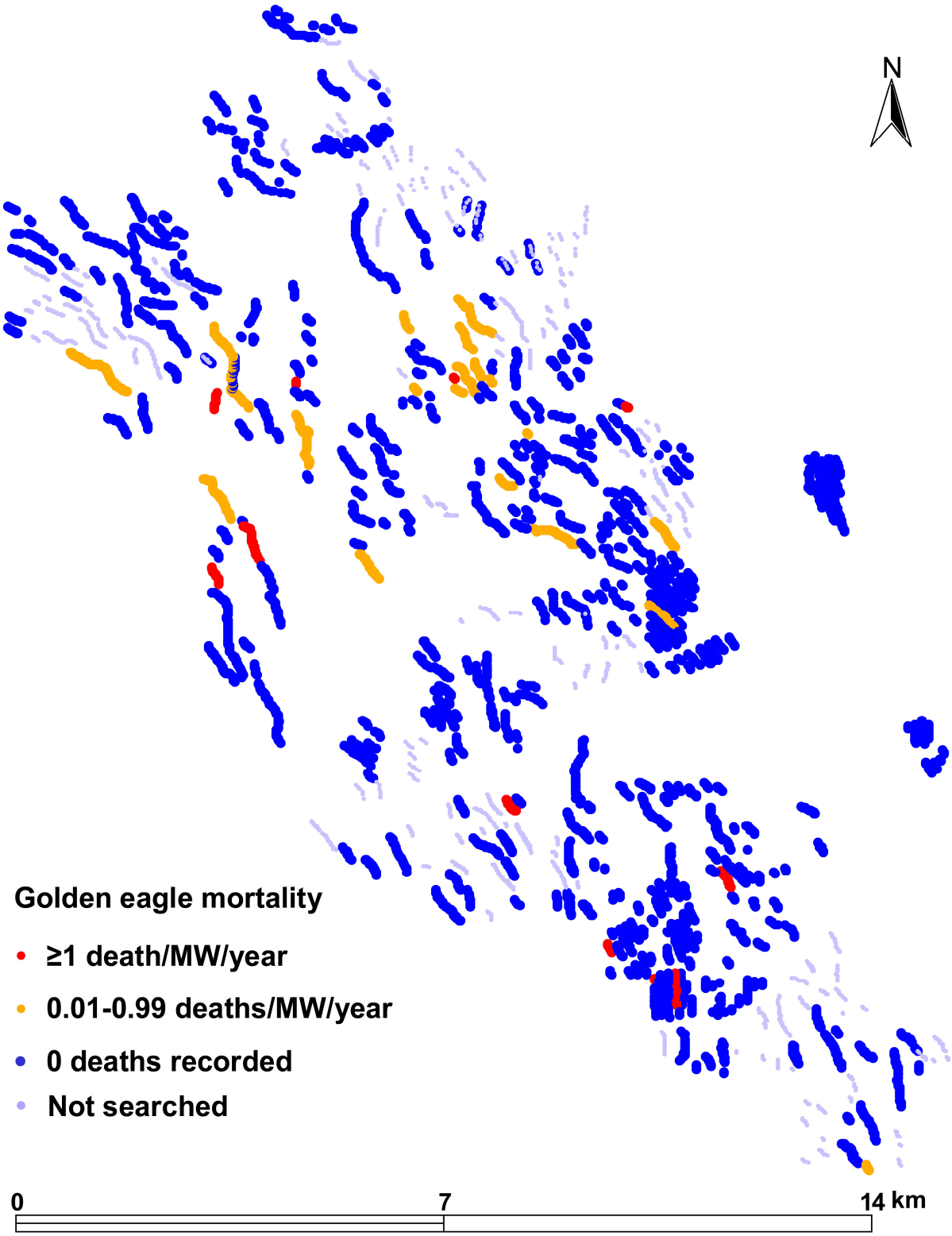


Figure 3-16. Spatial distribution of golden eagle mortality at the wind turbine string level of analysis. These mortality estimates were unadjusted for the effects of search radius, searcher detection, and removal of carcasses by scavengers.

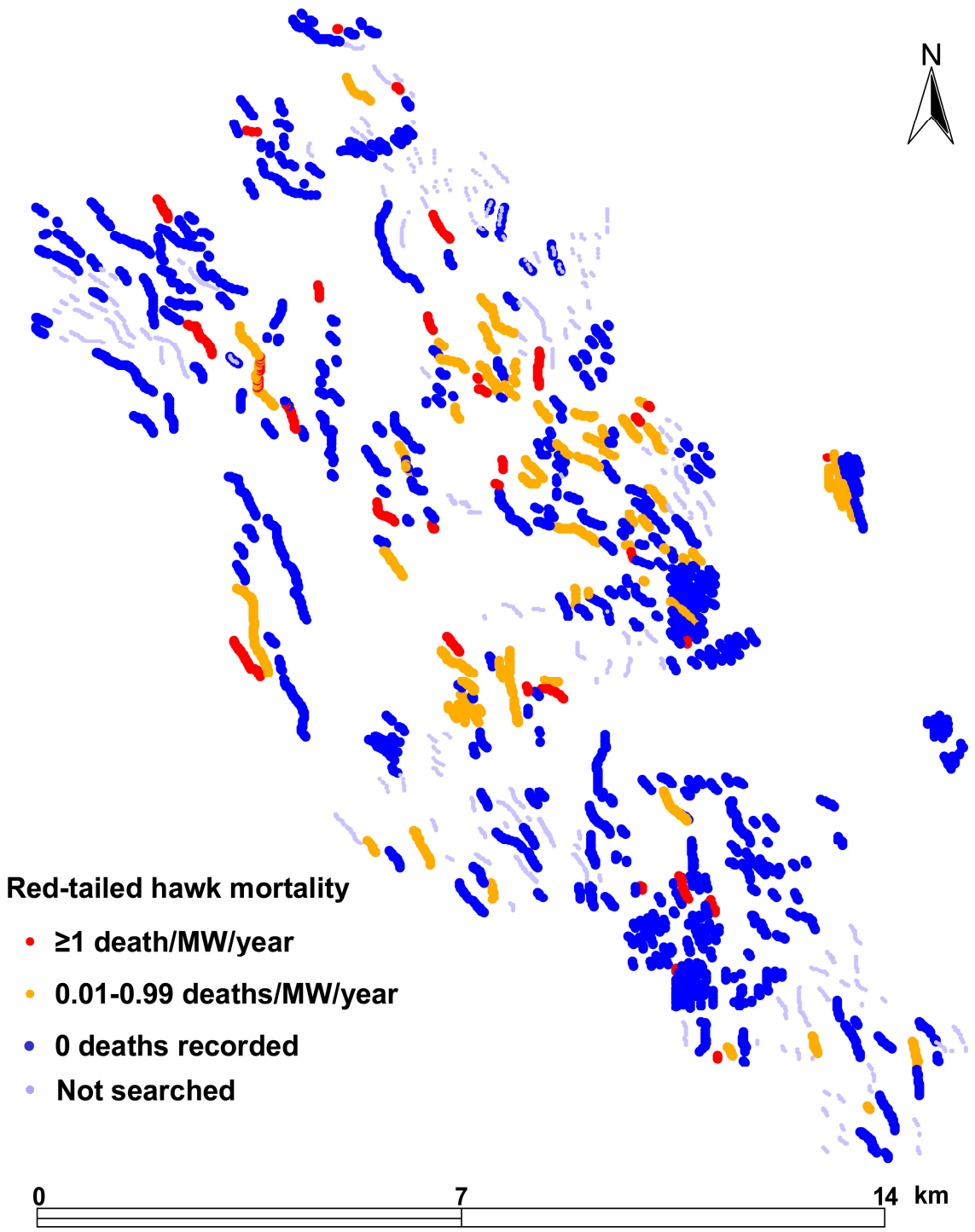


Figure 3-17. Spatial distribution of red-tailed hawk mortality at the wind turbine string level of analysis. These mortality estimates were unadjusted for the effects of search radius, searcher detection, and removal of carcasses by scavengers.

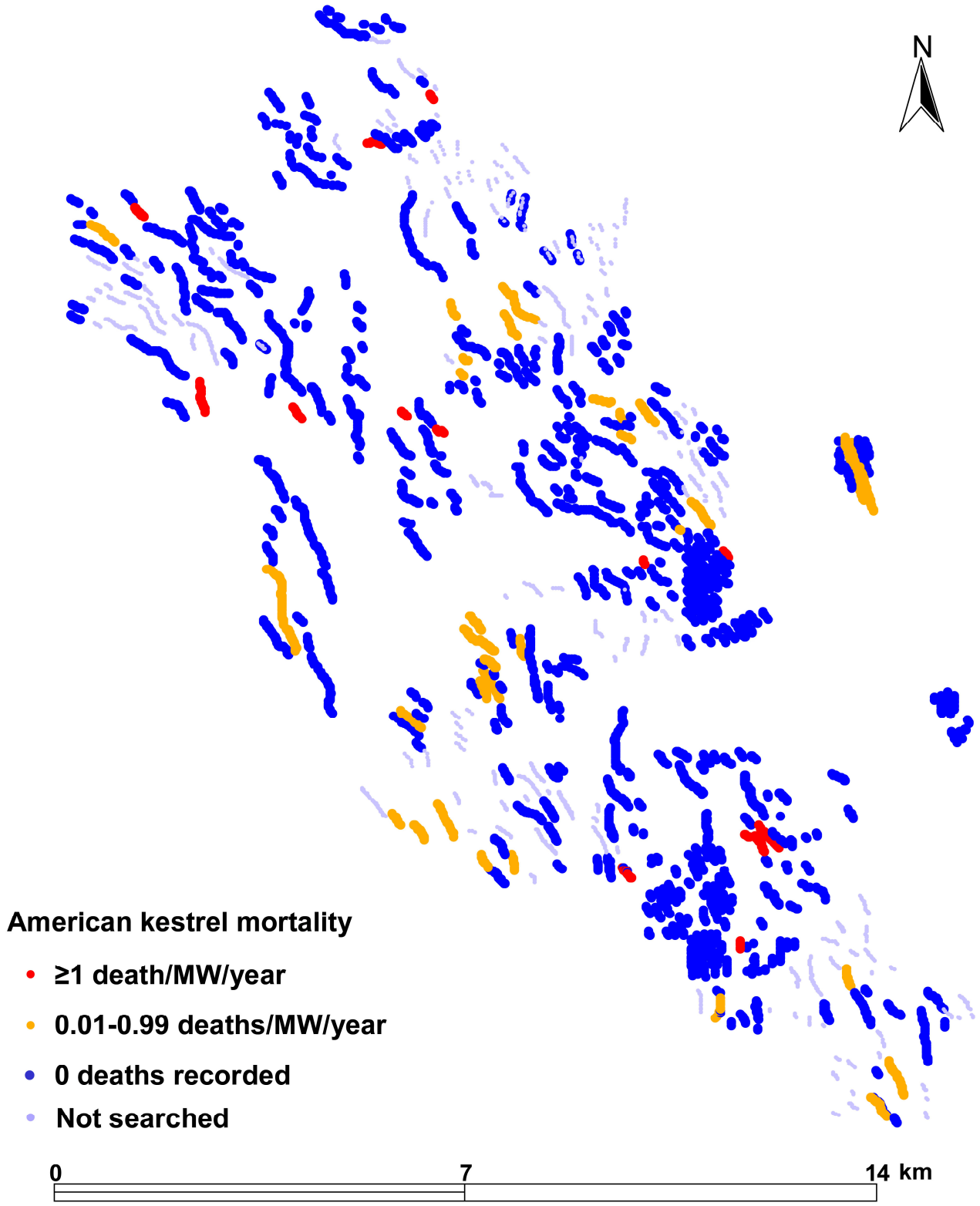


Figure 3-18. Spatial distribution of American kestrel mortality at the wind turbine string level of analysis. These mortality estimates were unadjusted for the effects of search radius, searcher detection, and removal of carcasses by scavengers.

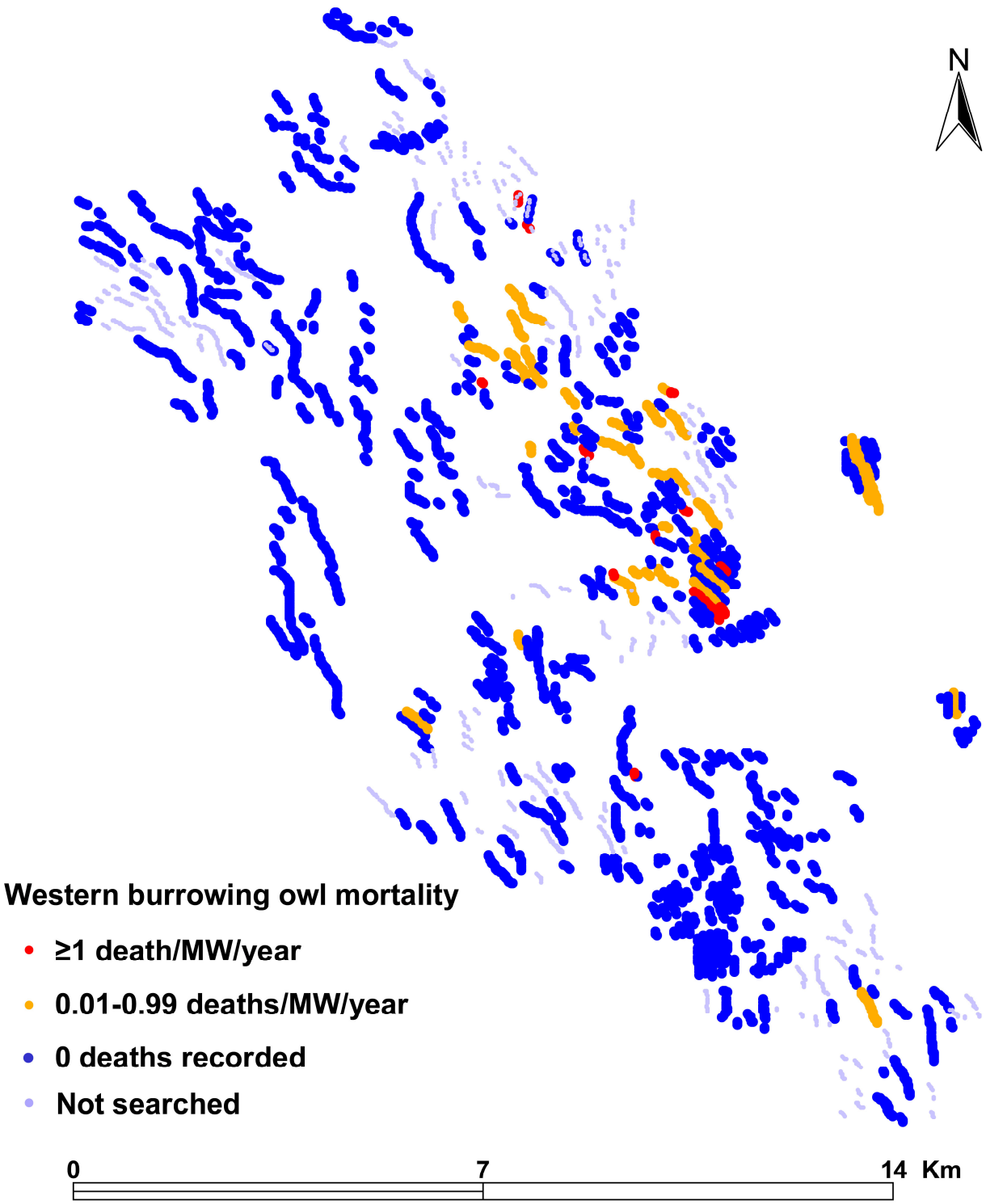


Figure 3-19. Spatial distribution of burrowing owl mortality at the wind turbine string level of analysis. These mortality estimates were unadjusted for the effects of search radius, searcher detection, and removal of carcasses by scavengers.

At those turbine strings searched all four years, the mortality of all hawks combined decreased significantly between the first and second and third and fourth years (Tables 3-3 and 3-8, Figure 3-10). The mortality of all raptors combined increased significantly between the first and second years and then decreased through year four (Tables 3-3 and 3-4, Figures 3-11 and 3-12). The mortality of all bird species combined increased steadily and significantly throughout the study, according to the comparison including all turbine strings searched for at least one year (Table 3-3, Figure 3-13), but it increased between years one and two, and decreased thereafter, according to the comparison, including only wind turbines searched all four years (Table 3-3, Figure 3-14).

Overall mortality estimates are presented in Table 3-9, and these are unadjusted for rates of searcher detection and scavenger removal of carcasses. Relative search efforts are presented in Figure 3-15, and unadjusted mortality estimates are depicted among wind turbine strings in the APWRA for golden eagle (Figure 3-16), red-tailed hawk (Figure 3-17), American kestrel (Figure 3-18), and burrowing owl (Figure 3-19). Table 3-10 presents the mortality estimates adjusted for searcher detection and scavenging rates. Table 3-11 lists the mortality estimates for the entire APWRA in terms of fatalities per MW per year and in terms of fatalities per year. To facilitate the comparison of mortality we estimated in the APWRA to mortality reported elsewhere, we also provide Table 3-12, which presents mortality in terms of fatalities/wind turbine/year.

Table 3-1. Summary of wind turbine-caused fatalities found by BioResource Consultants at the Altamont Pass Wind Resource Area from May 1998 through May 2003. Type A = Both fresh and old; Type B = Fresh; used to estimate mortality; Type C = at 1,526 turbines searched 1998–2002; Type D = at 2,548 turbines searched 2002–2003.

Species/Taxonomic Group	Number of Carcasses Found			
	Type A	Type B	Type C	Type D
Golden eagle	54	25	23	31
Turkey vulture	6	3	4	2
Red-tailed hawk	213	151	157	56
Ferruginous hawk	2	2	0	2
Buteo spp.	23	0	23	0
Northern harrier	3	3	3	0
White-tailed kite	1	0	1	0
Prairie falcon	3	3	3	0
American kestrel	59	57	44	15
Burrowing owl	70	68	66	4
Great horned owl	18	10	13	5
Barn owl	50	41	38	12
Unidentified raptors	17	0	5	12
California gull	7	6	7	0
Ring-billed gull	4	4	4	0
Unidentified gull species	18	6	5	13
American avocet	3	3	3	0

Table 3-1. (cont'd)

Species/Taxonomic Group	Number of Carcasses Found			
	Type A	Type B	Type C	Type D
Cattle egret	1	1	0	1
Double-breasted cormorant	1	0	1	0
Lesser yellowlegs	1	1	1	0
Black-crowned night heron	2	2	2	0
Mallard	35	29	34	1
Ring-necked duck	1	1	0	1
Wild turkey	1	1	1	0
Rock dove	196	183	176	20
Mourning dove	34	34	29	5
Northern flicker	6	6	3	3
Common raven	12	9	10	2
American crow	5	5	5	0
Brown-headed cowbird	2	2	1	1
Blackbird (unspecified)	1	1	1	0
Brewer's blackbird	13	13	10	3
Red-winged blackbird	12	12	12	0
Tricolored blackbird	1	1	1	0
European starling	67	59	47	20
Horned lark	23	22	22	1
Western meadowlark	96	94	80	16
Northern mockingbird	1	1	1	0
Loggerhead shrike	5	5	4	1
Western kingbird	1	1	1	0
Pacific-slope flycatcher	1	1	1	0
Mountain bluebird	5	4	2	3
Violet-green swallow	1	1	1	0
Cliff swallow	5	5	5	0
Yellow warbler	1	1	1	0
Savannah sparrow	2	2	1	1
House sparrow	1	1	0	1
House finch	14	12	14	0
Cockatiel	1	1	1	0
Passerine	16	10	14	2
Unknown	43	15	25	18
Hoary bat	4	4	4	0
Raptors	519	363	380	139
TOTAL	**1,162**	**923**	**910**	**252**

Table 3-2. Status of birds found killed by wind turbines in the APWRA May 1998–May 2003.

Species/Taxonomic group	Species name	Status [a]
Golden eagle	*Aquila chrysaetos*	CSC, CFP
Turkey vulture	*Cathartes aura*	
Red-tailed hawk	*Buteo jamaicensis*	
Ferruginous hawk	*Buteo regalis*	FSC, CSC
Northern harrier	*Circus cyaeneus*	CSC
White-tailed kite	*Elanus leucurus*	CFP
Prairie falcon	*Falco mexicanus*	CSC
American kestrel	*Falco sparverius*	
Burrowing owl	*Athene cunicularia hypugea*	CSC
Great horned owl	*Bubo virginianus*	
Barn owl	*Tyto alba*	
California gull	*Larus californicus*	CSC
Ring-billed gull	*Larus delawarensis*	
American avocet	*Recurvirostra americana*	
Cattle egret	*Bubulcus ibis*	
Double-crested cormorant	*Phalacrocorax auritus*	CSC
Lesser yellowlegs	*Tringa flavipes*	
Black-crowned night heron	*Nycticorax nycticorax*	CSA
Mallard	*Anas platyrhynchos*	
Ring-necked duck	*Aythya collaris*	
Wild turkey[1]	*Melleagris gallopavo*	
Rock dove[1]	*Columba livia*	
Mourning dove	*Zenaida macroura*	
Northern flicker	*Colaptes auratus*	
Common raven	*Corvus corax*	
American crow	*Corvus brachyrhynchos*	
Brown-headed cowbird	*Molothrus ater*	
Brewer's blackbird	*Euphagus cyanocephalus*	
Red-winged blackbird	*Agelaius phoeniceus*	
Tricolored blackbird	*Agelaius tricolor*	FSC, CSC
European starling[1]	*Sturnus vulgaris*	
California Horned lark	*Eremophila alpestris actia*	CSC
Western meadowlark	*Sturnella neglecta*	
Northern mockingbird	*Mimus polyglottos*	
Loggerhead shrike	*Lanius ludovicianus*	FSC, CSC
Western kingbird	*Tyrannus verticalis*	
Pacific-slope flycatcher	*Empidonax difficilis*	
Mountain bluebird	*Sialia currucoides*	
Violet-green swallow	*Tachycineta thalassina*	
Cliff swallow	*Hirundo pyrrhonota*	
Yellow warbler	*Dendroica petechia brewsteri*	CSC
Savannah sparrow	*Passerculus sandwichensis*	

Table 3-2. (cont'd)

Species/Taxonomic group	Species name	Status [a]
House sparrow[1]	*Passer domesticus*	
House finch	*Carpodacus mexicanus*	
Cockatiel[1]	*Leptolophus hollandicus*	
Hoary bat[1]	*Lasiurus cinereus*	

[a] FE = Federal Endangered, FT = Federal threatened, FC = Federal candidate for listing, FSC = Federal species of concern, CE = California Endangered, CT = California threatened, CSA = California Special Animal, CFP = California Fully Protected, CSC = California Department of Fish and Game listing of California Species of Concern.

[1] Species not protected under the federal Migratory Bird Treaty Act.

Table 3-3. Tests for inter-annual changes in mortality. The tests in the left columns included all turbine strings searched for at least a year. Those in the right columns included only those searched through all four years of the study. Note that those in the right columns also included only turbine strings within areas of rodent control applied during all four years of the study, which might have confounded the comparisons in the table.

Species	Turbine strings searched ≥1 year df = 3, 639		Turbine strings searched 4 years, df = 3, 247	
	F-value	P-value	F-value	P-value
Golden eagle	0.622	0.601	1.469	0.224
American kestrel	0.871	0.456	0.406	0.749
Red-tailed hawk	3.461	0.016	5.212	0.002
Burrowing owl	3.202	0.023	1.239	0.296
Great horned owl	1.176	0.318	0.705	0.550
Barn owl	5.326	0.001	4.481	0.004
Western meadowlark	1.422	0.235	1.193	0.313
All hawks	1.927	0.124	4.098	0.007
All raptors	5.259	0.001	5.392	0.001
All birds	7.193	0.000	3.910	0.009

Table 3-4. Inter-annual changes in mortality for selected turbine strings that were searched during first and second years, df = 1, 19. These were 10 EnXco turbine strings that were dropped from search rotations after the second year.

Species	F-value	P-value	Change
Golden eagle	no test	---	---
American kestrel	no test	---	---
Red-tailed hawk	1.000	0.404	---
Burrowing owl	5.024	0.005	0.00 → 0.43
Great horned owl	no test	---	---
Barn owl	1.374	0.266	---
Western meadowlark	3.048	0.041	0.78 → 0.06
All hawks	1.000	0.404	---
All raptors	3.917	0.016	0.00 → 1.27
All birds	2.202	0.105	---

Table 3-5. Inter-annual changes in mortality for selected turbine strings that were searched during second and fourth years, df = 1, 57. These were SeaWest and AIC turbines, and those overlooking Livermore (no rodent control). No tests were significant for either groups of turbine strings with (N = 48) and without (N = 11) rodent control).

Species	F-value	P-value	Change
Golden eagle	0.568	0.454	---
American kestrel	0.025	0.876	---
Red-tailed hawk	0.789	0.378	---
Burrowing owl	0.014	0.907	---
Great horned owl	0.724	0.398	---
Barn owl	0.751	0.390	---
Western meadowlark	1.245	0.269	---
All hawks	1.398	0.242	---
All raptors	1.592	0.212	---
All birds	0.540	0.465	---

Table 3-6. Inter-annual changes in mortality for selected turbine strings that were searched during third and fourth years, df = 1, 75. These were SeaWest-owned turbines where rodent control was implemented during the fourth year.

Species	F-value	P-value	Change
Golden eagle	1.000	0.321	---
American kestrel	0.798	0.374	---
Red-tailed hawk	0.130	0.719	---
Burrowing owl	4.435	0.039	0.42 → 0.05
Great horned owl	1.000	0.321	---
Barn owl	1.000	0.321	---
Western meadowlark	3.358	0.071	---
All hawks	0.041	0.840	---
All raptors	0.195	0.660	---
All birds	2.757	0.101	---

Table 3-7. Inter-annual changes in mortality for selected turbine strings that were searched during irst, third, and fourth years, df = 2, 32. These were some EnXco and Enron turbines where rodent control was implemented throughout the study period.

Species	F-value	P-value	Change
Golden eagle	no test	---	---
American kestrel	no test	---	---
Red-tailed hawk	1.071	0.355	---
Burrowing owl	1.000	0.380	---
Great horned owl	no test	---	---
Barn owl	1.000	0.380	---
Western meadowlark	0.575	0.569	---
All hawks	1.131	0.336	---
All raptors	0.949	0.398	---
All birds	2.074	0.143	---

Table 3-8. Inter-annual changes in mortality for selected turbine strings that were searched during second, third, and fourth years, df = 2, 29. These were SeaWest-owned turbines where rodent control was implemented during the fourth year.

Species	F-value	P-value	Change
Golden eagle	1.000	0.381	---
American kestrel	0.991	0.384	---
Red-tailed hawk	2.569	0.095	---
Burrowing owl	6.040	0.007	1.01→ 0→ 0
Great horned owl	2.245	0.125	---
Barn owl	0.520	0.600	---
Western meadowlark	2.110	0.141	---
All hawks	6.270	0.006	1.20 → 0.06 → 0.39
All raptors	12.680	0.000	2.87 → 0.23 → 0.91
All birds	0.904	0.417	---

Table 3-9. Summary of unadjusted mortality estimates for two sets of wind turbines searched at different time periods at the Altamont Pass Wind Resource Area. Set 1 included 1,526 wind turbines searched May 1998–September 2002, and Set 2 included 2,548 wind turbines searched November 2002–May 2003.

Species/Taxonomic group	Mortality (deaths/MW/year) across first set of 1,526 turbines		Mortality (deaths/MW/year) across second set of 2,548 turbines	
	Mean among turbine strings	Standard error of mean	Mean among turbine strings	Standard error of mean
Golden eagle	0.0380	0.01172	0.1391	0.06497
Turkey vulture	0.0098	0.00576	0.0000	0.00000
Red-tailed hawk	0.2953	0.06327	0.2490	0.08353
Ferruginous hawk	0.0000	0.00000	0.0348	0.02489
Northern harrier	0.0027	0.00165	0.0000	0.00000
Prairie falcon	0.0042	0.00272	0.0000	0.00000
American kestrel	0.0614	0.01409	0.1251	0.03933
Burrowing owl	0.1674	0.03058	0.1000	0.06244
Great horned owl	0.0245	0.00975	0.0040	0.00400
Barn owl	0.0662	0.02396	0.0292	0.01494
California gull	0.0140	0.00625	0.0000	0.00000
Ring-billed gull	0.0149	0.00927	0.0000	0.00000
American avocet	0.0116	0.00962	0.0000	0.00000
Blk-crwnd night heron	0.0019	0.00137	0.0000	0.00000
Mallard	0.0711	0.02550	0.0119	0.01191
Rock dove	0.4999	0.10947	0.1132	0.04185
Mourning dove	0.1585	0.05477	0.0222	0.01161
Northern flicker	0.0140	0.00907	0.0197	0.01633
Common raven	0.0184	0.01180	0.0091	0.00907
Brown-headed cowbird	0.0033	0.00327	0.0227	0.02268
Brewer's blackbird	0.0207	0.00971	0.0500	0.03299
Red-winged blackbird	0.0358	0.01244	0.0000	0.00000
European starling	0.1286	0.02910	0.1353	0.06542
Horned lark	0.0427	0.01139	0.0000	0.00000
Western meadowlark	0.2078	0.04092	0.1975	0.07690
Loggerhead shrike	0.0216	0.01492	0.0131	0.01308
Mountain bluebird	0.0054	0.00486	0.0172	0.01406
Cliff swallow	0.0150	0.00781	0.0000	0.00000
House finch	0.0496	0.01903	0.0000	0.00000
Hoary bat	0.0072	0.00455	0.0000	0.00000
All hawks	0.5073	0.08250	0.4591	0.09812
All raptors	0.9526	0.09095	1.2332	0.17686
All birds	2.1500	0.20734	1.4690	0.22695

Table 3-10. Summary of mortality estimates in the APWRA and adjusted for searcher detection and scavenger removal rates and specific to sets of wind turbines sampled at different time periods as well as a set not sampled

Species/Group	Mortality (deaths/MW/year) adjusted for:					
	Searcher detection rate			Searcher detection and scavenging		
	Set 1[a]	Set 2[b]	Set 3[c]	Set 1[a]	Set 2[b]	Set 3[c]
Golden eagle	0.0483	0.1767	0.1303	0.0584	0.2814	0.2008
Turkey vulture	0.0115	0.0000	0.0042	0.0139	0.0000	0.0050
Red-tailed hawk	0.4003	0.3376	0.3603	0.4835	0.5375	0.5180
Ferruginous hawk	0.0000	0.0409	0.0261	0.0000	0.0652	0.0416
Northern harrier	0.0042	0.0000	0.0015	0.0051	0.0000	0.0018
Prairie falcon	0.0082	0.0000	0.0030	0.0099	0.0000	0.0036
American kestrel	0.0761	0.1550	0.1264	0.1921	0.7906	0.5743
Burrowing owl	0.2292	0.1370	0.1703	0.5789	0.6988	0.6555
Great horned owl	0.0289	0.0047	0.0134	0.0349	0.0075	0.0174
Barn owl	0.0954	0.0421	0.0614	0.1153	0.0671	0.0845
California gull	0.0455	0.0000	0.0164	0.1098	0.0000	0.0397
Ring-billed gull	0.0454	0.0000	0.0164	0.1098	0.0000	0.0397
American avocet	0.0376	0.0000	0.0136	0.0909	0.0000	0.0329
Black-crowned night heron	0.0071	0.0000	0.0026	0.0171	0.0000	0.0062
Mallard	0.2182	0.0366	0.1022	0.5271	0.1165	0.2649
Rock dove	1.3198	0.2989	0.6679	6.6656	3.0496	4.3565
Mourning dove	0.4433	0.0621	0.1999	2.2391	0.6334	1.2137
Northern flicker	0.0341	0.0479	0.0429	0.1723	0.4890	0.3745
Common raven	0.0448	0.0221	0.0303	0.1081	0.0705	0.0841
Brown-headed cowbird	0.0160	0.1106	0.0764	0.0806	1.1287	0.7499
Brewer's blackbird	0.0543	0.1314	0.1036	0.2745	1.3409	0.9554
Red-winged blackbird	0.1092	0.0000	0.0395	0.5517	0.0000	0.1994
European starling	0.3244	0.3412	0.3351	1.6382	3.4814	2.8152
Horned lark	0.1088	0.0000	0.0393	0.5495	0.0000	0.1986
Western meadowlark	0.5498	0.5227	0.5325	2.7769	5.3333	4.4093

Table 3-10. (cont'd)

Species/Group	Mortality (deaths/MW/year) adjusted for:					
	Searcher detection rate			Searcher detection and scavenging		
	Set 1[a]	Set 2[b]	Set 3[c]	Set 1[a]	Set 2[b]	Set 3[c]
Loggerhead shrike	0.0526	0.0319	0.0394	0.2658	0.3256	0.3040
Mountain bluebird	0.0166	0.0524	0.0395	0.0837	0.5347	0.3717
Cliff swallow	0.0365	0.0000	0.0132	0.1843	0.0000	0.0666
House finch	0.1210	0.0000	0.0437	0.6109	0.0000	0.2208
Hoary bat	0.0177	0.0000	0.0064	0.0892	0.0000	0.0323
All hawks	0.6886	0.6232	0.6468	0.8316	0.9923	0.9342
All raptors	1.2790	1.6558	1.5196	1.5447	2.6366	2.2419
All birds	4.4895	2.2285	3.0457	9.7800	7.2120	8.1401

[a] Set 1 includes the 1,526 wind turbines (151.165 MW) in the search rotation through September 2002.
[b] Set 2 includes 2,548 wind turbines (267.090 MW) in the November 2002–May 2003 rotation.
[c] Set 3 includes the 1,326 wind turbines (161.750 MW) not included in any search rotation. Mortality for Set 3 was estimated by taking the weighted average from the two sampled sets of wind turbines ((mortality of Set 1 × 151.165 MW) + (mortality of Set 2 × 267.09 MW)) ÷ 418.255 MW.

Table 3-11. Bird mortality estimates across the APWRA. These estimates are the sums of projections among 3 sets of wind turbines, where each projection was specific to the associated set of wind turbines. For a given species, the projection for the 1,526 wind turbines in the first set was added to that of the 2,548 wind turbines in the second set and to that of the 1,326 turbines of the third set. We regard the mortality estimates in the left and right columns as the low and high values of the uncertainty range for each species or group.

Species/Taxonomic group	Mortality (deaths/MW/year)		Mortality (deaths per year)	
	Adjusted for search detection	Adjusted for search detection and scavenging	Adjusted for search detection	Adjusted for search detection and scavenging
Golden eagle	0.1303	0.2008	75.6	116.5
Turkey vulture	0.0042	0.0050	2.4	2.9
Red-tailed hawk	0.3602	0.5180	208.9	300.4
Ferruginous hawk	0.0261	0.0416	15.2	24.1
Northern harrier	0.0015	0.0018	0.9	1.1
Prairie falcon	0.0030	0.0036	1.7	2.1
American kestrel	0.1264	0.5743	73.3	333.1
Burrowing owl	0.1703	0.6555	98.8	380.2
Great horned owl	0.0134	0.0174	7.8	10.1
Barn owl	0.0614	0.0845	35.6	49.0
California gull	0.0164	0.0397	9.5	23.0
Ring-billed gull	0.0164	0.0397	9.5	23.0
American avocet	0.0136	0.0329	7.9	19.1
Black-crowned night heron	0.0026	0.0062	1.5	3.6
Mallard	0.1022	0.2649	59.3	153.6
Rock dove	0.6679	4.3566	387.4	2526.8
Mourning dove	0.1999	1.2137	115.9	703.9
Northern flicker	0.0429	0.3745	24.9	217.2
Common raven	0.0303	0.0841	17.6	48.8
Brown-headed cowbird	0.0764	0.7499	44.3	434.9
Brewer's blackbird	0.1036	0.9554	60.1	554.2
Red-winged blackbird	0.0395	0.1994	22.9	115.7
European starling	0.3351	2.8153	194.4	1632.9
Horned lark	0.0393	0.1986	22.8	115.2
Western meadowlark	0.5325	4.4094	308.8	2557.4
Loggerhead shrike	0.0394	0.3040	22.9	176.3

Table 3-11. (cont'd)

Species/Taxonomic group	Mortality (deaths/MW/year)		Mortality (deaths per year)	
	Adjusted for search detection	Adjusted for search detection and scavenging	Adjusted for search detection	Adjusted for search detection and scavenging
Mountain bluebird	0.0395	0.3717	22.9	215.6
Cliff swallow	0.0132	0.0666	7.7	38.6
House finch	0.0437	0.2208	25.4	128.1
Hoary bat	0.0064	0.0322	3.7	18.7
All hawks	0.6468	0.9342	375.2	541.9
All raptors	1.5196	2.2420	881.4	1300.3
All birds	3.0457	8.1402	1766.5	4721.3

Table 3-12. Mortality estimates across the APWRA in terms of deaths per wind turbine per year. We regard the mortality estimates in the left and right columns as the low and high values of the uncertainty range for each species or group.

Species/Taxonomic group	Mortality (deaths/turbine/year)	
	Adjusted for search detection	Adjusted for search detection and scavenging
Golden eagle	0.0140	0.0216
Turkey vulture	0.0004	0.0005
Red-tailed hawk	0.0387	0.0556
Ferruginous hawk	0.0028	0.0045
Northern harrier	0.0002	0.0002
Prairie falcon	0.0003	0.0004
American kestrel	0.0136	0.0617
Burrowing owl	0.0183	0.0704
Great horned owl	0.0014	0.0019
Barn owl	0.0066	0.0091
California gull	0.0018	0.0043
Ring-billed gull	0.0018	0.0043
American avocet	0.0015	0.0035
Black-crowned night heron	0.0003	0.0007
Mallard	0.0110	0.0284
Rock dove	0.0717	0.4679
Mourning dove	0.0215	0.1304
Northern flicker	0.0046	0.0402
Common raven	0.0033	0.0090
Brown-headed cowbird	0.0082	0.0805
Brewer's blackbird	0.0111	0.1026
Red-winged blackbird	0.0042	0.0214
European starling	0.0360	0.3024
Horned lark	0.0042	0.0213
Western meadowlark	0.0572	0.4736
Loggerhead shrike	0.0042	0.0326
Mountain bluebird	0.0042	0.0399
Cliff swallow	0.0014	0.0071
House finch	0.0047	0.0237
Hoary bat	0.0007	0.0035
All hawks	0.0695	0.1004
All raptors	0.1632	0.2408
All birds	0.3271	0.8743

3.4 DISCUSSION

Whereas we standardized our estimates of mortality by dividing the number of fatalities per MW and by the years spanning the search effort, our estimates of mortality might have been influenced by variable search efforts expressed as the number of years spanning the search period. For example, if few fatalities happened during a particular year, and we searched a group of wind turbines only during that year, then our mortality estimate from those wind turbines will be less than from other wind turbines and the comparison compromised. This shortfall in our study was beyond our control, since the owners of the wind turbines allowed us access to various new groups of turbines at different times during the study. For example, we did not gain access to our last addition of 2,548 wind turbines until late in 2002, after we completed our searches at all other wind turbines. However, this shortfall exists and needs to be divulged herein.

Our new mortality estimates are much larger than those reported in Smallwood and Thelander (in review), but our report to the National Renewable Energy Lab did not include data collected over most of the APWRA where we had not yet been granted access, and it did not include data from the wind turbines because we had not yet completed a full year of fatality searches on these turbines and decided to exclude them from our estimates of mortality. In fact, we had noticed that the mortality estimates representing the SeaWest-owned turbines were much larger than observed elsewhere, but we guessed that these larger estimates might be due to time spans consisting of less than a year because the denominator in the mortality estimate would be a fraction and would therefore artificially inflate the mortality estimate, as described in Chapter 3. However, continued searches at these wind turbines proved that the greater mortality previously observed (and excluded from our report) was not the result of insufficient time spanning the searches. Mortality at the SeaWest-owned portion of the APWRA substantially exceeds mortality observed over most of the rest of the APWRA.

We are unable to assess the risk of the APWRA's wind turbine operations to individual species' populations. The biological significance of bird mortality caused by wind turbines remains unknown. However, due to typically low recruitment and the relative rarity of raptor species, it would be prudent to regard the mortality of raptors as significant. There are additional reasons to regard these impacts as significant besides biological.

CHAPTER 4

IMPACTS TO BIRDS CAUSED BY WIND ENERGY GENERATION

4.1 INTRODUCTION

Bird mortality studies reporting on wind energy facilities elsewhere regularly report that bird mortality in the APWRA is unusually high there and is, therefore, an anomaly among wind energy facilities in the United States. We found that recent published comparisons of mortality estimates between different facilities relied solely on mortality estimates between the different facilities, but they failed to incorporate bird abundance at those facilities in their comparisons (e.g., Erickson et al. 2001). The argument is often put forth that because most potential wind energy generating facilities in the United States lack the number of raptors that occur in the APWRA, raptor mortality can be expected to be less significant at new sites, and that raptor mortality in the APWRA is not indicative of mortality nationally. We reexamine whether this characterization of the APWRA is accurate, using data for bird use and mortality.

Mortality is only one measure of impact. Bird mortality at energy generating facilities can also be measured relative to the abundance of the species occurring at the facilities. For example, if the habitat area of the wind farm supported only one pair of red-tailed hawks, and a wind turbine killed one or both of that pair, then the wind farm would have had a significant adverse impact on that species within the area of the wind farm. Some locations are inherently less productive for particular bird species, and so these species occur there more rarely. Rarity is not a condition that guarantees impacts will be less significant, and in some cases rarity is a condition that should heighten concern for the facility-caused loss of birds. In this chapter, we will not assess the site-specific significance of rarity in the mortality of birds, but we will synthesize the estimates of mortality that are also accompanied by estimates of relative abundance.

4.2 METHODS

We reviewed published reports of bird mortality at wind energy facilities, and we extracted from those reports the mortality estimates and associated attributes of the study. Studies from which we collected mortality estimates and related data included Howell (1997), Howell and DiDonato (1991), Howell et al. (1991), Howell and Noone (1992), Orloff and Flannery (1992), Kerlinger (2000), Howe (2001) (c.f., in Erickson et al. 2001), Strickland et al. (2001a,b), Thelander and Rugge (2001), Johnson et al. (2002), Erickson et al. 2003, Anderson et al. (in review, a; in review, b), and Smallwood and Thelander (2004). Data were also collected from Janss and Clave (2000) and Winkelman (1989, 1992), but not used in the analyses reported herein because they involved wind farms in Europe.

The extracted data were organized into a spreadsheet for synthesis. We recorded whether the mortality estimate was based on raw numbers of fatalities or whether they were adjusted by scavenging rates, detection bias, or other factors, and we recorded whether the estimate included only fatalities caused by wind turbine collisions or whether they included all fatalities caused by all

facilities and human activities at the wind farm. We recorded the number and types of wind turbines used to generate the estimates, as well as the span of time used for monitoring for bird carcasses. We also recorded the carcass search radius, scavenging rates, searcher detection rates, and search interval in days. Site location was recorded along with the year of the estimate. Multi-annual studies were represented by the middle year when annual estimates were not provided.

For the purpose of comparing estimates among project sites, we needed to standardize the mortality estimates to the extent possible. For example, because we found 11.2% of the bird carcasses outside our 50-m search radius in the APWRA, and because our sample of bird fatalities was larger than recorded at any other wind energy facility or related study, we relied on our rates of carcass detection within distance intervals from the wind turbines to adjust the mortality estimates reported in the other studies we reviewed. For example, Orloff and Flannery (1992) searched out to 30.7 to 61.4 m from wind turbines, and within 30.7 m we found 68.6% of all our bird carcasses and 65.6% of all our raptor carcasses. We assume that Orloff and Flannery would have missed up to 34.4% of the raptor carcasses and 31.4% of all the bird carcasses that we found. Additionally, we assume that we missed half the carcasses beyond our 50-m search radius, and that Orloff and Flannery would have missed these also (our only basis for this assumption is experience in the field, and so represents our professional judgment). Adding in our assumed error rate translates to Orloff and Flannery's finding of 57.4% of all bird carcasses found within 30.7 m and 51.4% of all raptor carcasses found, all other factors not considered. Therefore, we adjusted Orloff and Flannery's mortality estimates by dividing them by 0.574 for all birds and 0.514 for raptors.

For each reported search radius equal or larger to 50 m, we identified the proportion of bird carcasses we found beyond that radius and multiplied it by two (again, assuming a 50% miss rate). This product was divided into the reported mortality estimate. We did not adjust reported mortality estimates by scavenging rates, searcher detection rates, or search intervals because these attributes were too scant in the literature to be useful at this time. In some cases, mortality estimates were already adjusted by these factors, but in most cases they were not. The reported scavenging rates were reported in two formats: (1) percent of carcasses remaining after so many days, and (2) the number of days until all carcasses were removed. The use of both formats among research reports was an inconsistency that prevented reliable adjustments for scavenging in our synthesis. Search intervals were usually reported, but we could not adjust the mortality estimate by this factor without within-study reporting of the variation in mortality due to variation in search interval.

4.3 RESULTS

Bird mortality correlated significantly with the number of birds observed per hour during point counts (Figure 4-1). It did not correlate significantly with the carcass search interval in days, the radius of the search around the wind turbine, the years spanning the searches for carcasses, and the number of megawatts generated by the wind turbines that were sampled. Raptor mortality also correlated significantly with the number of birds observed per hour during point counts (Figure 4-2), but not with the number of raptors observed per hour, nor with the carcass search interval in days, the radius of the search around the wind turbine, the years spanning the searches for carcasses, and the number of megawatts generated by the wind turbines that were sampled.

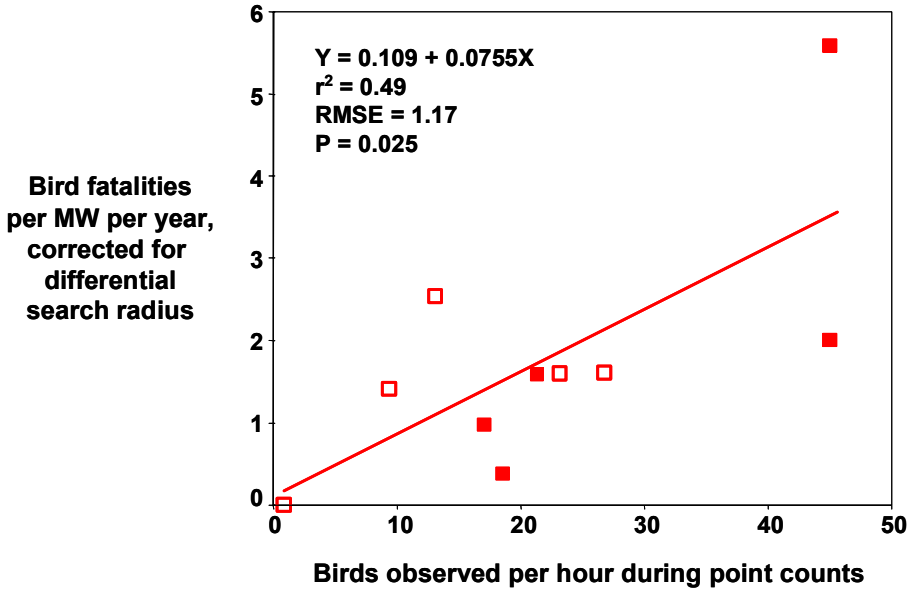


Figure 4-1. Mortality estimates for all birds related positively but not significantly to the number of birds seen per hour during point counts. Solid symbols represent estimates made in the APWRA, and open symbols represent estimates made at other project sites.

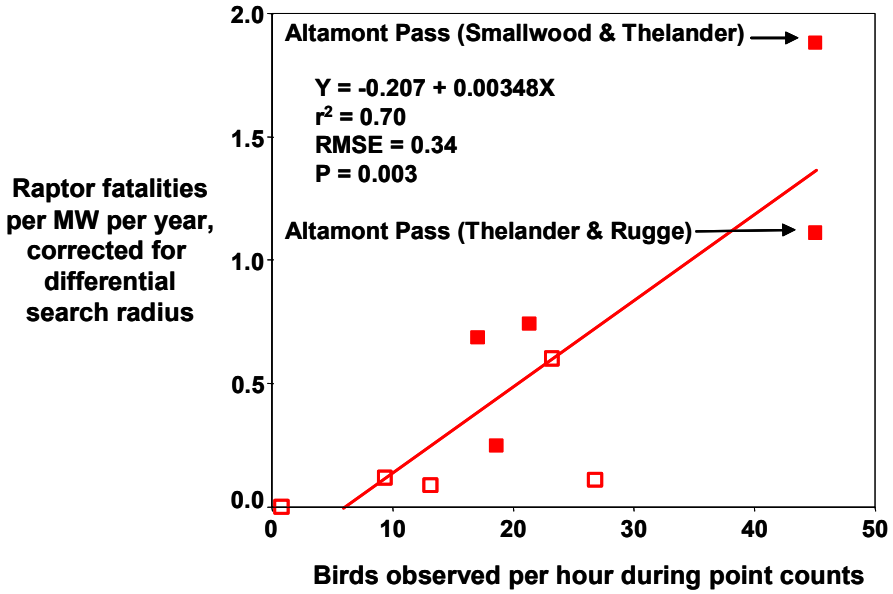


Figure 4-2. Mortality estimates for raptors related positively and significantly to the number of birds seen per hour during point counts. Solid symbols represent estimates made in the APWRA, and open symbols represent estimates made at other project sites.

Our most recent estimate of bird mortality in the APWRA was larger than the mean among estimates reported among all project sites in the United States (Figure 4-3A). Our most recent estimate of raptor mortality in the APWRA was about three times the size of the mean among all project sites (Figure 4-3B). The rate of fatalities appears to be higher in the APWRA than at most other wind energy generating facilities studied to date.

Relative to bird use of the project sites, the most recent mortality estimate for all birds in the APWRA was twice the mean of mortality at all U.S. project sites (Figure 4-4A), and the most recent mortality estimate for raptors in the APWRA was very near the mean of all project sites compared (Figure 4-4B). The risk of wind turbine-caused bird mortality was greater in the APWRA than at most other wind energy generating facilities, whereas the risk of wind turbine-caused raptor mortality was about the same as the average among wind energy generating facilities.

Both bird and raptor mortality in the APWRA tended to increase with the number of birds seen per hour at the project site (Figure 4-5A), although neither regression slope was significantly different from zero. However, raptor mortality in the APWRA tended to decrease with increasing rate of observations of raptors (Figure 4-5B). Bird mortality in the APWRA tended to increase from 1988 through 2000 (Figure 4-6A) , and so did raptor mortality (Figure 4-6B), although neither regression slope was statistically significant from zero.

The number of bird observations per hour increased from 1988 through 2000; whereas, the number of raptor observations did not (Figure 4-7A). The risk index (mortality divided by individuals counted per hour) of birds in the APWRA did not change significantly over these years; whereas, that of raptors increased substantially (Figure 4-7B). No comparable data exist to test whether the risk of bird collisions has changed through time at other wind energy generating facilities.

4.4 DISCUSSION

4.4.1 APWRA Impacts Relative to Other Wind Energy Generating Facilities

The assertion that the APWRA is anomalous in its bird mortality is largely untrue. It appears true for raptor mortality at face value, but factoring in relative raptor abundance clarifies that the impact is relative to the local abundance. The impacts in the APWRA are nearly equal to impacts elsewhere relative to local abundance. Whereas the available data suggest that the APWRA kills more raptors than do other wind energy generating facilities, the risk index demonstrates that the APWRA kills no more raptors *relative to the number seen per hour* than do most other wind energy facilities. Adjusting for local relative abundance, the existing data indicate that most wind energy generating facilities have an equal impact on the local raptors.

This result highlights the need for monitoring bird activity levels at wind energy facilities, in addition to conducting carcass searches. It would be misleading for researchers to conclude that a wind energy facility had only a slight impact on species X because it killed only two members of that species when only those two individuals were present at the wind farm. The real impact would be a complete removal of that species from the area encompassing the wind farm, which would be a

strong adverse impact, locally. Absolute numbers are insufficient for concluding impact; relative abundance must be taken into consideration to fairly assess local impact.

Taking relative abundance into consideration, it is important to point out that despite lower levels of raptor use, the raptor risk index has increased substantially in the APWRA since 1988 (Figure 4-7B). Whereas raptor mortality has remained relatively unchanged since 1988 (Figure 4-6B), raptors might have slightly reduced their occurrence in the APWRA during this time (Figure 4-7A) for reason(s) we cannot determine. A larger proportion of those raptors visiting the APWRA are now being killed by the wind turbines.

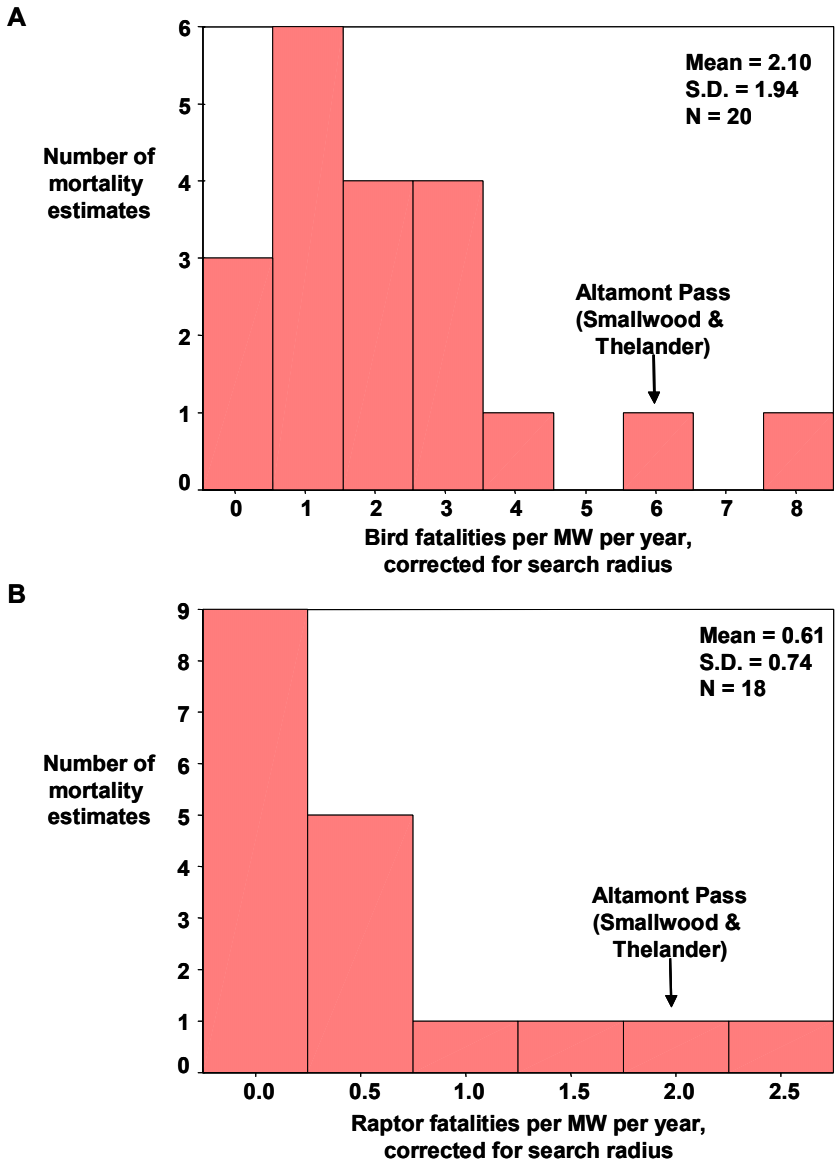


Figure 4-3. Bird mortality in the APWRA was nearly three times the mean of all reported estimates (A), and so was raptor mortality (B).

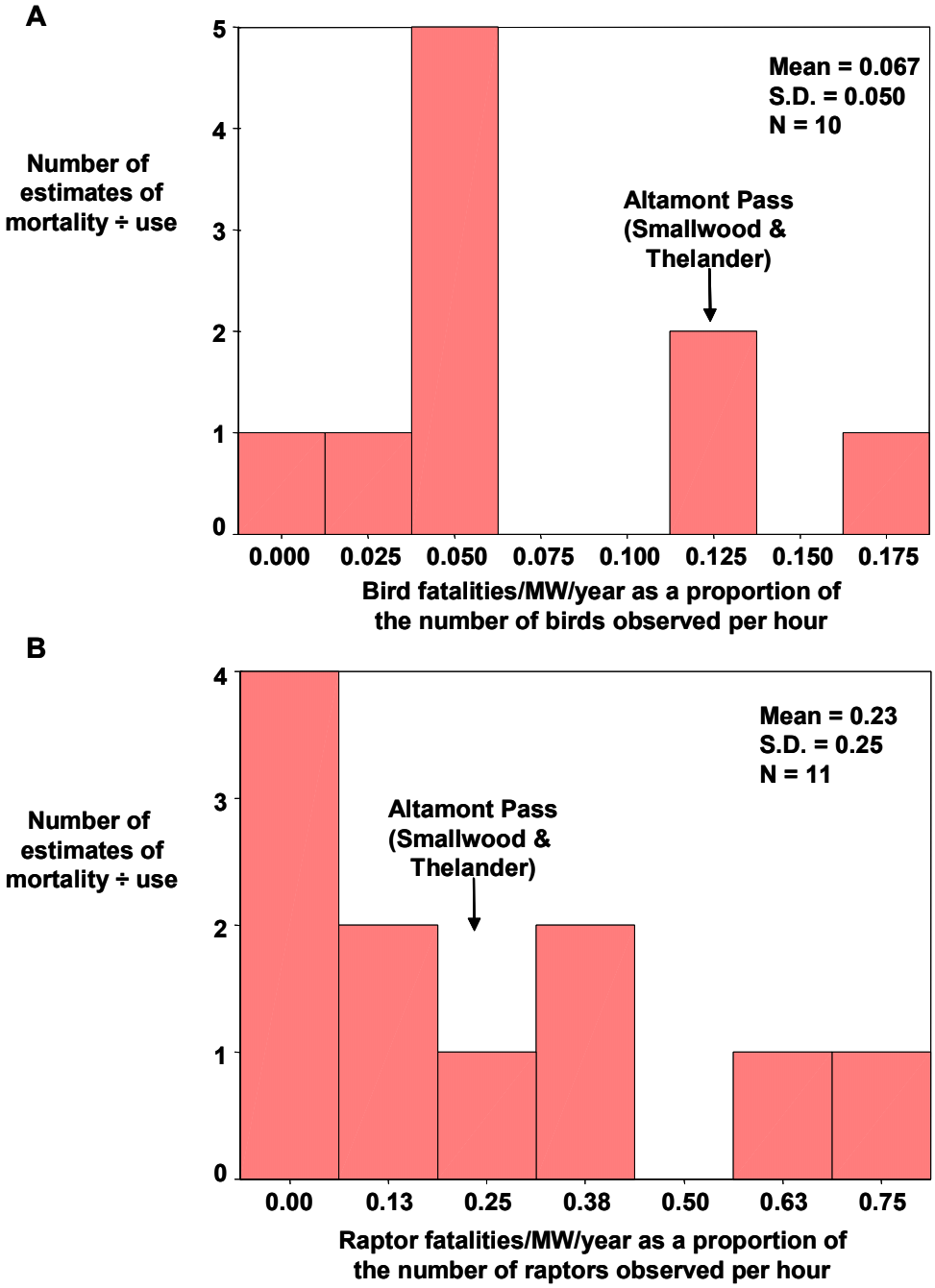


Figure 4-4. Estimates of the risk index, or the mortality divided by the birds seen per hour of point counts, were more platykurtic in distribution than were estimates of mortality alone, and the risk index of all birds in the APWRA was twice the mean among all reports (A) and that of raptors in the APWRA was close to mean among all reports (B).

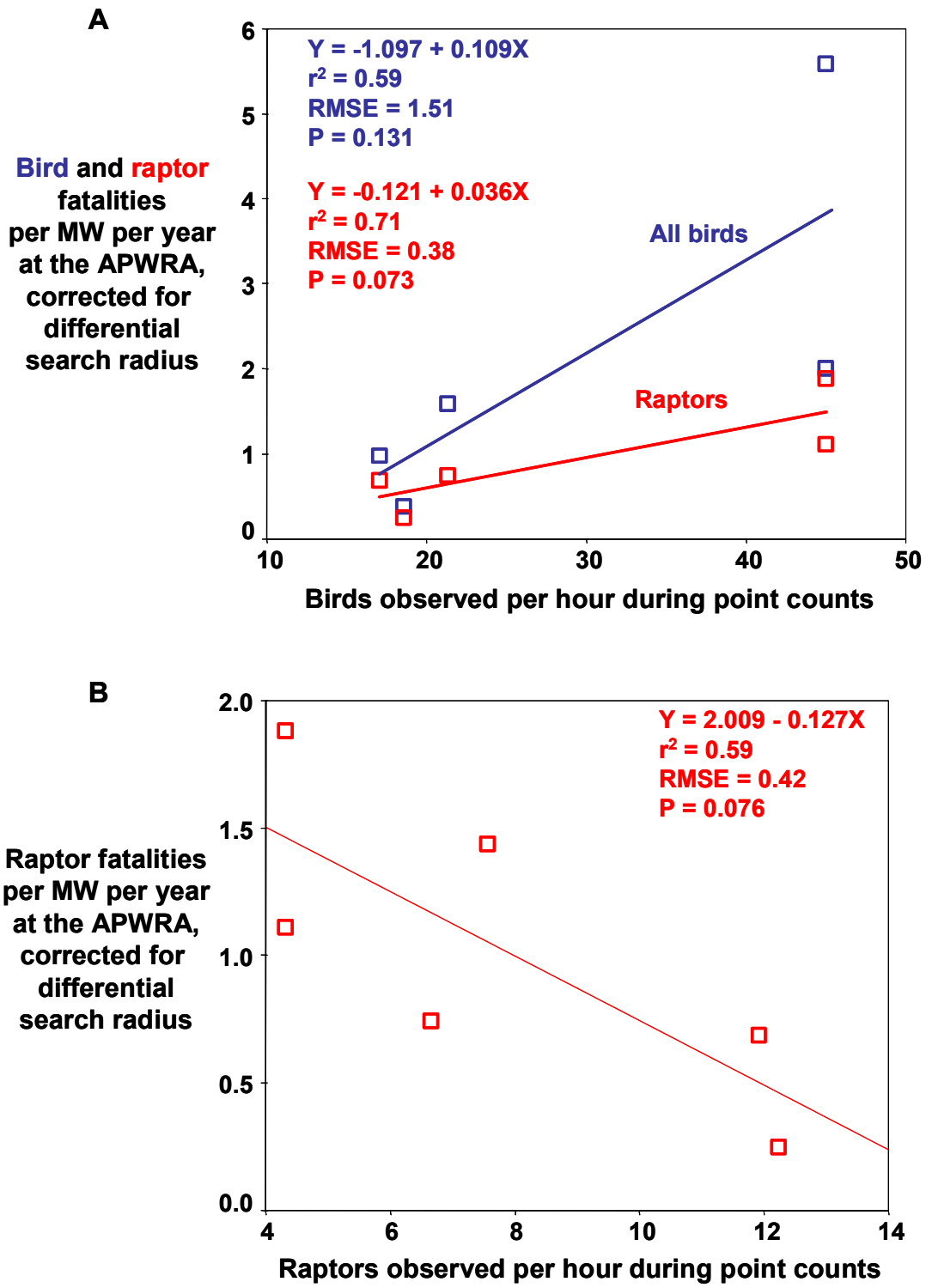


Figure 4-5. The mortality of all birds and raptors tended to increase with the rate of bird observations per hour during point counts (A), whereas the mortality of raptors tended to decline with increasing number of raptors seen per hour of point counts (B). All symbols represent reported estimates of mortality derived from the APWRA during the past 15 years.

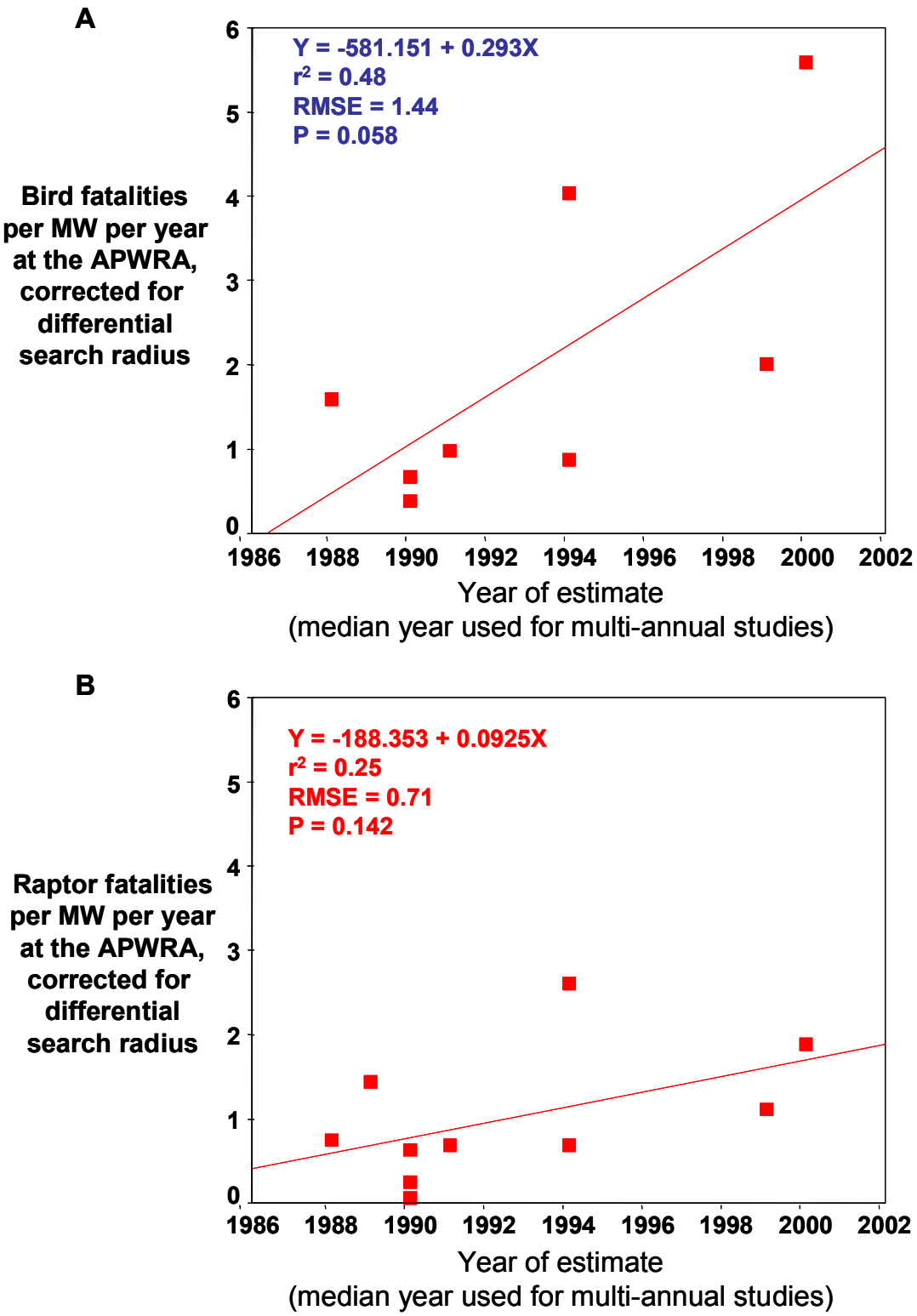


Figure 4-6. Mortality estimates of birds (A) and raptors (B) have tended to increase through time in the APWRA, though not significantly.

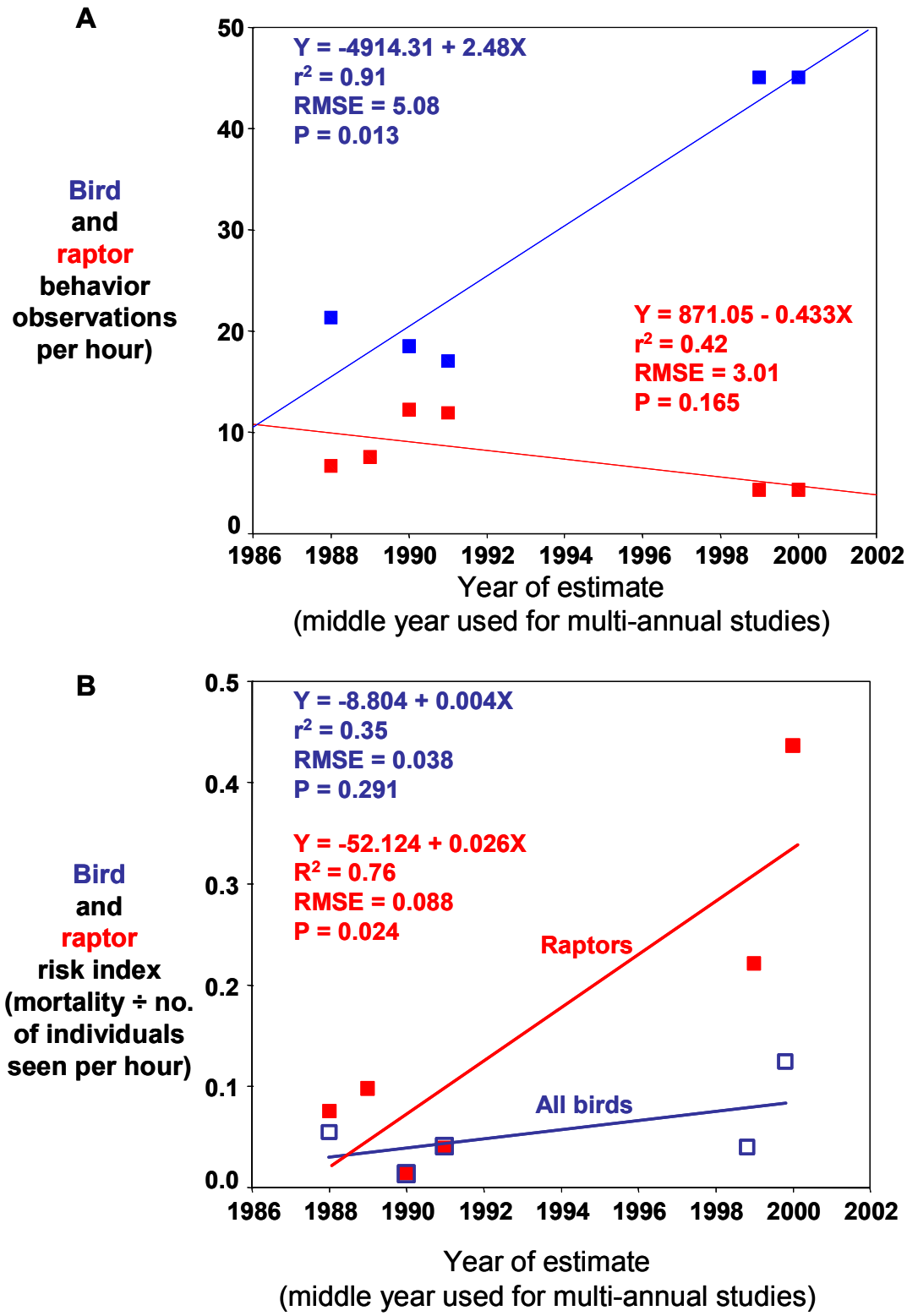


Figure 4-7. Bird observations per hour increased over the past 15 years in the APWRA, whereas raptor observations per hour did not (A), and the risk of death by wind turbine collision remained unchanged for birds but increased for raptors (B).

4.4.2 Reporting Shortfalls

Searcher detection rates and scavenging rates are rarely reported in published results of wind energy-caused bird mortality studies. When they are reported, they lack the standardization necessary for useful comparisons. Also, the reported search radii are too short in many of the studies. The search radius needs to be expanded in relation to the size of the turbines being surveyed, with a minimum of 70 meters used for even the shortest of turbines currently in operation. Finally, more of the bird mortality studies need to account for the mortality caused by facilities other than the wind turbines. Study reports often exclude wire strikes, vehicle collisions, greasing of birds in wind turbines, and electrocutions on distribution poles. These fatalities are all part of the impact of the wind farm and need to be included in estimates of mortality.

Bird use of the wind farm should be measured along with every mortality estimate made. Measuring mortality in the absence of bird use at a wind energy site is almost meaningless, because local conditions are not addressed in the mortality estimate. When measuring bird use of the site, it is important to standardize methods. Point counts need to last sufficiently long to represent bird use, and should be replicated often and over each season of the year and period of the day. Some reports have presented bird use as the mean number of birds seen per five minutes, some per ten minutes, and some per 30 minutes. All reported estimates should be standardized to a per-hour basis so that the risk index is not too large. Also, sufficient sample sizes are important to prevent the generation of risk estimates composed of means near zero and standard deviations much larger than the mean. In other words, it is important to generate and use reliable, robust risk estimates, which are indicated by standard deviations being smaller than the means.

As of January 2004, the American Wind Energy Association (AWEA) reports that the wind-energy generating capacity in the United States totals 6,374 MW. Relying on the most recent estimate from each of nine study sites (wind energy generating facilities), we estimated the weighted mean mortality of birds to be 5.45 deaths/MW/year, and the weighted estimate of raptor mortality from seven study sites was 1.74 deaths/MW/year (two sites reported bird mortality but not raptor mortality). At 6,374 MW of capacity, and assuming the weighted mean mortality among studies is representative of mortality among all U.S. wind energy generating facilities, one can expect that about 35,000 bird fatalities per year would occur, of which about 11,000 would be raptor fatalities. AWEA also reports that the current wind generating capacity is about 1/300th of the estimated potential capacity in the United States. To meet this projection while avoiding killing large numbers of birds will require robust before-construction surveys and avoidance of high bird-use areas.

These mortality estimates for wind power generation, expressed in terms of MW, can be compared to those of other forms of energy generation. By converting MWs to the average number of households served, researchers will be better able to compare bird mortalities caused by various human activities in order to assess the relative impacts of these activities. Of course, these comparisons still do not address local conditions, such as inherent levels of rarity or regional congregations of birds at migration pathways.

CHAPTER 5

RANGE MANAGEMENT AND ECOLOGICAL RELATIONSHIPS IN THE APWRA

5.1 INTRODUCTION

Historically, range management practices have significantly altered California's landscape. By the mid-1800s, most of the native perennial grasslands had been converted to cismontane annual grass species. This conversion was in large part the result of introducing livestock and grazing practices that allowed the introduced grass species to eventually out compete and replace the natives.

Today, range management and livestock grazing practices in the APWRA play a significant role in the ecological relationships between producers, consumers, and various predators. This is most certainly true for the relationship between grazing cattle and rodent populations, both of which bear on raptor activity in the APWRA. As our study progressed, it became evident that cattle grazing practices and the presence of cattle among the wind turbines affected common rodents, such as pocket gophers, California ground squirrels, and other raptor prey items, which likely played a significant role in bird fatalities, as well.

In the APWRA, we observed that cattle spend a disproportionate amount of time grazing and resting near wind turbine towers (Photos 5-1 A and B). During hot days, they congregate around the towers and often rest in the shade, or in the shadow cast by the towers. Because these towers vary in heights and configuration, the resulting shadows vary in dimension and intensity. We suspected that cattle selected certain tower designs over others because of their shading capabilities, although we did not test whether this was the case in this study. Also, we suspected that towers might be more or less favored by cattle due to their physiographic features.

Where cattle congregate, the vegetation tends to be more intensively grazed and cattle pats (i.e., fecal droppings) dot the landscape much more so than in areas less used by cattle. Typically, areas with relatively open vegetation canopy favor certain small mammal species over others. Some of these mammalian benefactors of intense cattle grazing are prey for raptors that frequent the APWRA.

Similarly, increased cattle pat abundance fuels a food web that attracts certain bird species that are more prone to colliding with wind turbine blades. At certain times of the year, cattle pats are inundated by grasshoppers as a readily available food source and possibly a source of moisture. These readily available grasshoppers are preyed upon by multiple predators, including loggerhead shrike, burrowing owl, American kestrel, and red-tailed hawk. Several locally abundant lizard species also prey on grasshoppers and thus also might proliferate. In general, lizards are prey species for numerous raptorial bird species that are killed more frequently than others in the APWRA.

Desert cottontails often occur in relatively high abundance near wind turbines in the APWRA, especially those constructed on old concrete pads (Photo 5-2) or when rock piles are nearby (Photos 5-3 through 5-4).

In this chapter, we present some fundamental information relating to range management practices. From this early work, it is clear that much remains to be done to fully understand how cattle grazing may affect bird fatalities.

Photos 5-1 A and B. Cattle congregate near wind turbines, where they leave more pats and graze the grass more intensively.

Photo 5-2. Desert cottontails burrow under concrete pads of wind turbines and are concentrated around the turbines.

Photo 5-3. Desert cottontails use rock piles that were originally created near turbine laydown areas as a mitigation measure for San Joaquin kit fox.

Photos 5-4 A and B. Desert cottontails use rock piles created as a mitigation measure for San Joaquin kit fox nearby turbine laydown areas.

5.2 METHODS

For this effort, we visited 1,526 wind turbines that had been sampled through August 2002. During September 2002, we rated the laydown areas at each of these turbine towers for their lateral and vertical edge, which also relates to the abundance of species that are prey of bird species commonly killed. Vertical edge consists of a vertical change in physiography, such as a berm or artificial levee on an otherwise flat landscape. Lateral edge consists of a sharp change in plant cover or soil condition on a flat landscape, such as the boundary between a dirt road and a grassland. Vertical and lateral edges are often found to be used disproportionately more often as burrow sites by fossorial mammals.

We also counted lizards and cattle pats. We estimated the average vegetation height, and by counting fecal pellets, we collected data that yielded an index of desert cottontail abundance.

Between 0830 hours and 1400 hours each day we visited each wind turbine and recorded the data representing the variables described below. One observer walked one transect along the string of turbines (string transect) and returned 20 m to one side of the turbines (grass transect).

The edge index was measured from the string transect while viewing the 40-m radius from the wind turbine: 0 = no vertical or lateral edge within 40 m of wind turbine; 1 = some lateral edge such as the presence of a dirt road other than just the service road found at all of the wind turbines, or cleared area adjacent to vegetated area, or area tilled for pipeline, etc.; 2 = lots of lateral edge; 3 = some vertical edge such as road cut, road embankment, or cut into the hillside for creating a flat laydown area; 4 = lots of vertical edge, covering half or more of the area within 40 m of the wind turbine; and 5 = lots of both vertical and lateral edge.

The cottontail abundance index was recorded along the string transect and grass transect. We recorded the presence or absence of cottontail fecal pellets along 40-m transects and within 5 m of the observer (the same 5 m strip transects used for cattle pats, as well as a 5 m strip transect along the turbine string). We also noted whether or not cottontail fecal pellets were especially abundant.

Lizards were counted along the string transect and the grass transect and within 5 m of the observer.

We estimated the numbers of reasonably fresh cattle pats along the string transect and within 5 m of the observer, and we did the same along the grass transect. Reasonably fresh cattle pats were those that had not been broken up yet and were clearly identifiable as cattle pats.

The vegetation height index was measured only along the grass transect. We estimated the average height (cm) of the vegetation along each grass transect. Wherever the grass had fallen down, we estimated the height that would have been standing a month or two before when the grass had not yet fallen.

The locations of wind turbines were classified as physical features composing the relief, including plateaus, peaks, ridge crests, ridgelines, convex slopes, concave slopes, convex break in slope, concave break in slope, saddles in ridges, and ravines. Wind turbines were also classified as whether inside or outside of "canyons," which really were the largest watersheds in the APWRA

and the boundaries subjectively delineated. Their locations were also classified by slope aspect, including flat, north, northeast, east, southeast, south, southwest, west, and northwest. Rodent control intensity at the site of the wind turbine was classified as none, intermittent, and intense. All of these variables and others appearing in the results section are described further in Chapter 7.

5.2.1 Statistical Analysis

Our analysis was restricted to the 1,526 wind turbines we searched from through September 2002. We used analysis of variance mean comparisons and least significant difference tests. We relied on an alpha level of significance of 0.05, but considered P-values between 0.10 and 0.05 as indicative of trends.

5.3 RESULTS

5.3.1 Vegetation Height

String Level of Analysis

Vegetation height per wind turbine was 18% greater on ownerships where rodenticides were intermittently deployed, which tended to be significant in one-way ANOVA (ANOVA F = 2.83; df = 2, 191; P = 0.061) and was significant in an LSD test (mean difference from heavy rodenticide use = 4.28 cm, P < 0.05). It varied significantly by type of physical relief characteristic of the turbine string (ANOVA F = 2.72; df = 10, 191; P = 0.003), and post-hoc LSD tests showed that vegetation was higher on ridge crests compared to other types of relief (Table 5-1).

Table 5-1. LSD test results comparing vegetation height per turbine string to physical relief

Type of Relief	Other Types of Relief	Mean difference (cm)	P-value
plateau	Peak and slope	-12.35	0.040
ridge crest	Plateau	13.66	0.000
	Plateau and slope	11.60	0.002
	Ridgeline	8.76	0.048
	Slope	9.48	0.001
	Slope and ridgeline	7.35	0.009
	Convex slope	7.37	0.005

It also varied significantly by the dominant slope aspect characteristic of the turbine string (ANOVA F = 2.07; df = 11, 191; P = 0.025), and post-hoc LSD test showed vegetation was taller on south-facing and northwest-facing slopes (Table 5-2).

Table 5-2. LSD test results comparing vegetation height per turbine string to slope aspect

Slope Aspect	Other Slope Aspects	Mean difference (cm)	P-value
south	Flat	10.84	0.003
	Northeast	13.15	0.004
	East	12.90	0.002
	Southeast	12.33	0.009
	Southwest	19.00	0.005
northwest	Flat	6.07	0.044
	Northeast	8.38	0.037
	East	8.13	0.020
	Southwest	14.24	0.026

Vegetation height also correlated positively with percent of the string in canyons, steepness of slope, and with the number of cattle pats along the grass transect (Table 5-3).

Table 5-3. Correlation test results between vegetation height and independent variables (n = 192)

Independent Variable	Vegetation height (cm)
Cottontail abundance on grass transect	$r_p = -0.15$*
Mean elevation	ns
Change in elevation	ns
Elevation change per turbine	$r_p = 0.20$**
Percent in canyon	$r_p = 0.46$**
Variation in physical relief	ns
Cattle pats per turbine on grass transect	$r_p = 0.19$**
Cattle pats per turbine on string transect	ns
Edge index per turbine	ns

Wind Turbine Level of Analysis

Vegetation height varied significantly by physical relief (ANOVA F = 6.391; df = 10, 1489; P < 0.001), and post-hoc LSD tests showed that it was tallest on slopes and ridge crests (Table 5-4).

Table 5-4. LSD test results comparing vegetation height per wind turbine to slope aspect, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Physical Feature	Other Physical Features	Mean difference (cm)
Ridge crest	Plateau	5.32**
	Ridgeline	5.57**
	Concave slope	8.29*
	Breaking concave slope	11.60*
	Convex slope	5.75**
	Saddle	5.55*
	Ravine	7.05[t]
Slope	Plateau	5.64**
	Ridgeline	5.89**
	Concave slope	8.61*
	Breaking concave slope	11.92*
	Convex slope	6.07**
	Saddle	5.87*
	Ravine	7.37[t]

Vegetation height varied significantly by slope aspect (ANOVA F = 8.388; df = 8, 1486; P < 0.001), and post-hoc LSD tests showed that it was tallest on southern and northwestern-facing slopes (Table 5-5).

Table 5-5. LSD test results comparing vegetation height per wind turbine to slope aspect, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Slope Aspect	Other Slope Aspects	Mean difference (cm)
South	Flat (no aspect)	6.51**
	North	4.61*
	Northeast	5.85*
	East	7.09**
	Southeast	5.44**
	Southwest	6.61*
Northwest	Flat (no aspect)	8.11**
	North	6.21**
	Northeast	7.45**
	East	8.68**
	Southeast	7.03**
	Southwest	8.21*

It was significantly taller in canyons (ANOVA F = 218.561; df = 1, 1499; P < 0.001), averaging 68% taller. It varied significantly by edge index (ANOVA F = 4.231; df = 4, 1499; P < 0.005), and post-hoc LSD tests showed that vegetation height was greatest around wind turbines with lots of

vertical edge (Table 5-6). It did not vary significantly by position of the tower in the string (ANOVA F = 1.225; df = 3, 1498; P = 0.299).

Table 5-6. LSD test results comparing vegetation height per wind turbine to edge index, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Slope Aspect	Other Slope Aspects	Mean difference (cm)
Some vertical edge	No edge	3.57[t]
Lots of vertical edge	No edge	6.29**
	Some lateral edge	2.53*
	Lots of lateral edge	3.61**
	Some vertical edge	2.71*

5.3.2 Cattle Use Intensity

String Level of Analysis

The cattle pat abundance index along the grass transect averaged 5 pats more on ownerships where rodenticides were intermittently deployed (ANOVA F = 3.09; df = 2, 191; P = 0.048; LSD mean difference from none = 5.15, P = 0.023), as depicted in Figure 5-1. Along the turbine string transect, it was more than twice as great where rodenticides were intermittently deployed (ANOVA F = 20.02; df = 2, 191; P = 0.000; LSD mean difference of intermittent deployment = 19.1 and 14.5 pats from none and heavy deployment, respectively). Cattle pat abundance did not differ significantly between the grass and turbine string transects on ownerships with no use of rodenticides, but it was significantly greater along the turbine string transect where owners intermittently and heavily used rodent control (Table 5-7).

Table 5-7. Mean comparisons of the number of cattle pats by rodent control intensity, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Intensity of Rodent Control	Mean	SD	Paired-sample t	df	P (2-tailed)
None					
Grass	10.58	8.67			
Turbine string	11.97	10.34	-0.984	35	0.332
Intermittent					
Grass	15.73	10.52			
Turbine string	31.10	19.60	-7.318	65	0.000
Heavy					
Grass	12.44	11.75			
Turbine string	16.62	16.76	-3.176	89	0.002

The abundance of cattle pats along the string transect correlated positively with steepness of slope, percent of the string in canyons, and vegetation height, but none of these were strong (Table 5-8).

Table 5-8. Correlation test results between number of cattle pats and independent variables (n = 192), where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Independent Variable	Cattle pats on grass transect	Cattle pats on string transect
Mean elevation	$r_p = 0.16$*	ns
Change in elevation	ns	ns
Elevation change per turbine	ns	$r_p = 0.26$**
Percent in canyon	ns	$r_p = 0.30$**
Variation in physical relief	ns	$r_p = -0.16$*
Vegetation height (cm)	ns	$r_p = 0.19$*
Edge index per turbine	ns	ns

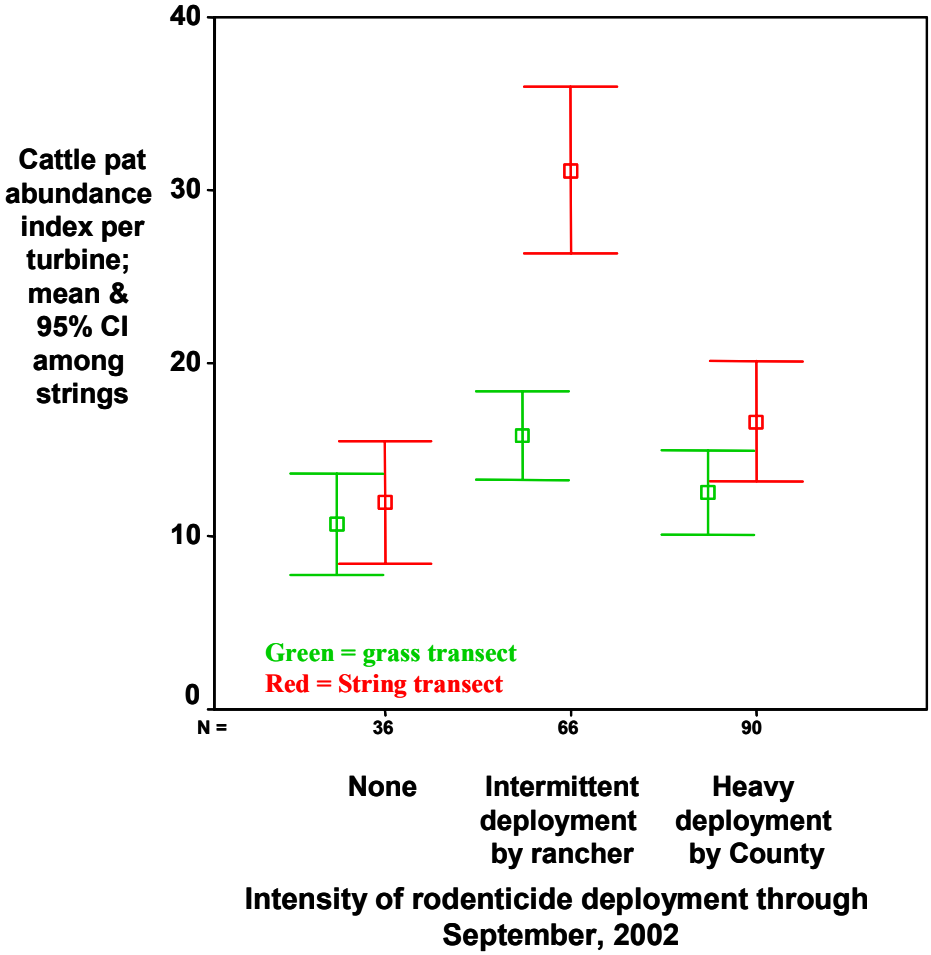


Figure 5-1. Cattle pat abundance was greatest along transects at wind turbine strings where rodenticide was deployed intermittently.

The abundance of cattle pats varied significantly by type of physical relief along both the grass transect (ANOVA F = 2.960; df = 10, 191; P < 0.001) and the turbine string transect (ANOVA F = 4.120; df = 10, 191; P < 0.005), and post-hoc LSD tests showed that cattle pats were generally more abundant on ridge crests and ridgelines, especially along the turbine string transects (Table 5-9).

The abundance of cattle pats did not differ significantly by the dominant slope aspect along both the grass transect (ANOVA F = 1.161; df = 11, 191; P = 0.318) and the turbine string transect (ANOVA F = 1.735; df = 11, 191; P = 0.069), but post-hoc LSD tests showed that cattle pats were generally more abundant on flat terrain with no particular aspect, and on western slopes compared to eastern slopes (Table 5-10).

Table 5-9. LSD test results comparing mean number of cattle pats per turbine string to physical relief, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Physical Feature	Other Physical Features	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Plateau	Concave slope	7.43*	ns
Ridge crest	Peak and slope	ns	22.81*
	Plateau	ns	16.20*
	Plateau and slope	7.50*	20.39**
	Slope	6.78*	15.58**
	Slope and Ridge	5.82*	12.91*
	Convex slope	9.26**	18.39**
	Concave slope	ns	23.81*
	Saddle	ns	22.17*
Ridge crest/Ridgeline	Convex slope	10.24*	
Ridgeline	Peak and slope	ns	23.69*
	Plateau	ns	17.07*
	Plateau and slope	11.69*	21.26*
	Slope	10.97*	16.46*
	Slope and Ridge	10.01*	13.79*
	Concave slope	15.91*	24.68*
	Convex slope	13.44**	19.27*
	Saddle	ns	23.05*

Table 5-10. LSD test results comparing mean number of cattle pats per turbine string to slope aspect of the string of turbines, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Slope Aspect	Other Slope Aspects	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Flat (no aspect)	Northeast	7.49*	ns
	East	6.21*	ns
West	Northeast	12.25*	ns
	East	10.97[t]	ns
Northwest	Northeast	ns	15.57*
	East	ns	12.50*

It varied significantly by tower type along both the grass transect (ANOVA F = 6.773; df = 8, 191; P < 0.001) and the turbine string transect (ANOVA F = 12.531; df = 8, 191; P < 0.001), and post-hoc LSD tests showed that cattle pats were generally more abundant nearby vertical axis, tubular, and horizontal lattice towers—especially along the string transect (Table 5-11).

Table 5-11. LSD test results comparing mean number of cattle pats per turbine string to tower type, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Type of Tower	Other Tower Types	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Bonus tubular	Diagonal lattice	8.53**	21.47**
	Horizontal lattice	ns	13.08**
	Micon 65	6.60*	22.78**
	Enertech	8.14*	24.89**
	Windmatic	11.04*	27.48**
Vertical axis	Bonus tubular	7.15*	ns
	Diagonal lattice	15.68**	25.16**
	Horizontal lattice	5.59*	16.77**
	KVS-33	14.84*	19.81[t]
	Danwin tubular	10.46*	13.21[t]
	Micon 65	13.75**	26.47**
	Enertech	15.29**	28.58**
	Windmatic	18.20**	31.17**
Horizontal lattice	Diagonal lattice	10.09**	8.39[t]
	Micon 65	8.16*	9.70*
	Enertech	9.70**	11.80*
	Windmatic	12.61*	14.40*
Danwin tubular	Enertech	ns	15.37*

Wind Turbine Level of Analysis

Cattle pat abundance did not differ significantly between the inside and the outside of canyons along the grass transect (ANOVA F = 0.00; df = 1, 1533; P = 0.966) but it did differ along the turbine string transect (ANOVA F = 67.734; df = 1, 1532; P < 0.001). Survey results indicated that cattle pats were twice as numerous inside the canyon compared to outside. The number of cattle pats varied significantly by edge conditions along the grass transect (ANOVA F = 7.964; df = 4, 1533; P < 0.001) and the turbine string transect (ANOVA F = 5.467; df = 4, 1532; P < 0.001). Post-hoc LSD tests showed cattle pats were least abundant around towers with extensive vertical edge (Table 5-12).

Table 5-12. LSD test results comparing mean number of cattle pats per wind turbine to edge condition, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Edge Condition	Other Edge Conditions	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Lots of lateral edge	Some vertical edge	2.41*	ns
Lots of vertical edge	None	-6.31**	ns
	Some lateral edge	-5.12**	-6.80*
	Lots of lateral edge	-5.51**	-7.70**
	Some vertical edge	-3.10*	-5.44*

Cattle pat abundance varied significantly by position of the tower in the string along the grass transect (ANOVA F = 6.838; df = 3, 1532; P < 0.001) and the turbine string transect (ANOVA F = 36.859; df = 3, 1531; P < 0.001). Post-hoc LSD tests showed that interior towers had fewer cattle pats than other towers, towers at the edges of gaps had more than those at the ends of strings, and non-operational towers had more pats than did end and interior towers (Table 5-13).

Table 5-13. LSD test results comparing mean number of cattle pats per wind turbine to position of the tower in the string, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Tower position	Other Tower positions	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Gap	End	3.37*	17.61**
Interior	End	-2.02*	-3.77*
	Gap	-5.39**	-21.38**
	Non-operational	-8.51*	-28.60**
Non-operational	End	ns	24.83**

5.3.3 COTTONTAIL ABUNDANCE

String Level of Analysis

The cottontail abundance index along the grass transect was twice as great on ownerships where no rodenticides were deployed (ANOVA F = 5.94; df = 2, 191; P = 0.003; LSD mean difference from none = 0.30 and 0.31 for intermittent and heavy, respectively), as depicted in Figure 5-2.

Along the turbine string transect, cottontail abundance was also twice as great where no rodenticides were deployed (ANOVA F = 4.53; df = 2, 191; P = 0.012; LSD mean difference from none = 0.34 and 0.27 for intermittent and heavy, respectively). Cottontail abundance did not differ significantly between the grass and turbine string transects on ownerships with no or intermittent deployment of rodenticides, but it was significantly greater along the turbine string transect where owners heavily attempted rodent control (Table 5-14).

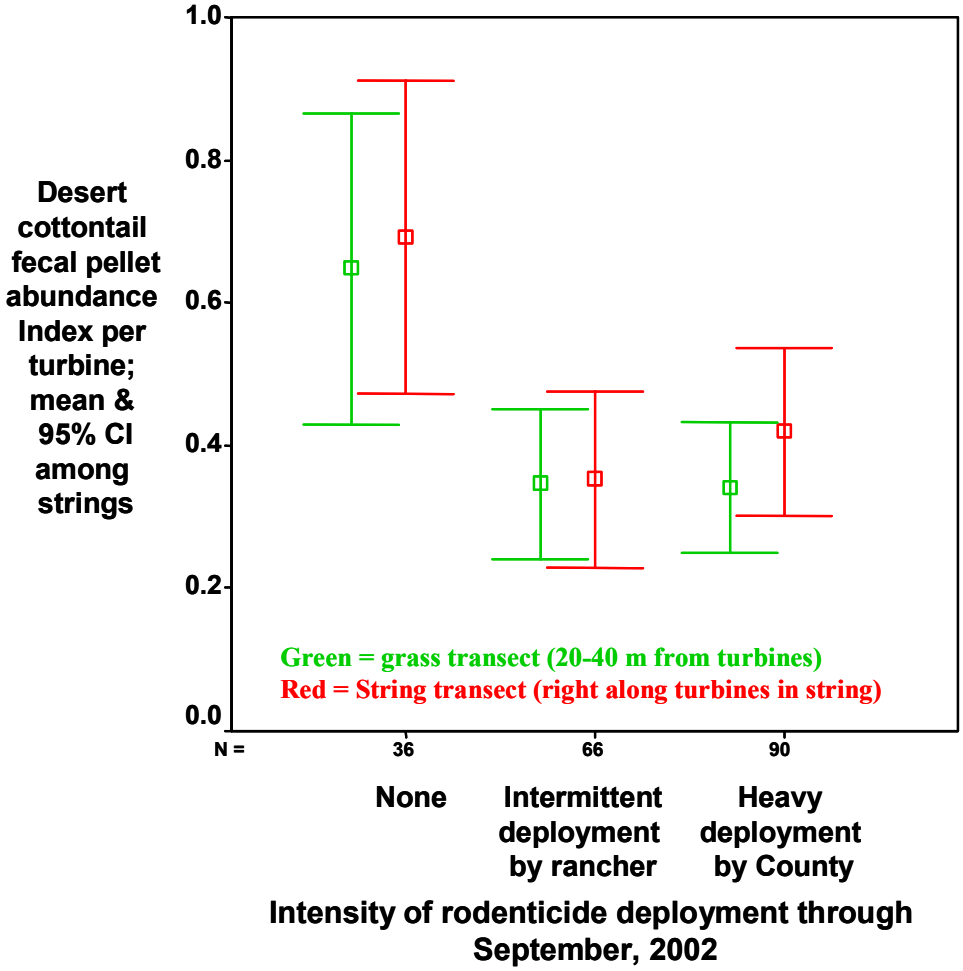


Figure 5-2. Desert cottontail abundance near wind turbines was greatest where no rodenticide was deployed, and it was greater at wind turbines more than 40 m away where rodenticide was heavily deployed.

Table 5-14. Mean comparisons of the cottontail abundance index by rodent control intensity

Intensity of Rodent Control	Mean	SD	Paired-sample t	df	P (2-tailed)
None					
Grass	0.64	0.64			
Turbine string	0.69	0.65	-0.91	35	0.368
Intermittent					
Grass	0.34	0.43			
Turbine string	0.35	0.50	-0.292	65	0.771
Heavy					
Grass	0.33	0.44			
Turbine string	0.42	0.56	-2.18	89	0.032

Cottontail abundance correlated inversely with elevation, steepness of slope along the turbine string, percentage of the string in canyons, vegetation height, and cattle pats found along the transect. However, none of these correlations were strong (Table 5-15).

Table 5-15. Correlation test results between cottontail abundance index and independent variables (n = 192), where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Independent Variable	Cottontail abundance index on grass transect	Cottontail abundance index on turbine string transect
Mean elevation	r_p = -0.23**	r_p = -0.28**
Change in elevation	r_p = -0.21**	r_p = -0.17*
Elevation change per turbine	r_p = -0.20**	r_p = -0.14*
Percent in canyon	r_p = -0.23**	ns
Variation in physical relief	ns	ns
Vegetation height (cm)	r_p = -0.15*	ns
Cattle pats on grass transect	r_p = -0.26**	r_p = -0.26**
Cattle pats on String transect	r_p = -0.33**	r_p = -0.31**
Edge index per turbine	ns	ns

Cottontail abundance varied significantly by tower type along both the grass transect (ANOVA F = 19.75, df = 8, 191, P < 0.001) and the turbine string transect (ANOVA F = 19.92; df = 8, 191; P < 0.001). Post-hoc LSD tests showed that cottontails were generally more abundant around vertical axis, Micon-65, and Enertech towers (Table 5-16).

Cottontail abundance varied significantly by type of physical relief along both the grass transect (ANOVA F = 3.345; df = 10, 191; P < 0.001) and the turbine string transect (ANOVA F = 4.092; df = 10, 191; P < 0.001). Post-hoc LSD tests showed that cottontails were generally more abundant on plateau/slope combinations, slopes, and saddles (Table 5-17).

Cottontail abundance varied significantly by the dominant slope aspect along both the grass transect (ANOVA F = 1.890; df = 11, 191; P =0.043) and the turbine string transect (ANOVA F = 2.144; df = 11, 191; P =0.019). Post-hoc LSD tests showed that cottontails were generally most abundant on southwest slopes and least abundant on northwest slopes (Table 5-18).

Table 5-16. LSD test results comparing mean cottontail abundance index values per turbine string to tower type, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Type of Tower	Other Types of Tower	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Vertical axis	Bonus tubular	0.25*	0.30*
	Diagonal lattice	0.38**	0.32*
	Horizontal lattice	0.26*	0.35*
	Enertech	-0.56**	-0.71**
	Windmatic	-1.09**	-0.94**
Micon 65	Bonus tubular	0.32**	0.50**
	Diagonal lattice	0.45**	0.52**
	Horizontal lattice	0.33**	0.55**
	KVS-33	ns	0.72*
	Enertech	-0.49**	-0.51**
	Windmatic	-1.02**	-0.74**
Enertech	Bonus tubular	0.81**	1.01**
	Vertical axis	0.56**	0.71**
	Diagonal lattice	0.94**	1.03**
	Horizontal lattice	0.82**	1.06**
	KVS-33	0.92**	1.23**
	Danwin tubular	0.83**	0.68**
	Micon 65	0.49**	0.51**
	Windmatic	-0.52*	ns

Table 5-17. LSD test results comparing mean cottontail abundance index values per turbine string to physical relief, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Physical Feature	Other Physical Features	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Plateau and slope	Plateau	0.56*	0.58*
	Ridge crest	0.61**	0.65**
	Ridge crest/Ridgeline	0.68**	0.83**
	Ridgeline	0.69**	0.65*
	Slope	0.43*	0.35^{t}
	Slope and Ridge	0.62**	0.74**
	Convex slope	0.42*	0.47*
Slope	Ridge crest	ns	0.30*
	Ridge crest/Ridgeline	ns	0.49*
	Slope and Ridge	ns	0.39*
Saddle	Plateau	ns	1.07*
	Ridge crest	ns	1.14**
	Ridge crest/Ridgeline	ns	1.32**
	Ridgeline	ns	1.14*
	Slope	ns	0.83*
	Slope and Ridge	ns	1.22**
	Concave slope	ns	0.89*
	Convex slope	ns	0.96*

Table 5-18. LSD test results comparing mean cottontail abundance index values per turbine string to physical relief, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Slope Aspect	Other Slope Aspects	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Southwest	Flat (no aspect)	ns	0.70*
	East	ns	0.63*
	Southeast	ns	0.63*
	South	ns	0.72*
	West	0.82*	1.13*
	North	ns	0.67*
	Northwest	0.72*	1.06*
Northwest	Flat (no aspect)	-0.32*	-0.36*
	North to South	-0.34*	-0.56*
	North	-0.41*	-0.39*
	Northeast	-0.41*	-0.47*
	East	-0.38*	-0.43*
	Southeast	-0.35*	-0.43*

Wind Turbine Level of Analysis

Cottontail abundance at the wind turbine-level of analysis decreased significantly with increasing elevation, vegetation height, and with the number of cattle pats present near the wind turbines (Table 5-19).

Table 5-19. Correlation test results between cottontail abundance index and independent variables (n = 1325), where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Independent Variable	Cottontail abundance index on grass transect	Cottontail abundance index on turbine string transect
Mean elevation	r_p = -0.17**	r_p = -0.25**
Vegetation height (cm)	r_p = -0.12**	r_p = -0.06*
Cattle pats on grass transect	r_p = -0.09*	r_p = -0.13**
Cattle pats on String transect	r_p = -0.13**	r_p = -0.14**

Cottontail abundance was significantly greater (95% greater) outside the canyons along the grass transect (ANOVA F = 14.09; df = 1, 1533; P < 0.001), but not along the turbine string transect (ANOVA F = 2.83; df = 1, 1533; P = 0.093). Within canyons, cottontail abundance averaged 83% greater along the turbine string than 20–40 m away, which was a significant difference (matched-pairs t-test: t = -3.970, df = 174, P < 0.001). Cottontail abundance also differed significantly between transects outside canyons (matched-pairs t-test: t = -2.893, df = 1356, P = 0.004), but less so (11% greater along string transect).

Cottontail abundance varied significantly among edge conditions surrounding the towers, both along the grass transect (ANOVA F = 5.28; df = 4, 1533; P < 0.001) and the turbine string transect (ANOVA F = 3.33; df = 4, 1531; P < 0.01). Post-hoc LSD tests showed that cottontail abundance was greatest at turbines surrounded by some lateral edge and least at those surrounded by vertical edge or no edge (Table 5-20).

Table 5-20. LSD test results comparing mean cottontail abundance index values per wind turbine to the edge index, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Edge condition	Other Edge conditions	Mean difference (cm) on Grass transect	Mean difference (cm) on String transect
Some lateral edge	No edge	0.24*	0.22*
	Lots of lateral edge	0.16*	0.13*
	Some vertical edge	0.18*	0.17*
	Lots of vertical edge	0.27**	0.22**
Lots of lateral edge	Lots of vertical edge	0.11*	0.10*
Some vertical edge	Lots of vertical edge	0.09*	ns

Cottontail abundance did not vary significantly by position of the tower in the string along the grass transect (ANOVA F = 0.79; df = 3, 1323; P = 0.506) or the string transect (ANOVA F = 1.61; df = 3, 1322; P = 0.186).

5.3.4 Lizard Abundance

String Level of Analysis

Lizard abundance per wind turbine tended to vary among turbine strings based on intensity of rodenticide deployment (ANOVA F = 2.54; df = 2, 191; P = 0.081), and post-hoc LSD tests suggested that lizard abundance was 50% to 60% greater on ownerships that deployed no rodenticides compared to those that heavily and intermittently deployed them, respectively (P < 0.05 for both LSD tests), as depicted in Figure 5-3.

Lizard abundance correlated slightly positively with the edge index, and slightly negatively with the number of cattle pats per turbine along the string transect (Table 5-21). It varied significantly by type of physical relief (ANOVA F = 3.04; df = 10, 191; P < 0.001). Post-hoc LSD tests suggested that lizard abundance was especially greater on saddles (Table 5-22). It did not vary significantly by dominant aspect of the slope (ANOVA F = 1.188; df = 11, 191; P = 0.298). Post-hoc LSD tests suggested that lizard abundance was generally greater on southeast and southwest slopes (Table 5-23). It varied significantly by tower type (ANOVA F = 4.187; df = 8, 191; P < 0.001). Post-hoc LSD tests suggested that lizard abundance was greater under and around wind towers that lacked concrete pads, such as lattice towers and those installed for Windmatic turbines (Table 5-24).

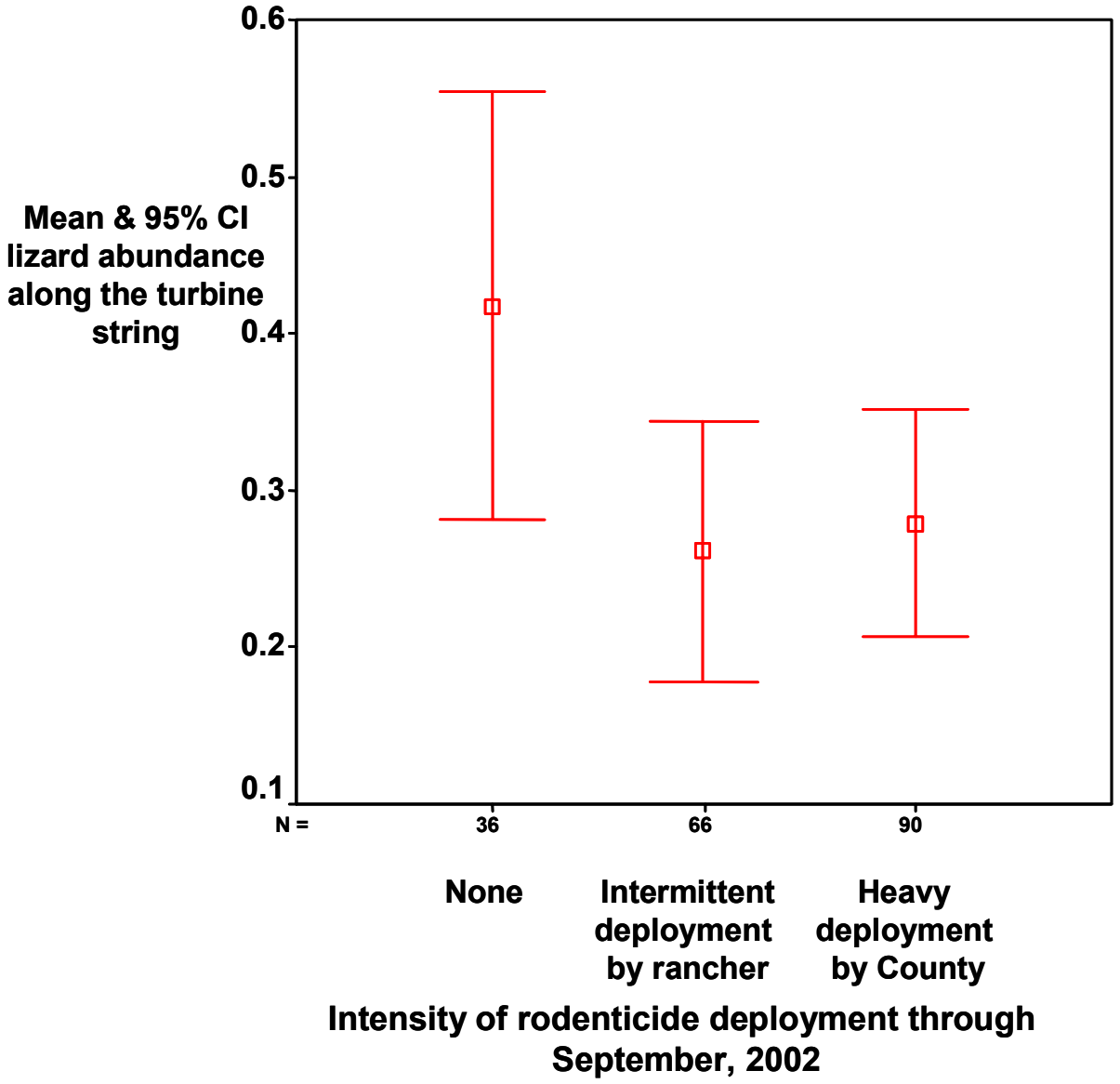


Figure 5-3. Lizard abundance near wind turbines was greatest where no rodenticide was deployed.

Table 5-21. Correlation test results between lizard abundance and independent variables (n = 192), where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Independent Variable	Lizard abundance
Vegetation height (cm)	ns
Mean elevation	ns
Change in elevation	ns
Elevation change per turbine	ns
Percent in canyon	ns
Variation in physical relief	ns
Cattle pats per turbine on grass transect	ns
Cattle pats per turbine on string transect	$r_p = -0.21$**
Edge index per turbine	$r_p = 0.17$*

Table 5-22. LSD test results comparing lizard abundance per wind turbine to physical relief, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Physical Feature	Other Physical Features	Mean difference (cm)
Slope and Ridge	Ridge crest	0.22*
Convex slope	Ridge crest	0.16*
Saddle	Peak and slope	0.78*
	Plateau	0.84**
	Plateau and slope	0.71**
	Ridge crest	0.92**
	Ridge crest/Ridgeline	0.92**
	Ridgeline	0.96**
	Slope	0.87**
	Slope and Ridge	0.70**
	Concave slope	0.67*
	Convex slope	0.92**

Table 5-23. LSD test results comparing mean lizard abundance per wind turbine to dominant slope aspect of the string of turbines, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Slope Aspect	Other Slope Aspects	Mean difference (cm)
Southeast	Flat (no aspect)	0.30*
	North	0.32*
	Northwest	0.31*
Southwest	Flat (no aspect)	0.34^t
	North	0.37^t
	Northwest	0.35^t

Table 5-24 LSD test results comparing mean lizard abundance per wind turbine to tower type, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Type of Tower	Other types of Tower	Mean difference (cm)
Vertical axis	Bonus tubular	0.20*
	Horizontal lattice	0.24*
Diagonal lattice	Bonus tubular	0.28*
	Horizontal lattice	0.32**
	KVS-33	0.43 [t]
Micon-65	Horizontal lattice	0.17 [t]
Windmatic	Bonus tubular	0.61**
	Vertical axis	0.41*
	Diagonal lattice	0.33*
	Horizontal lattice	0.65**
	KVS-33	0.77*
	Danwin tubular	0.53*
	Micon 65	0.48*
	Enertech	0.52**

Wind Turbine Level of Analysis

Lizard abundance correlated significantly with only one continuous variable, but the coefficient was not large enough to warrant reporting. It did not vary significantly by edge conditions surrounding the wind towers, or by position of the tower in the string.

5.4 DISCUSSION

This study resulted in many statistically significant tests, but many of which were somewhat redundant due to shared variation among variables. Table 5-25 summarizes the strongest associations that we believed were also more orthogonal in their expressions of underlying factors. The remainder of this discussion focuses on these associations.

Vegetation height near the wind turbines was greater on ridge crests than most of the other types of physical relief considered. It was greater on steeper slopes and on south-facing and northwest-facing slopes. Vegetation height also was greater in canyons, and where vertical edge was particularly evident near towers. It correlated positively with the number of cattle pats present along a transect 20 m from the turbine string.

Table 5-25. Highlighted associations between variables based on level of statistical significance and shared variation with other associations

Dependent Variable	Relationship with Association Variable
Vegetation height	Taller on ridge crests and slopes
	Taller in canyons
	Taller on south- and northwest-facing slopes
	Taller where vertical edge is greater around tower laydown areas
Cattle pats	More in area of intermittent rodent control
	More at turbines than 20 m away in areas of rodent control
	More in canyons and on steeper slopes and greater vertical edge
	More on ridge crests and ridgelines
	More by vertical axis, tubular and horizontal lattice towers
	More by non-operational towers and those at edges of gaps in string
Cottontail abundance	More in areas of no rodent control
	More at turbines than 20 m away in areas of intense rodent control
	More at lower elevations
	More on shallower slopes outside canyons
	More where there are fewer cattle pats
	More on southwest-facing slopes
	More by wind tower laydown areas with some lateral edge
Lizard abundance	More in areas without rodent control
	More on southeast and southwest slopes
	More on saddles of ridges
	More at wind towers with no concrete pads

The intensity of cattle use of laydown areas, as inferred from the number of cattle pats along two transects, was greatest on the ownership where rodenticide was deployed intermittently, and likely reflected the stocking rate and control methods of the single rancher who controlled this area. Another possible explanation was that this ownership included more of the tubular towers, which cattle appear to use for shade, and another was that the intermittent control may have resulted in greater clustering of rodents around wind turbines, which perhaps fostered a greater growth of plants preferred by cattle. At sites where rodenticides were applied, cattle pats were significantly more abundant immediately around turbines than they were 20–40 m away; however, there was no difference in abundance where rodent control programs were not implemented.

Cattle use intensity in the immediate area surrounding wind turbines was also greatest on ridge crests and ridgelines, and on west- and northwest-facing slopes and on flat areas with no slope aspect. It was greater nearby Bonus tubular towers and vertical axis towers, and least where tower laydown areas were surrounded by lots of vertical edge. Based on these associations, it appears that some factors, such as rodent control, steepness of slope, ridge crests, and northwest-facing slopes, cause cattle to spend more time closer to the wind turbines. This association was especially true for Bonus tubular towers, perhaps because these towers provided more shade during the hot days of summer and early fall. When concentrated among the wind turbine towers, cattle appeared to spend more time within gaps of the turbine string and next to non-operational turbines than elsewhere,

perhaps offsetting some aspect(s) of the wind turbines cattle might find annoying, such as the noise or motion of moving blades.

Cottontail abundance was twice as great on ownerships where no rodenticide was deployed, and there was no apparent clustering of cottontails near the wind towers. However, where rodenticide was heavily deployed, cottontails were more abundant at the wind towers than they were 20 m away. Cottontail abundance correlated negatively with cattle pat abundance. It correlated positively with plateaus, slopes, and saddles, on southwest-facing slopes, and where some lateral edge was evident.

Lizard abundance was greatest on ownerships that deployed no rodenticide, and was greater on saddles and on southeast- and southwest-facing slopes. It was also greatest at wind turbines lacking concrete pads.

Rodent control corresponded with greater clustering of cattle and cottontails at the wind turbines, whereas it corresponded with less abundance of cottontails and lizards and greater abundance of cattle pats. Some of these relationships might be confounded with other variables, such as differential stocking rates of cattle by ownership, or more or less availability of rock piles for cottontails to find den habitat.

The distribution of cattle, cottontails, lizards, and grass height appear to associate with physical relief and range management practices, as well as according to the types of wind turbine deployed by the wind industry. The interrelationships between grass height, cattle use intensity, cottontail abundance, and lizard abundance are complex, and not always intuitive. Each varies with range management practices, but each of these relationships is moderated by other factors, such as physiographic conditions. Therefore, it is inherently difficult to predict the effects of new range management practices on bird mortality caused by wind turbines because the ecological relationships affected by such practices are complex. In the chapter on fatality associations (Chapter 7), we test whether cattle pat abundance, cottontail abundance and vegetation height relate to bird fatalities.

CHAPTER 6

DISTRIBUTION AND ABUNDANCE OF FOSSORIAL ANIMAL BURROWS IN THE APWRA AND THE EFFECTS OF RODENT CONTROL ON BIRD MORTALITY

6.1 INTRODUCTION

The distribution and abundance of California ground squirrels *(Spermophilus beecheyi)* in the APWRA is of interest to researchers because they are a major prey species for golden eagles (Hunt and Culp 1997; Hunt et al. 1998; Curry and Kerlinger 2000; Environmental Science Associates 2002; Hunt 2002; Kerlinger and Curry 2003). Proponents of rodent control in the APWRA believe that reducing raptor prey populations in the APWRA through intensive control of California ground squirrels might discourage raptors from visiting the APWRA, and thus might reduce the number of raptor fatalities caused by wind turbines (Kerlinger and Curry 1999; Hunt 2002; Kerlinger and Curry 2003).

During the course of our studies, we noted that many raptors were killed south of Altamont Pass Road. This was in an area where by 1999 intense rodent control had nearly completely eradicated ground squirrels. We suspected that other prey species for raptors may occur there, or that the relationship between raptor visitation to a site and that site's ground squirrel occurrence was misunderstood.

Pocket gophers *(Thomomys bottae)* are abundant throughout the APWRA, but ground squirrels have an uneven, patchy distribution, as we demonstrate with data in this report. Red-tailed hawks and great horned owls rely heavily on pocket gophers (Fitch et al. 1946; Craighead and Craighead 1956; Orians and Kuhlman 1956), whereas golden eagles rely more heavily on larger prey such as ground squirrels and lagomorphs (Carnie 1954; Olendorff 1976). California vole *(Microtus californicus)* populations likely also influence the distributions of raptor species, as likely do small reptiles, amphibians, and arthropods, which are fed upon by burrowing owls and American kestrels, as examples. Pocket gopher burrows provide habitat for most of these additional raptor prey species. While there is some overlap, each raptor species using the APWRA likely pursues a somewhat different suite of prey resources.

Pocket gopher burrow systems typically occurred immediately adjacent to wind turbines (Photo 6-1), whereas ground squirrel burrow systems were often located farther away (Photos 6-2 and 6-3). Therefore, it occurred to us that raptors flying close to operating wind turbines might not be approaching to hunt ground squirrels, but rather to hunt pocket gophers and other species that associate with pocket gopher burrow systems. These early observations lead to an expanded line of research.

In alfalfa stands in the Central Valley, raptors spend a disproportionately large fraction of their flight time directly over pocket gopher burrow systems, where K. S. Smallwood (unpublished data) has

observed raptors capturing pocket gophers, voles, snakes, and black-tailed jackrabbits. Assuming the same may be the case in the APWRA, we decided to map the locations of pocket gopher and ground squirrel burrow systems in and around selected strings of wind turbines.

Photo 6-1. Pocket gopher burrow systems (see the light-colored mounds) typically occurred near wind turbines, such as along the cuts made into hillsides for wind tower laydown areas and access roads.

Photo 6-2. Ground squirrel burrow systems typically occurred on slopes below wind turbines located on ridge crests, such as those seen in this photo.

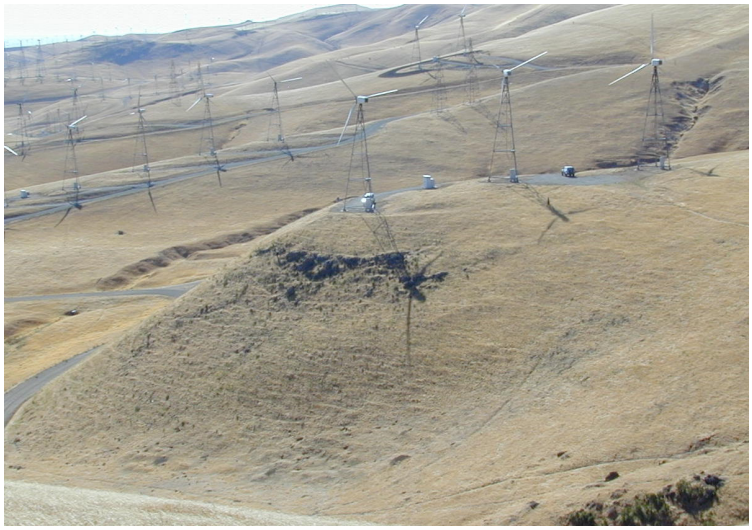


Photo 6-3. Ground squirrel burrow systems typically occurred on slopes below wind turbines located on ridge crests, such as to the lower left-center area in this photo.

Wind turbine operators in the APWRA controlled ground squirrels during or prior to 1997. Their consultants maintained data on where and how much effort was put into rodent control by the Alameda County agent who was funded by the turbine operators to implement the control program. We learned of this program in fall 2002, but we observed poison bait being dispensed throughout our study, beginning in 1998.

Our objectives for this research effort were to: (1) relate ground squirrel and pocket gopher distribution and abundance to the levels of rodent control intensity applied in the APWRA; (2) relate the distribution and abundance of these species to physiographic conditions, relevant turbine attributes, and season; and (3) compare the mortality of raptors to the densities and degree of contagion of burrow systems actively used by potential prey species around individual wind turbines and around turbine strings.

6.2 METHODS

We mapped rodent burrows near 571 wind turbines, composing 70 strings of wind turbines in the APWRA. Most wind turbine strings were selected arbitrarily, to represent a wide range of raptor mortality recorded during our fatality searches, as well as to represent a variety of physiographic conditions and levels of rodent control.

We had no control over the rodent control program. It was administered by the wind companies and carried out by Alameda County and some ranch owners. To characterize the levels of rodent control applied, we interviewed the Alameda County agent who dispensed the poison bait and was most familiar with the implementation of the program.

The rodent control applied in the APWRA has consisted of dispensing onto the ground rolled oats treated with 0.01% chlorophacinone, an anticoagulant. A truck was driven back and forth across treatment areas, and a dispenser broadcast the bait onto the ground. Two assistants walked over treated areas two weeks later and picked up dead animals lying on the ground. We were told that consultants to the turbine owners maintained a database on the number of ground squirrels picked up, but we were unable to obtain these data. In January 2004, we were provided copies of an unpublished report (Kerlinger and Curry 2003) on the rodent control program's effectiveness. A comparison of our results with those of Kerlinger and Curry (2003) appears in Appendix B to this report.

We mapped the approximate centers of pocket gopher, ground squirrel, and desert cottontail burrow systems using a Trimble Pathfinder Pro-XR GPS with an error rate < 0.5 m. We located burrow systems based on freshly excavated soil or scats at the burrow entrance, which indicated that the burrows were occupied. Although we easily recognized the boundaries of most individual pocket gopher and ground squirrel burrow systems, a pacing method (Smallwood and Erickson 1995) was used to separate burrows when continuity of sign rendered inter-burrow system distinctions difficult. We mapped burrows used by desert cottontails, kangaroo rats, burrowing owls, and mammalian carnivores as we encountered them.

Our search for burrows began within the string of wind turbines. A 15 m-wide strip transect was walked from 15 m beyond the wind turbine at one end of the string to 15 m beyond the wind turbine at the other end. Then perimeter transects were walked at 15, 30, 45, 60, 75, and 90 m away from the turbine string, thus covering increasingly larger areas around the turbine strings. These 15-m intervals correspond with the distance across the largest burrow systems of male pocket gophers (Smallwood and Erickson 1995). A laser rangefinder was used to maintain the intended distances away from the turbines while searching along perimeter transects.

The degree of clustering at wind turbines was estimated in two ways. In one, we estimated densities of gopher and ground squirrel burrow systems within each of the corresponding areas searched. Using least squares linear regression, densities of burrow systems were then regressed on the corresponding search areas and the steepness of the regression slope used as an indicator of contagion relative to the location of each string of wind turbines. Steeper inverse slopes indicated greater degrees of clustering at the wind turbines.

The other indicator of clustering near wind turbines was the observed divided by expected number of burrow systems within the 15-m zone of wind turbines, where the expected value was N burrows within 90 m multiplied by the ratio of the area in the 15-m zone to the area in the entire 90-m search area. Larger ratios of observed-to-expected number of burrow systems indicated greater degrees of clustering within 15 m of the wind turbines. Also, we estimated the density of burrow systems within 90 m of each string of wind turbines and compared these data to physiographic conditions, rodent control intensity, and other factors.

We learned *post hoc* about the rodent control in the APWRA. However, not all land owners participated with the program, which provided the basis for some fundamental comparisons. We divided the control intensity into three categories: none, intermittent, and intense. Information on where and how chlorophacinone-treated oats were dispersed in the APWRA was obtained by the

County's applicator. Using these data, we categorized specific wind turbines by the level of rodent control deployed per treatment area. Areas defined as having intermittent control were those not treated by the County but by the landowner in a manner that the County's field applicator felt was less systematic and less frequent than was done in ownerships we rated as receiving intense control. Some of the areas not treated through 2001 were treated in 2002; however, we considered these areas untreated in our comparisons, because rodent burrows were mapped previous to the treatments.

An edge index was measured from the string transect while viewing the 40–m radius from the turbine: 0 = no vertical or lateral edge within 40 m of the wind turbine; 1 = some lateral edge, such as the presence of a dirt road other than just the service road found at all of the wind turbines (Photo 6-4), or cleared area adjacent to vegetated area, or area tilled for pipeline, etc.; 2 = lots of lateral edge; 3 = some vertical edge, such as road cut, road embankment, or cut into the hillside for creating a flat laydown area for the tower pad; 4 = lots of vertical edge, covering half or more of the area within 40 m of the wind turbine; and 5 = lots of vertical and lateral edge within 40 m of the wind turbine. This index was related to burrow distributions to test whether burrowing animal species associate with vertical and lateral edge, as has often been suggested in the literature.

Photo 6-4. All wind turbines included access roads, but those in the foreground also were near regularly disked soil, either as a firebreak or over a pipeline. The wind turbine lowest on the slope would have been rated as having an index value for vertical and lateral edge. Turbines on the mid-slope have some vertical edge (and high index value for lateral edge), and those on the top of the slope have a high index value for lateral edge, but no vertical edge.

The densities and spatial distributions of burrow systems used by fossorial species were related to raptor mortality measured throughout the study period, as well as measured within a year of the date the burrows were mapped at the particular wind turbine string. Thus, mortality was measured nearer in time to the maps of burrow systems in the latter comparison, but it was measured more robustly while also expressed over more time in the former comparison. Mortality was measured as the number of fatalities recorded per megawatt of rated power output from the associated wind turbines per year, or deaths/MW/year.

6.3 RESULTS

6.3.1 Density and Distribution of Burrowing Animals

Pocket gopher burrow systems occurred within 90 m of all but one wind turbine string (Figure 6-1A), and the mean density of gopher burrow systems was less than that of ground squirrel burrow systems (Figure 6-1B). The density of ground squirrel burrow systems was often much greater than recorded pocket gopher burrow system density, but there were also 10 more study areas devoid of ground squirrels as compared to pocket gophers (Figures 6-1A and 6-1B). Two out of every three study areas lacked burrows of desert cottontail within 90 m of wind turbines and the mean density of cottontail burrows was low (Figure 6-2A). The density of burrow systems of all fossorial species mapped were approximately normally distributed among wind turbine strings (Figure 6-2B). Almost all areas that we searched lacked any burrowing owl burrows within 90 m of wind turbines during the summer (Figure 6-3).

As the density of pocket gopher burrow systems increased, it did so within 15 m of wind turbines at twice the rate as it did within 90 m of the wind turbines where rodent control was implemented, but not at all where rodent control was not applied (Figure 6-4A). Conversely, the density of ground squirrel burrow systems increased proportionally between 15 m and 90 m distances of wind turbines (Figure 6-4B), meaning that unlike pocket gophers, ground squirrels demonstrated no affinity for the areas within 15 m of wind turbines.

Desert cottontails showed the greatest affinity for the areas within 15 m of wind turbines, as the density of its burrows increased within 15 m of wind turbines at nearly four times the rate that it did within 90 m of the wind turbines (Figure 6-5).

Pocket gopher density consistently decreased as larger areas were searched around each string of wind turbines (Figure 6-6A), indicating that pocket gophers were clustered around the wind turbines. Nearly all turbine strings demonstrated a relationship between gopher burrow density and study area size that was similar to the pattern reported by Smallwood and Morrison (1999), which was an inverse power function. Similarly, most of the observed-divided-by-expected number of gopher burrow systems within 15 m of the wind turbines was greater than 1.0 (Figure 6-6B), meaning that gophers were almost always clustered to some degree around the wind turbines.

Because our regression-based index of clustering related precisely to the observed-divided-by-expected number of burrow systems within 15 m of the wind turbines (Figure 6-7), we opted to use the latter index throughout the remainder of this analysis. Another reason for our use of the latter index was that it enabled the inclusion of wind turbine strings with no pocket gophers within 90 m of the wind turbines, whereas the former index did not.

Based on the observed-divided-by-expected number of burrow systems within 15 m of wind turbines, ground squirrels on average appeared to avoid establishing burrow systems close to wind turbines (Figure 6-8A); whereas, desert cottontails selected these areas (Figure 6-8B). The collection of animal species studies showed a statistical preference for burrow establishment within 15 m of wind turbines (Figure 6-9).

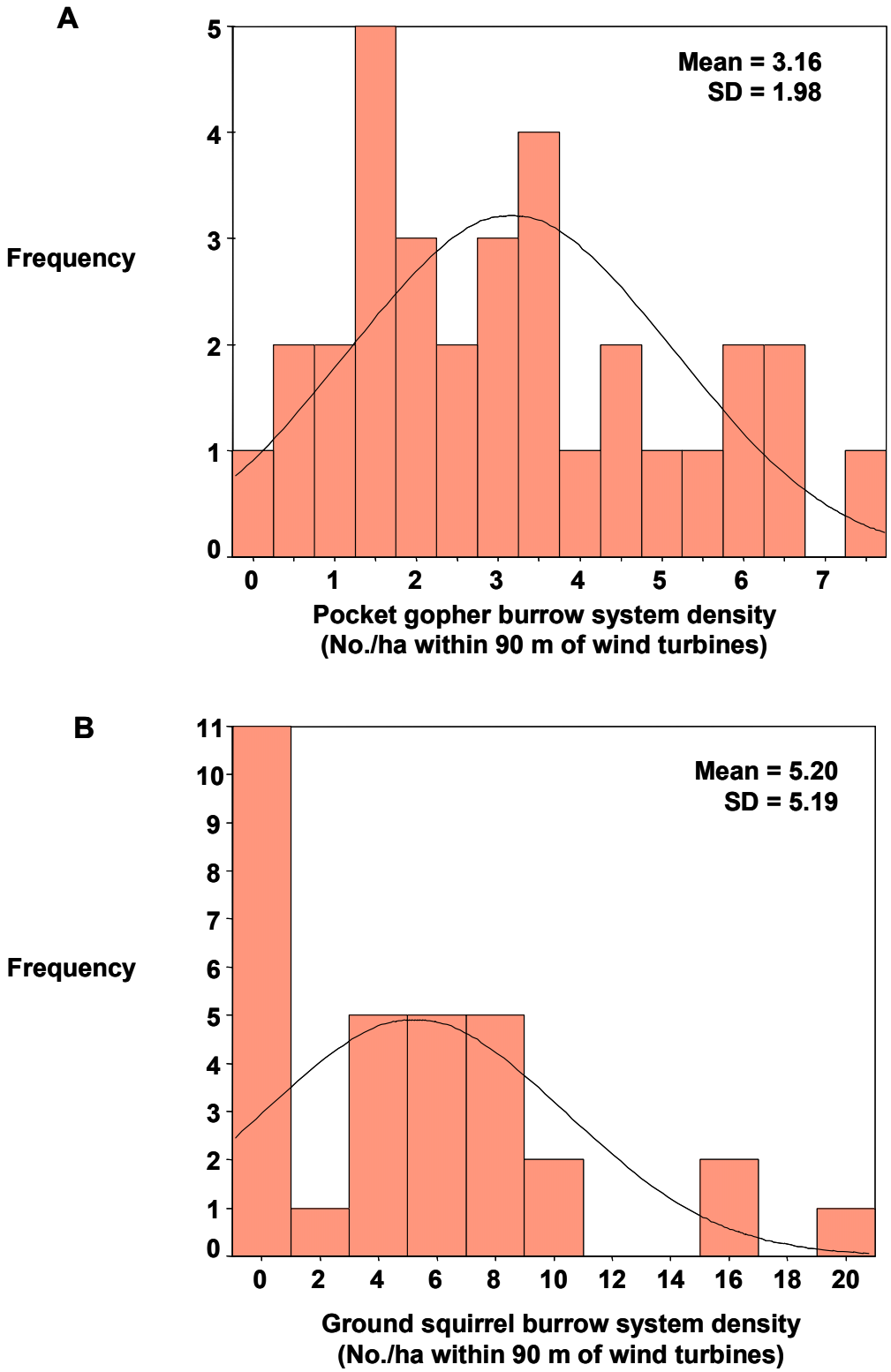


Figure 6-1. Frequency distributions of the density of burrow systems of pocket gophers (A) and ground squirrels (B) within 90 m of wind turbines

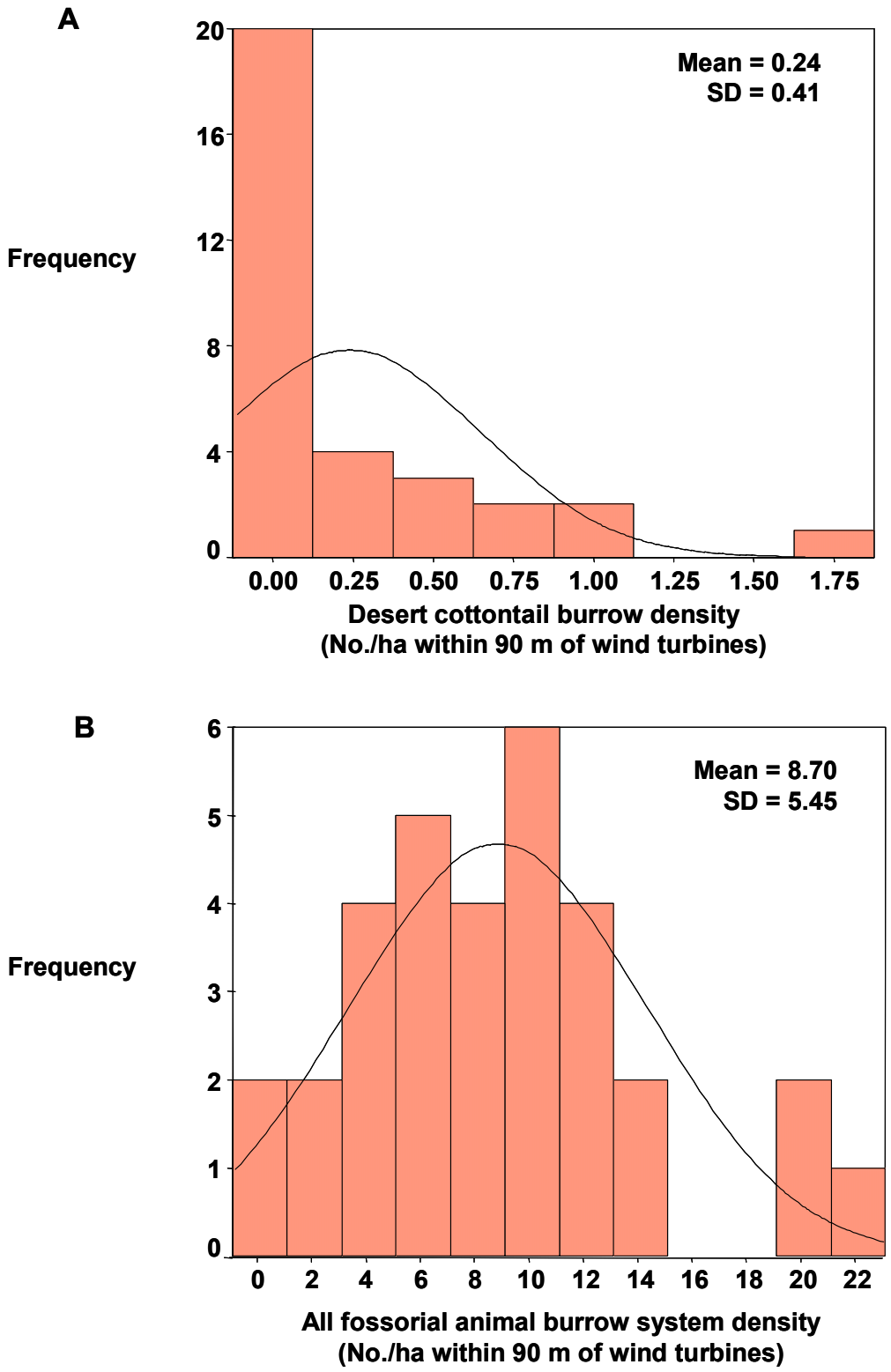


Figure 6-2. Frequency distributions of the density of burrow systems of desert cottontails (A) and all fossorial mammal species (B) within 90 m of wind turbines

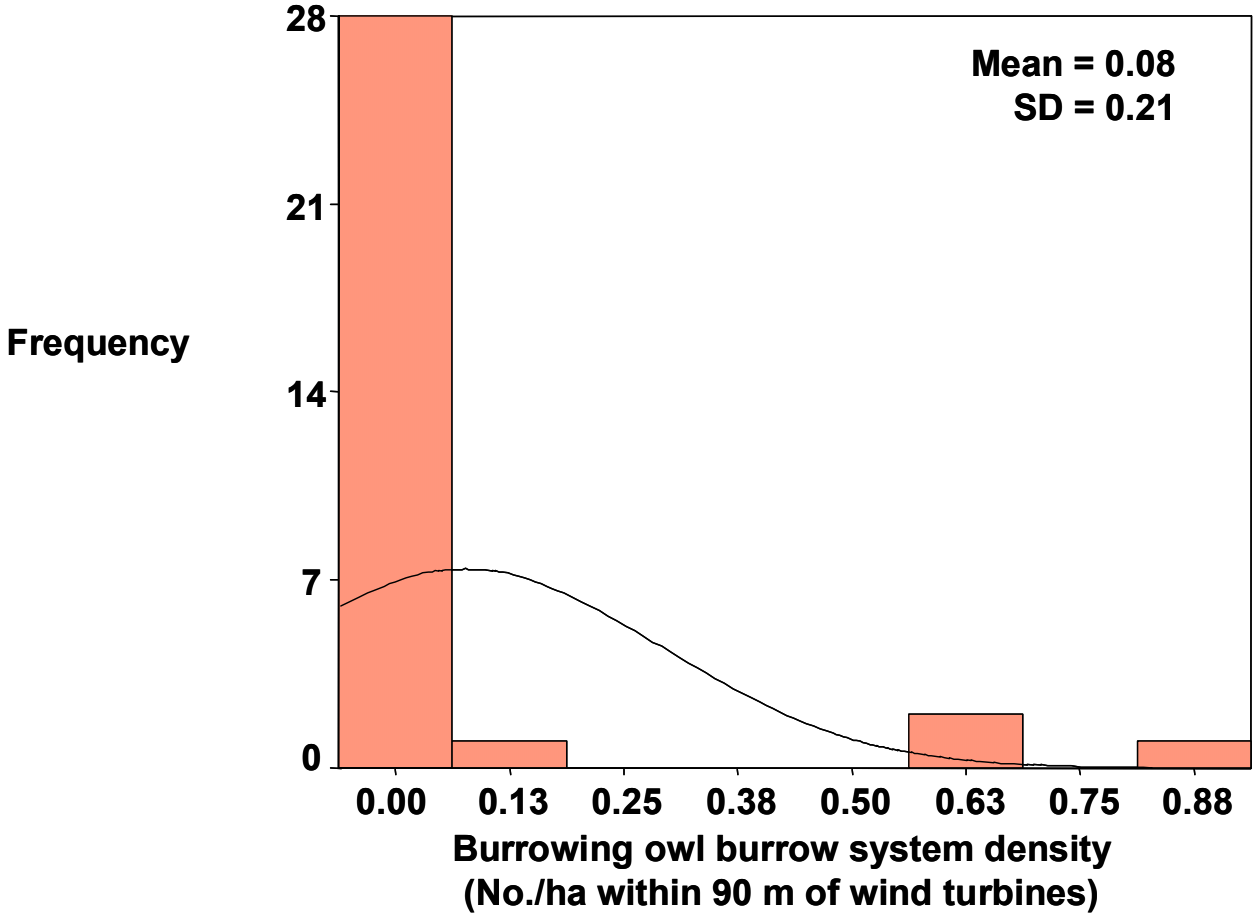


Figure 6-3. Frequency distribution of the density of burrowing owl burrows within 90 m of wind turbines

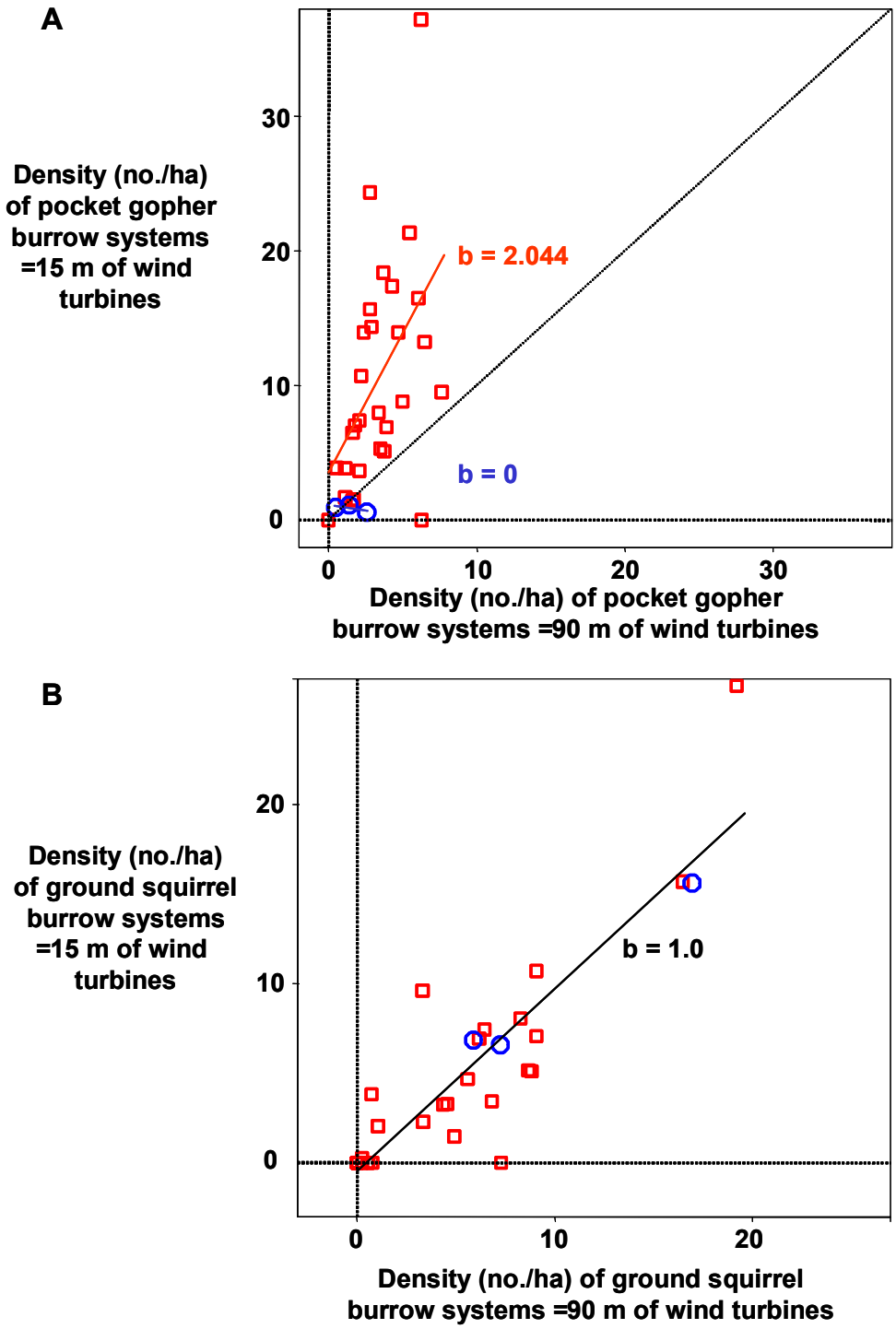


Figure 6-4. Density of burrow systems within 15 m of wind turbines related to density within 90 m for pocket gophers (A) and ground squirrels (B), illustrating the pocket gopher's greater affinity for the areas immediately next to the wind turbines. Blue circles denote the areas of no rodent control, and red squares denote the areas of rodent control. The letter "b" denotes the slope coefficient estimated by least-squares linear regression analysis.

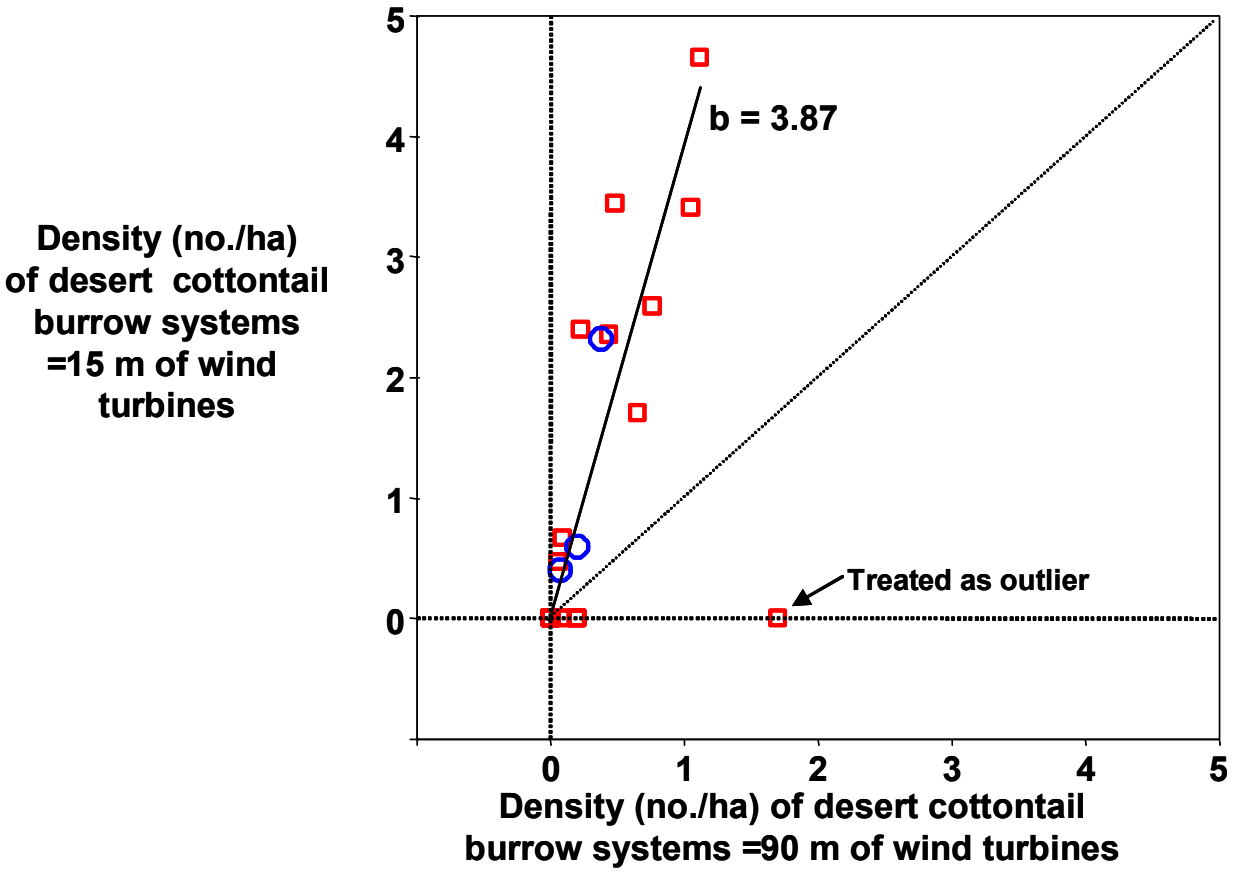


Figure 6-5. Density of desert cottontail burrow systems within 15 m of wind turbines related to density within 90 m. Blue circles denote the areas of no rodent control, and red squares denote the areas of rodent control. The letter "b" denotes the slope coefficient estimated by least-squares linear regression analysis.

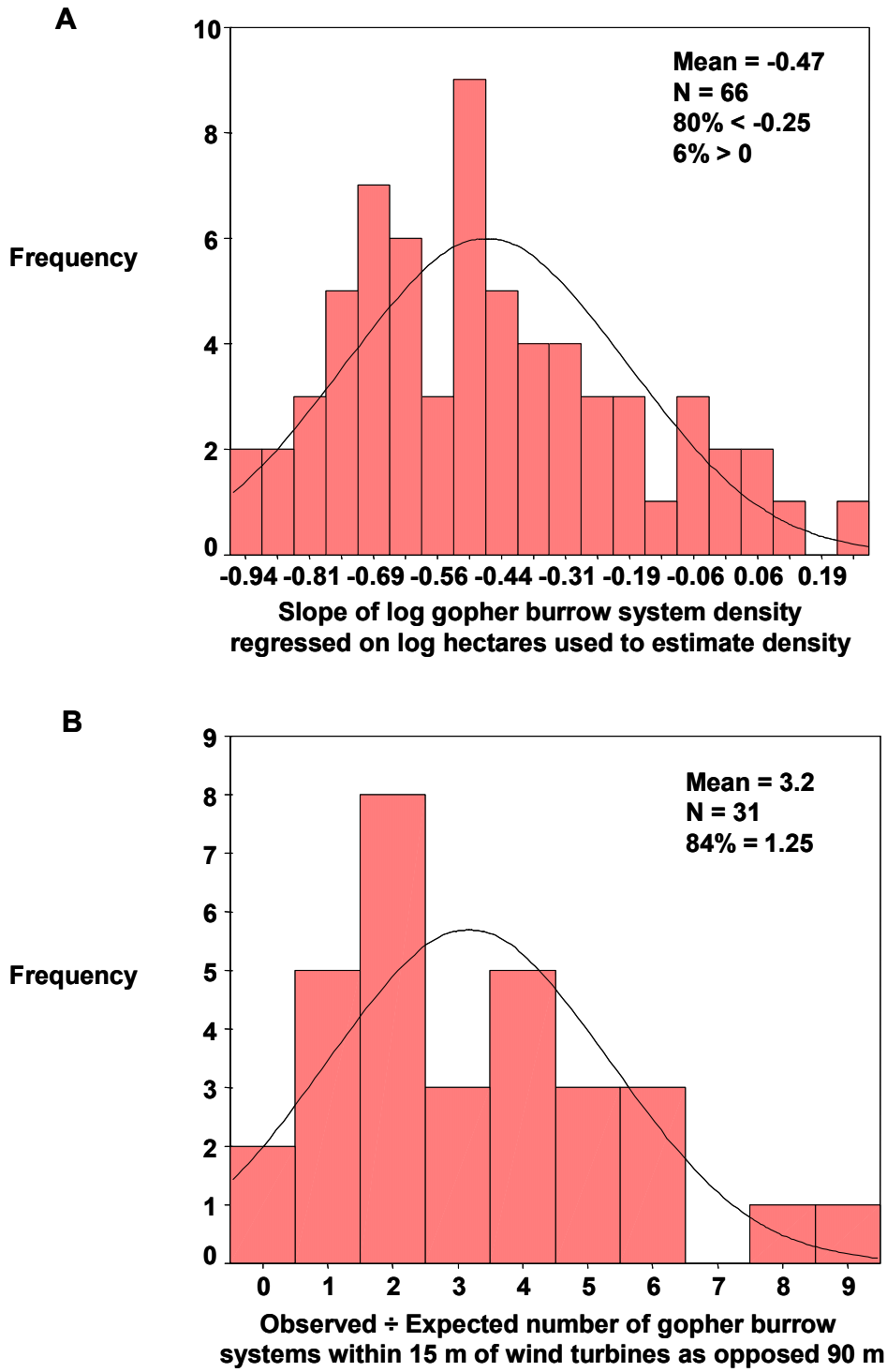


Figure 6-6. Frequency distributions of the degree of clustering of pocket gopher burrow systems at wind turbines represented by (A) the slope of log density regressed on log search area around each wind turbine string, and (B) the observed ÷ expected number of burrow systems within 15 m of the wind turbines, where strings of wind turbines were combined into groups when contiguous and mapped during the same year and season.

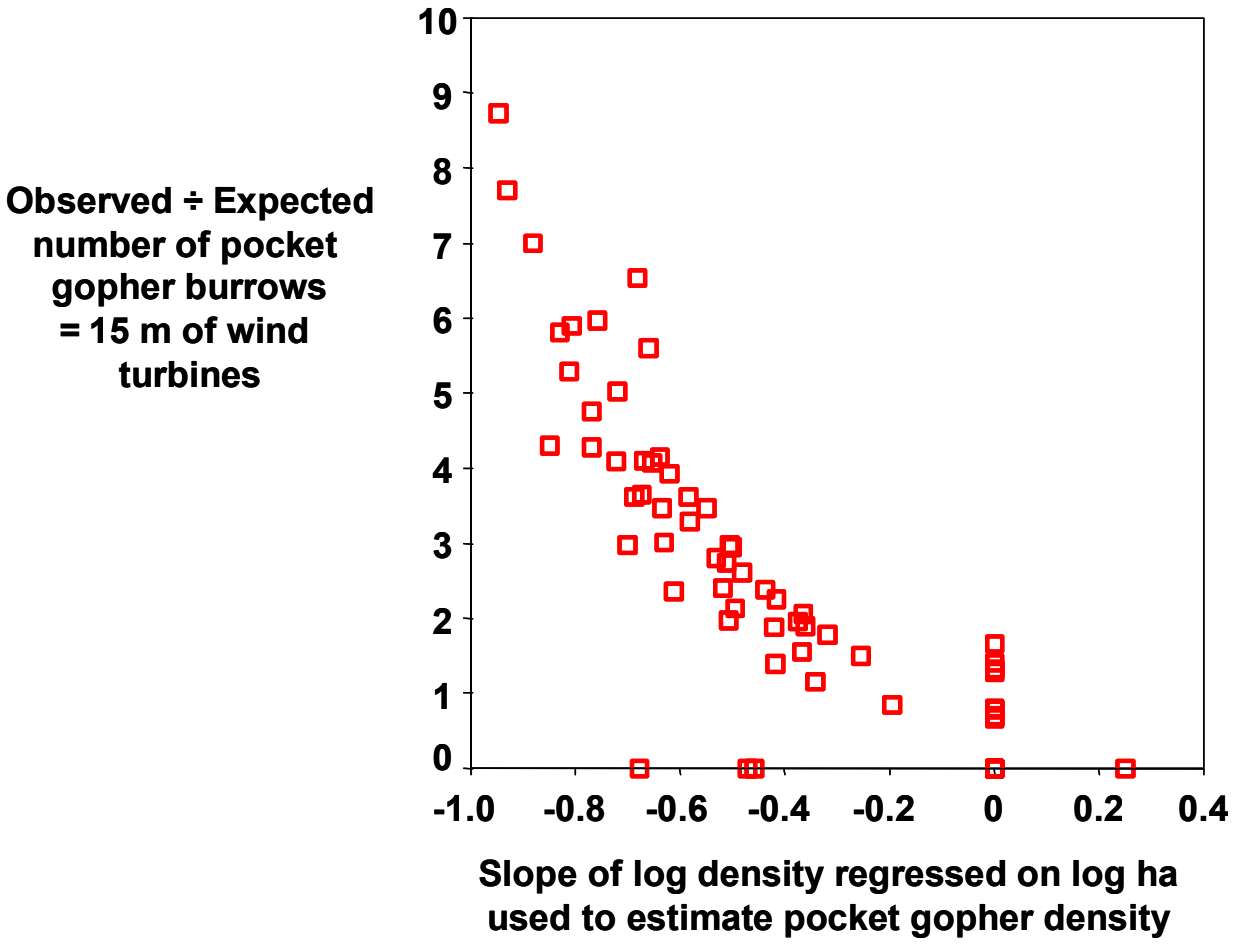


Figure 6-7. Relationship between two methods of characterizing the degree of clustering of burrow systems at wind turbines

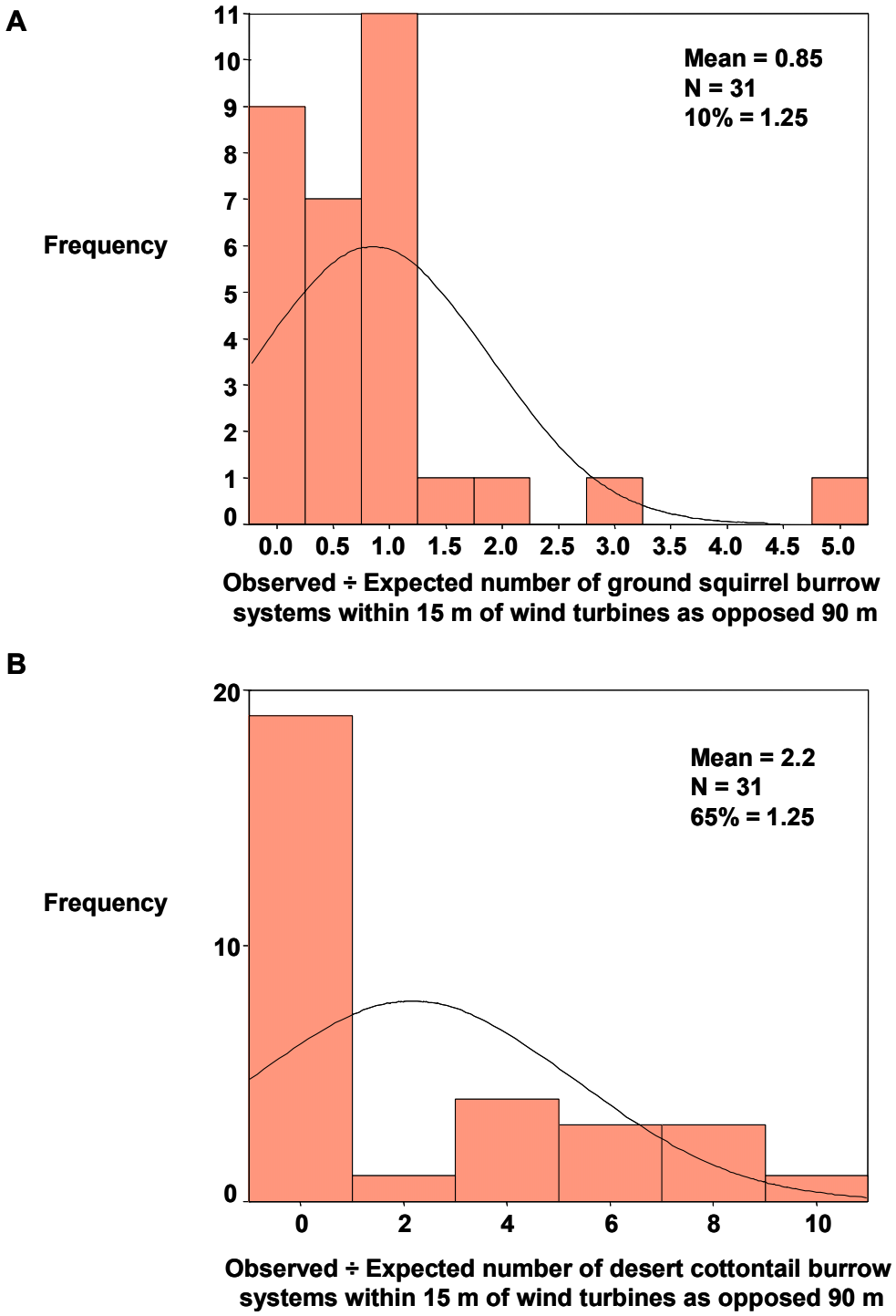


Figure 6-8. Frequency distributions of the degree of clustering of ground squirrel (A) and desert cottontail (B) burrow systems around wind turbines

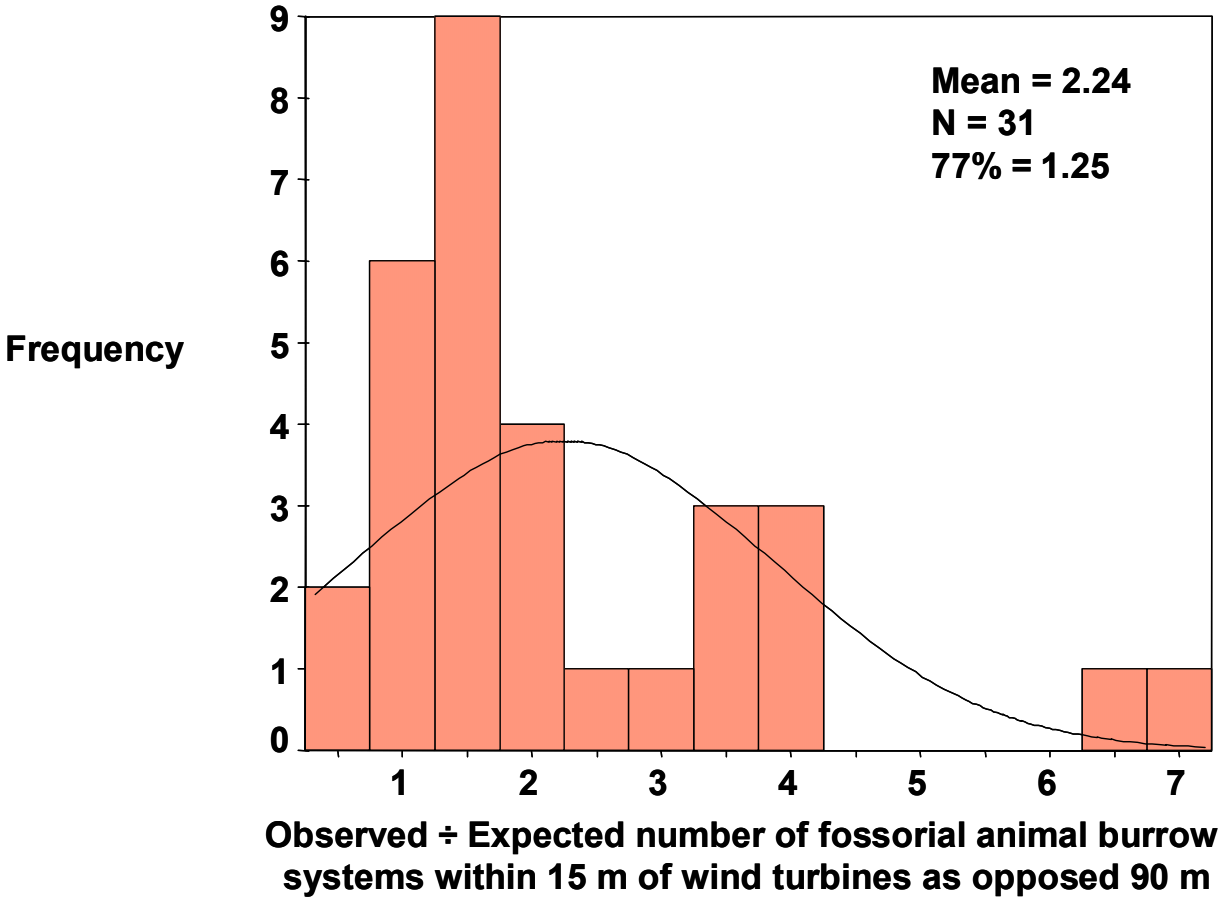


Figure 6-9. Frequency distribution of the degree of clustering of burrow systems of all fossorial mammals species around wind turbines

6.3.2 Seasonal and Inter-annual Variation in Distribution and Abundance

Eleven strings of wind turbines were selected for seasonal monitoring purposes, ten of which were on lands where rodenticide was applied in moderate intensity and one of which was on property where rodenticide was applied intensively. These wind turbine strings were grouped into eight groups (Figure 6-10), and for each group the seasonal distributions of burrow systems are shown in Figures 6-12, 6-14, 6-16, 6-18, 6-20, 6-22, 6-24, and 6-26. Each of these Figures is preceded by photographic representations of the conditions at the monitoring site (Figures 6-11, 6-13, 6-15, 6-17, 6-19, 6-21, 6-23, and 6-25).

The observed-to-expected ratio of pocket gopher burrow systems within 15 m of wind turbines differed significantly by season (ANOVA $F = 6.83$; $df = 3, 42$; $P < 0.001$). According to post-hoc LSD tests, this ratio was significantly less during winter, when it averaged slightly greater than zero (Figure 6-27A). Pocket gopher clustering at wind turbines did not differ significantly between spring, summer, and fall.

The observed-to-expected ratio of ground squirrel burrow systems within 15 m of wind turbines also differed significantly by season (ANOVA $F = 4.57$; $df = 3, 42$; $P < 0.010$). According to post-hoc LSD tests, this ratio was significantly greater during summer when it averaged 0.90 (Figure 6-27B). Ground squirrel avoidance of wind turbines did not differ significantly between winter, spring, and fall. Ground squirrels appeared to avoid locating burrow systems within 15 m of turbines during all seasons.

The density of pocket gopher burrow systems out to 90 m from wind turbines did not differ significantly among dates between summer 1999 and fall 2001 (ANOVA $F = 2.00$; $df = 4, 41$; $P = 0.114$). However, during this time period the density of ground squirrel burrow systems out to 90 m from wind turbines increased by 0.687 burrow systems per hectare (ha) per season (linear regression, ANOVA $F = 6.74$; $df = 1, 41$; $P < 0.050$). Figure 6-28 illustrates the difference in trends between pocket gopher and ground squirrel burrow system density out to 90 m from wind turbines.

6.3.3 Associations with Wind Turbine String Attributes and Range Management

The degree of clustering of pocket gophers within 15 m of wind turbines tended to differ significantly based on the intensity of rodent control implemented in the area (ANOVA $F = 2.88$; $df = 2, 30$; $P = 0.073$) (Figure 6-29). Based on post-hoc LSD tests, it was significantly less ($P = 0.048$) on areas without rodent control ($\bar{x} = 1.07$) compared to intermittent control ($\bar{x} = 3.67$).

In the rodent control areas, pocket gopher clustering at wind turbines varied significantly by slope aspect (ANOVA $F = 5.64$; $df = 5, 53$; $P < 0.001$), with the greatest degrees of clustering on west and southwest-facing slopes, followed by northwest-facing slopes (Table 6-1). Pocket gopher clustering at wind turbines did not vary significantly by slope aspect in the areas where rodents were not controlled (ANOVA $F = 0.62$; $df = 3, 14$; $P = 0.620$).

Figure 6-10. Locations of groups of wind turbines monitored for burrow system distributions by season during 2001 and 2002 Numbers correspond with the eight monitoring groups of turbines.

A

B

Figure 6-11. Wind turbine monitoring Group 1 viewed from the south (A) and from the northern aspect of the wind turbines toward the south (B)

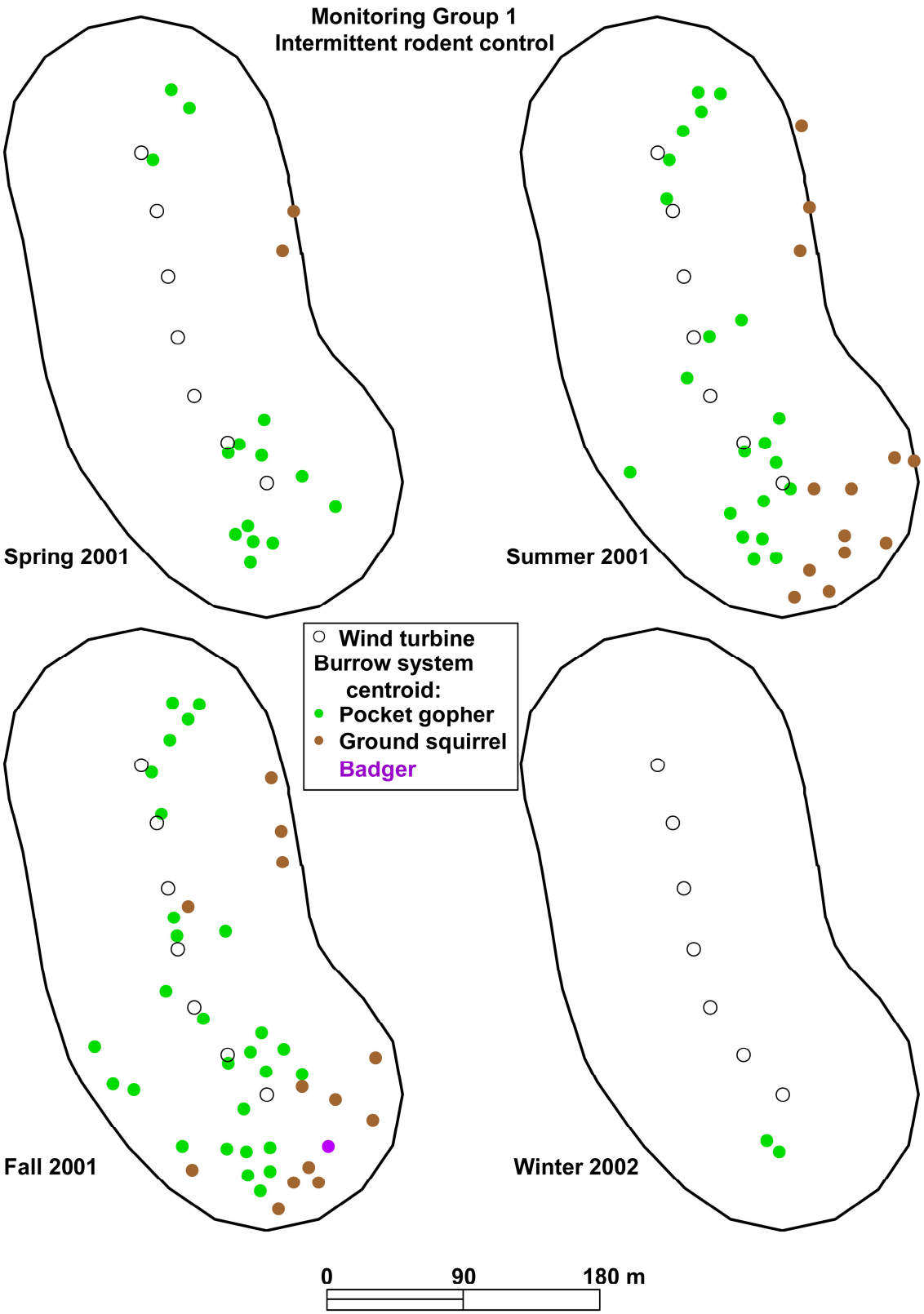


Figure 6-12. Seasonal distribution of burrow systems around wind turbine monitoring Group 1

Figure 6-13. Wind turbine monitoring Group 2 viewed from its southern aspect

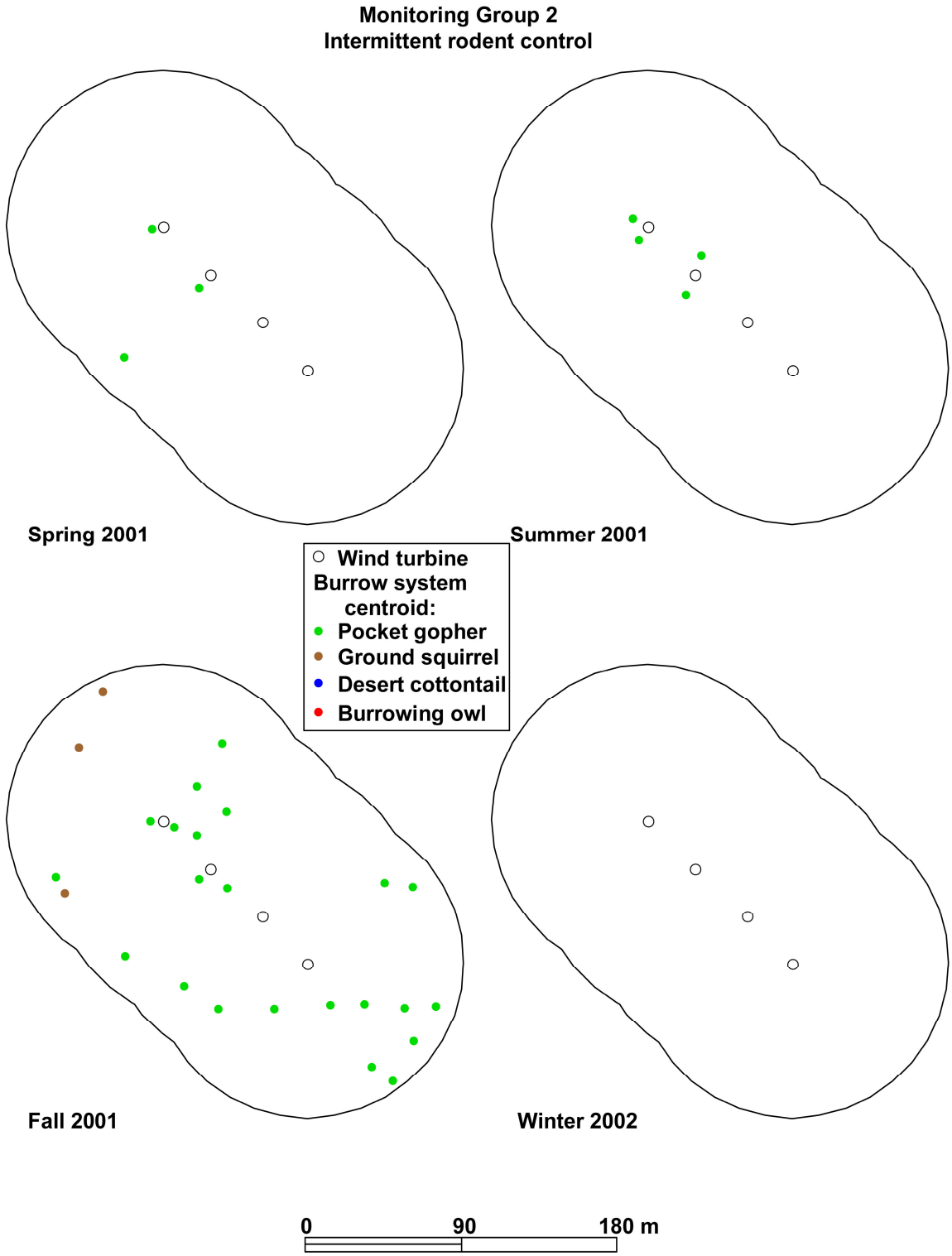


Figure 6-14. Seasonal distribution of burrow systems around wind turbine monitoring Group 2

Figure 6-15. Wind turbine monitoring Group 3 viewed from the north

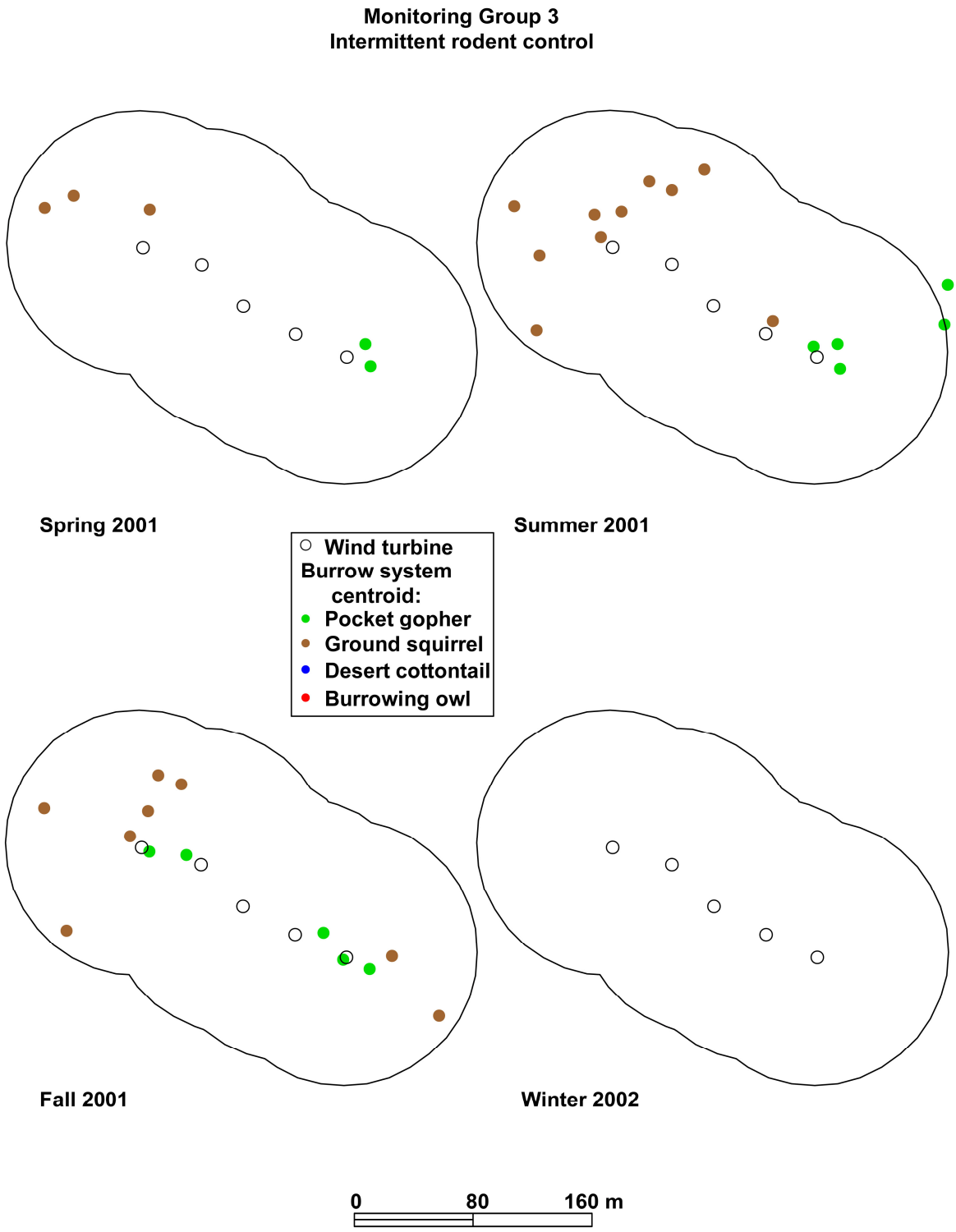


Figure 6-16. Seasonal distribution of burrow systems around wind turbine monitoring Group 3

Figure 6-17. Wind turbine monitoring Group 4 viewed north from the southern aspect of the wind turbines

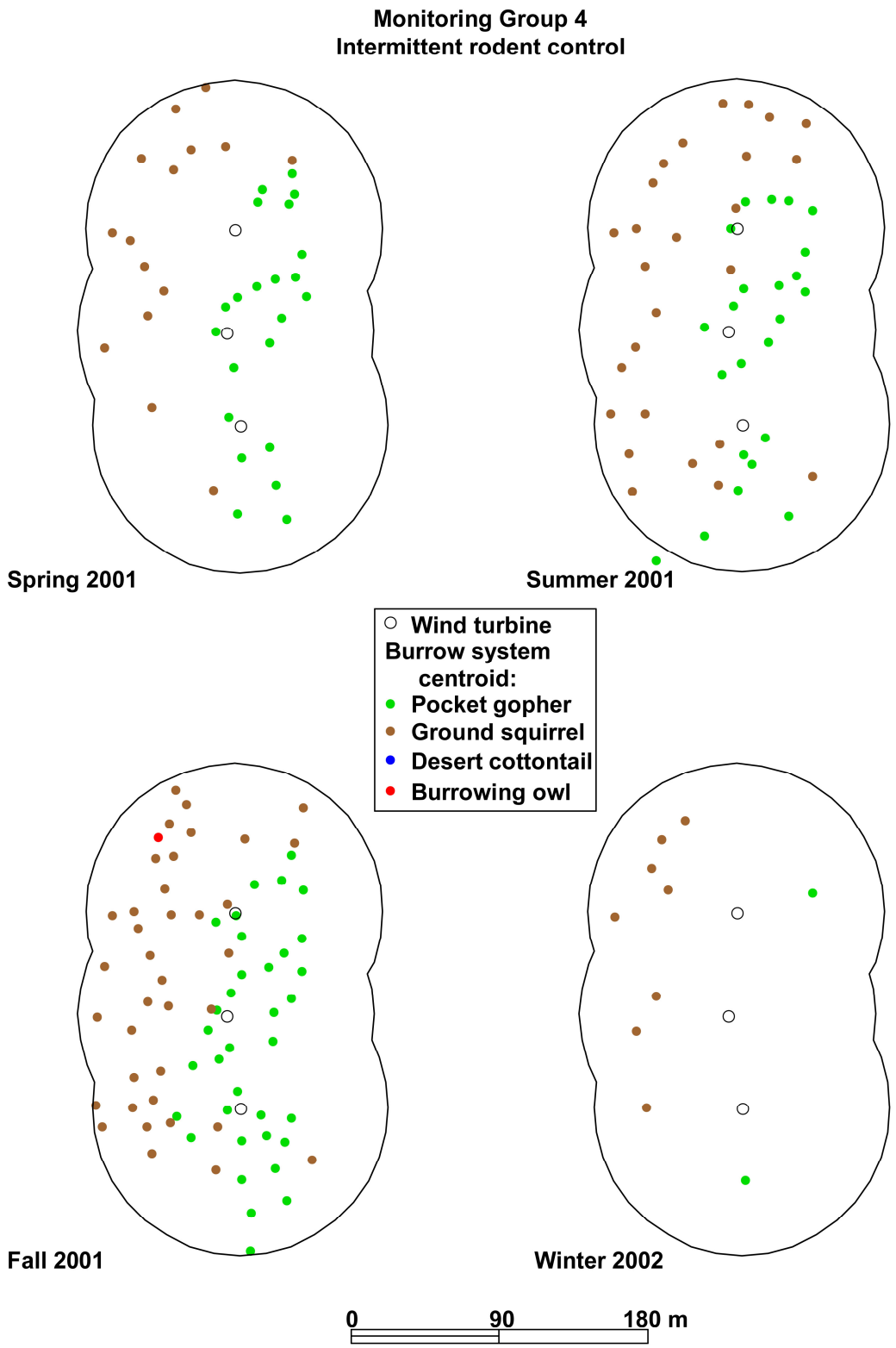


Figure 6-18. Seasonal distribution of burrow systems around wind turbine monitoring Group 4

Figure 6-19. Wind turbine monitoring Group 5 viewed north from the southern aspect of the wind turbines

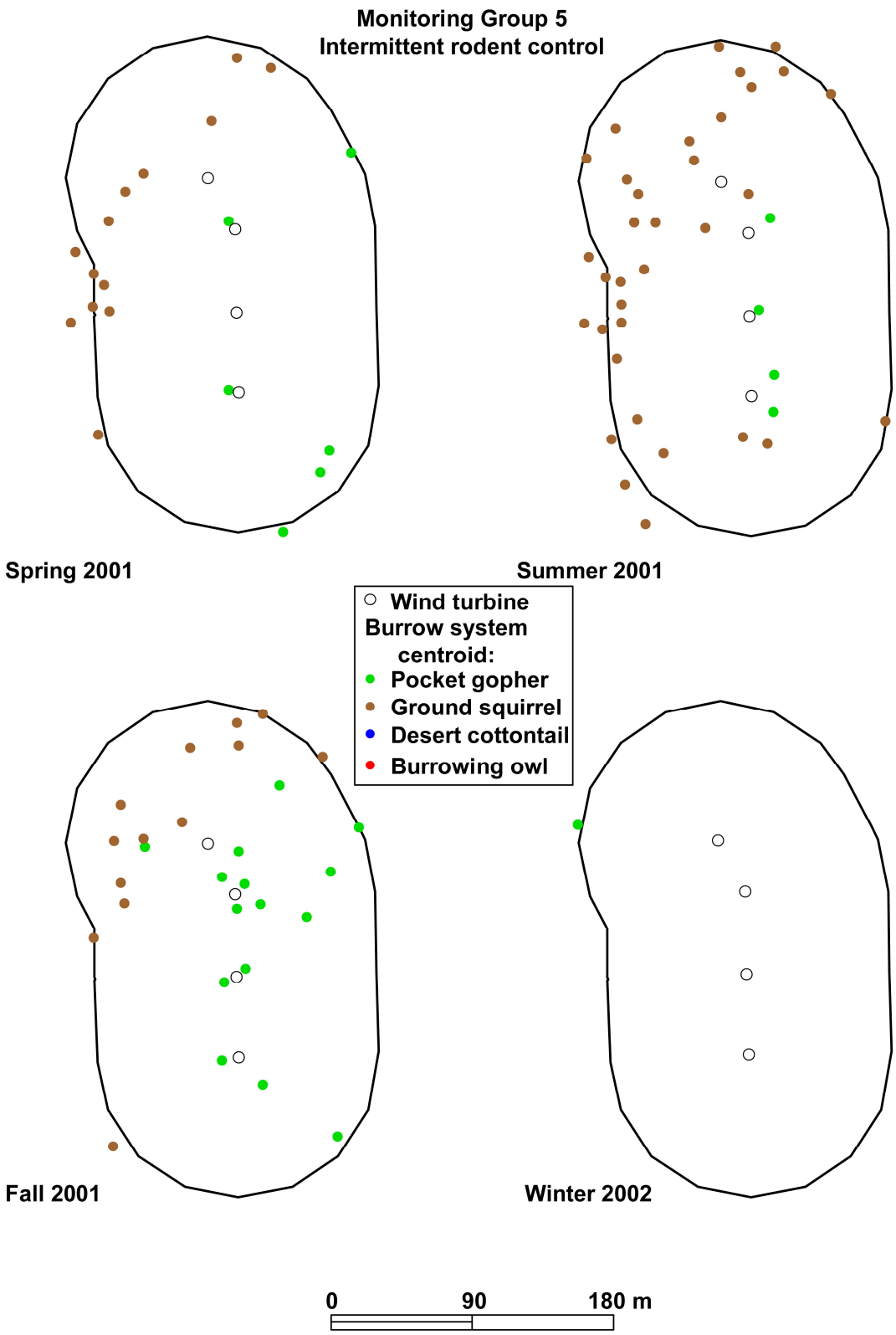


Figure 6-20. Seasonal distribution of burrow systems around wind turbine monitoring Group 5

A

B

Figure 6-21. Wind turbine monitoring Group 6 viewed south from the middle of the eastern row (A) and north from the middle of the western row (B)

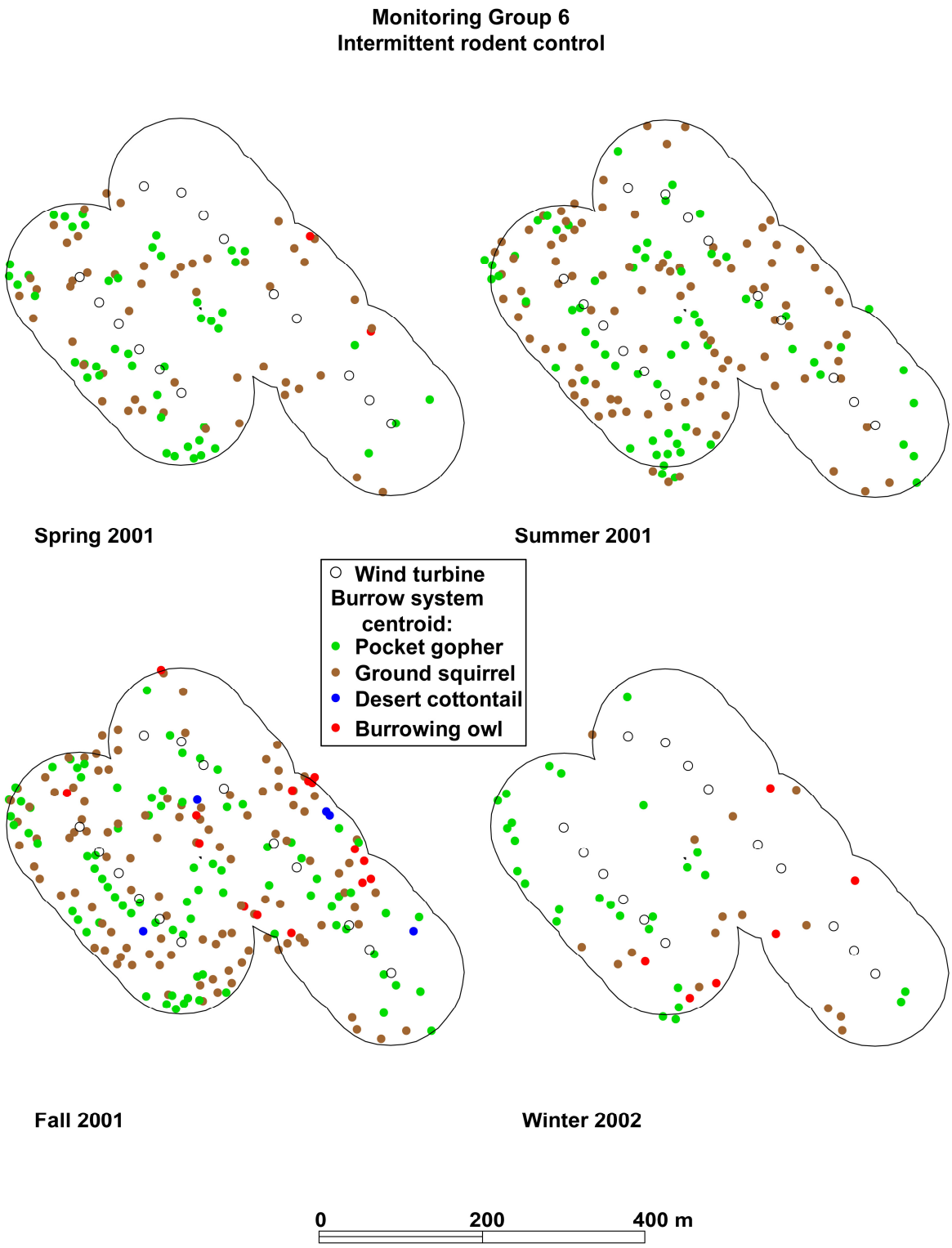


Figure 6-22. Seasonal distribution of burrow systems around wind turbine monitoring Group 6

Figure 6-23. Wind turbine monitoring Group 7 viewed north from the southern aspect of the wind turbines

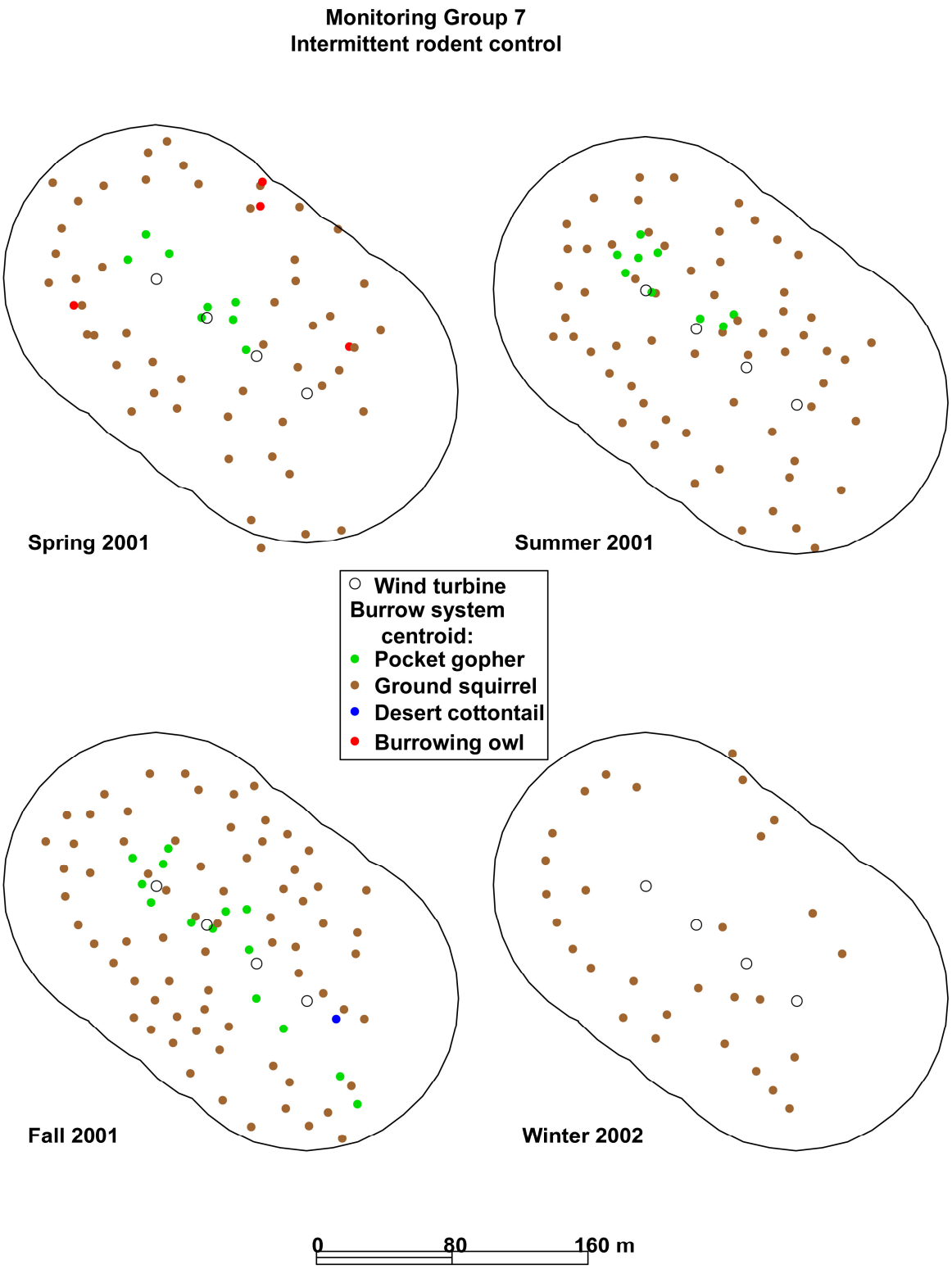


Figure 6-24. Seasonal distribution of burrow systems around wind turbine monitoring Group 7

A

B

Figure 6-25. Wind turbine monitoring Group 8 viewed south from the middle of the row (A) and north from the middle of the row (B). The large wind turbines in the foreground of photo B were non-operational throughout our study.

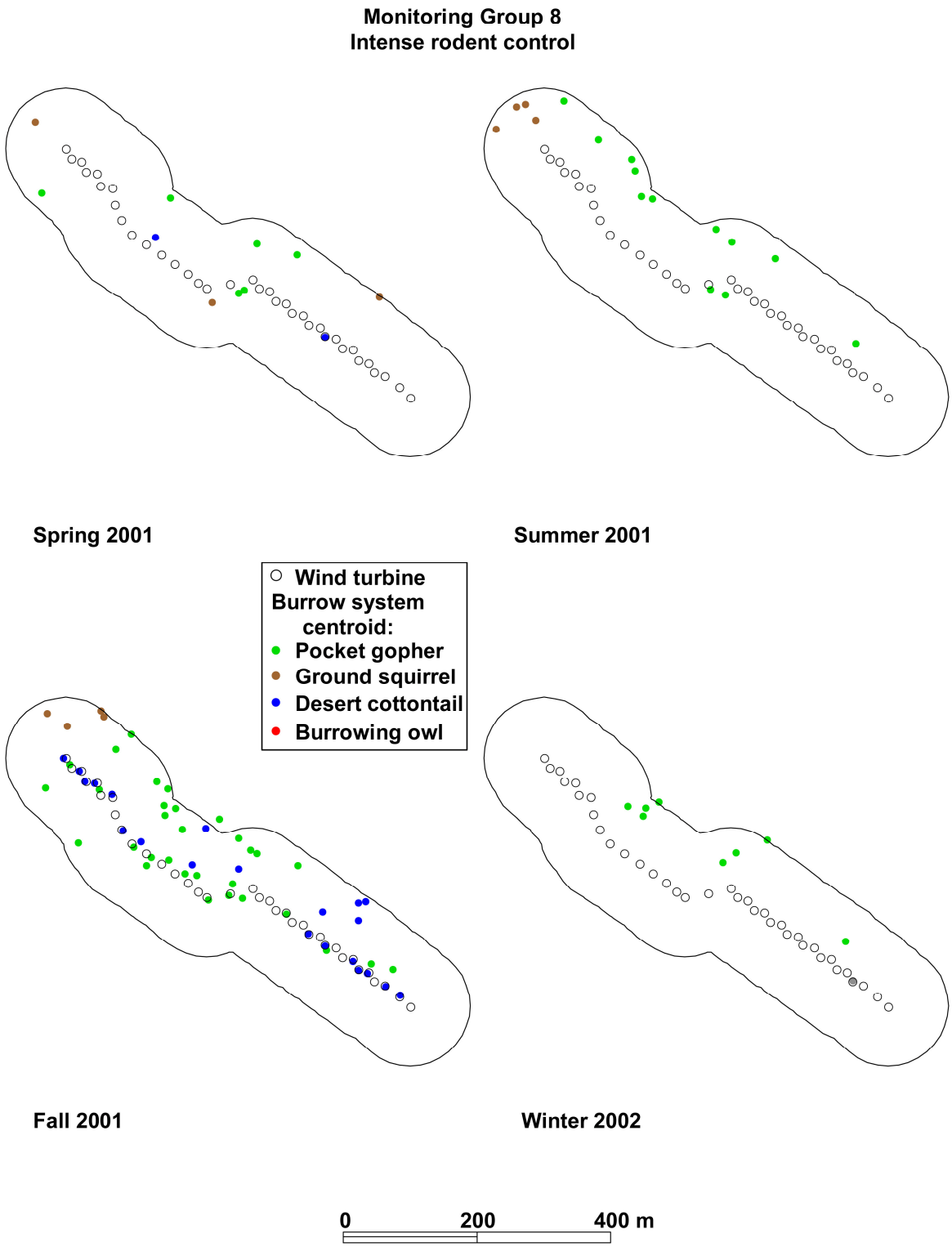


Figure 6-26. Seasonal distribution of burrow systems around wind turbine monitoring Group 8

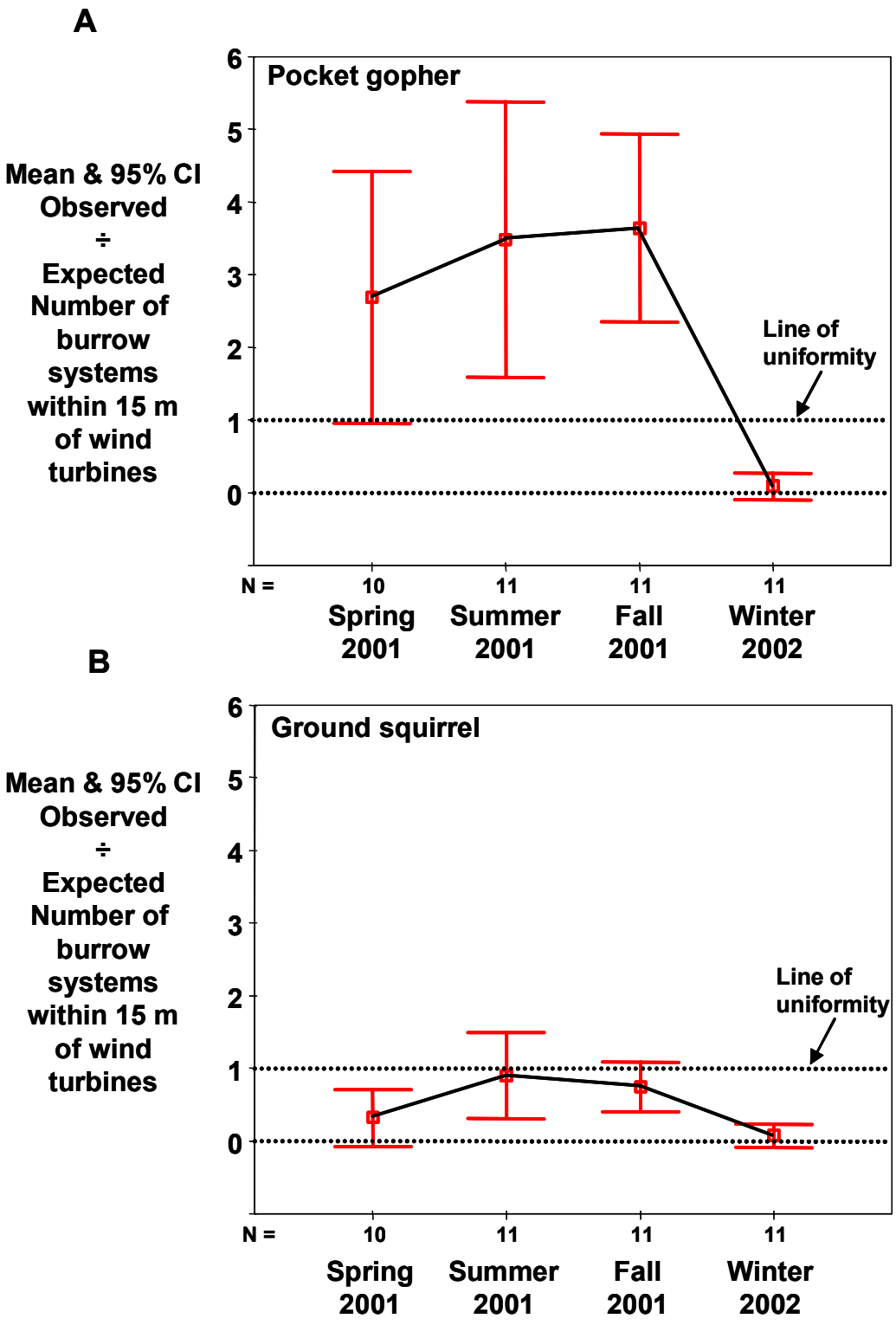


Figure 6-27. Seasonal pattern of the degree of clustering of burrow systems at wind turbines for (A) pocket gopher and (B) ground squirrel

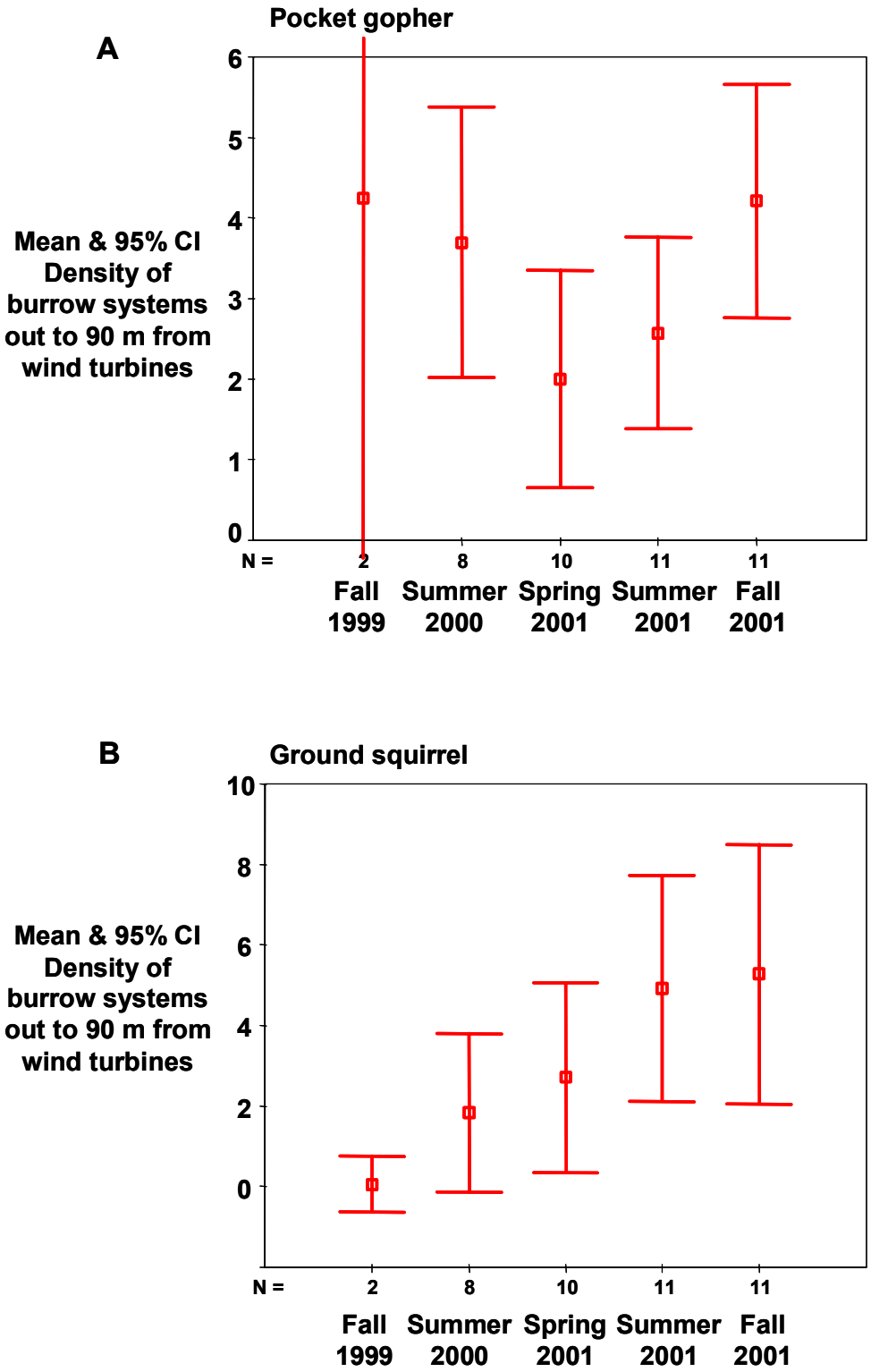


Figure 6-28. Trends through the study in density of burrow systems out to 90 m from wind turbines for (A) pocket gophers and (B) ground squirrels

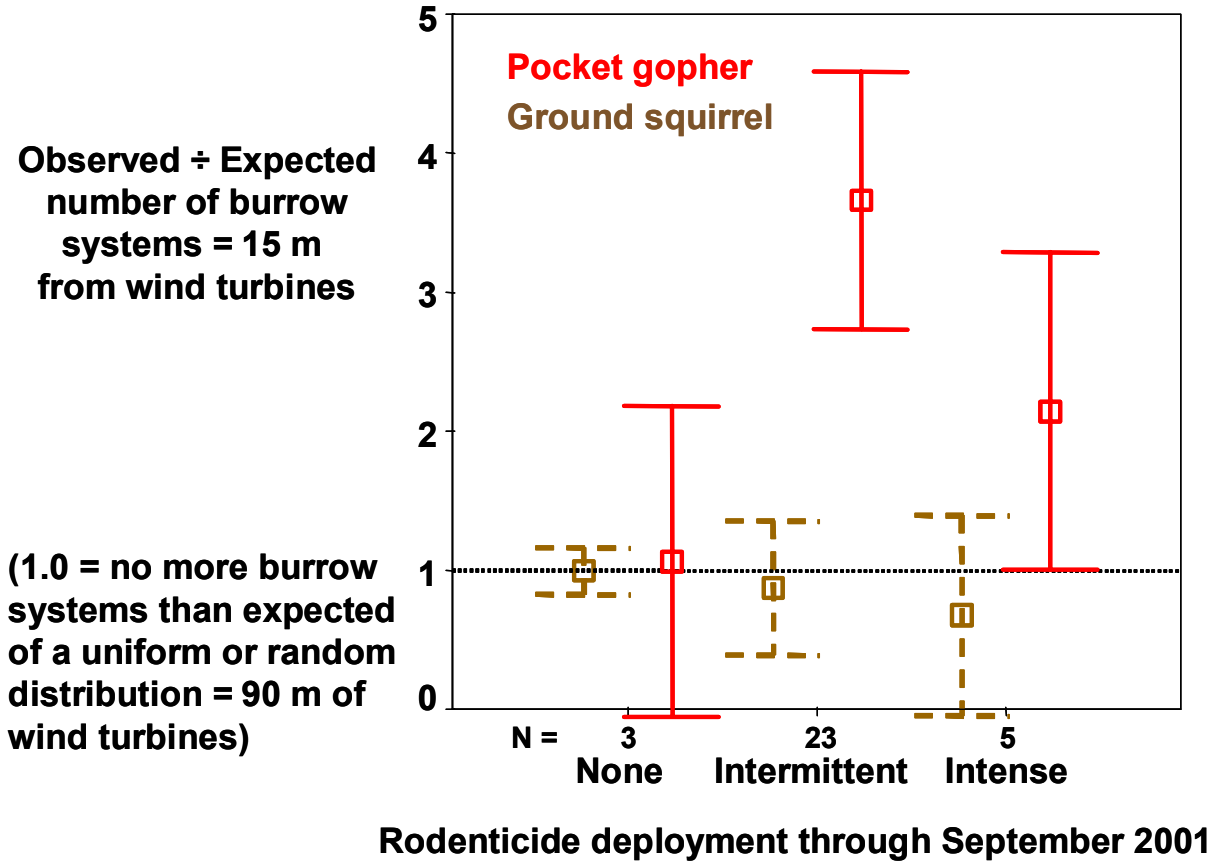


Figure 6-29. Relationship between degree of clustering of pocket gopher and ground squirrel burrow systems around wind turbines and the intensity of rodent control applied in the area

The degree of pocket gopher clustering at wind turbines did not vary significantly with physical relief, where relief was categorized as plateaus, slopes, and ridges (ANOVA F = 0.74; df = 2, 68; P = 0.479). It also did not vary significantly with relief within the areas of rodent control (ANOVA F = 0.07; df = 2, 53; P = 0. 929). It correlated positively with the average change in elevation per wind turbine in the string of wind turbines ($r_p = 0.27$, n = 69, $P < 0.05$), and with the percentage of the string in a canyon ($r_p = 0.36$, n = 69, $P < 0.001$). It did not correlate significantly with the average edge index in the string. It correlated positively with the average number of cattle pats per wind turbine along the turbine string ($r_p = 0.51$, n = 69, $P < 0.001$) and 20–40 m away ($r_p = 0.49$, n = 69, $P < 0.001$), but negatively with the index of the abundance of cottontail fecal pellets along the turbine string ($r_p = -0.32$, n = 69, $P < 0.001$) and 20–40 m away ($r_p = -0.32$, n = 69, $P < 0.001$).

Table 6-1. Mean comparison (ANOVA) of observed ÷ expected number of gopher burrow systems in areas treated with rodenticide

Aspect	N	Mean	SD	LSD test, P < 0.05
Flat	10	2.48	2.04	
Over hill or ridge	10	3.44	1.88	
East, Northeast	12	1.60	1.40	
Southeast, South	6	3.82	2.10	
Southwest, West	2	10.27	9.87	> all other aspects
Northwest, North	14	4.27	1.97	>East Northeast

Ground squirrel burrows did not cluster at wind turbines to the degree that pocket gopher burrow systems did, and they did not differ significantly according to intensity of rodent control (ANOVA F = 0.10; df = 2, 30; P = 0.905) (Figure 6-29). Ground squirrels did not cluster around the wind turbines (Figures 6-8A and 6-12), which means they did not cluster around the access roads and cuts into the hillsides made for wind turbine laydown areas.

The degree of ground squirrel clustering at wind turbines correlated inversely with increasing elevation (r_p = -0.32, n = 69, P < 0.001). It correlated positively with the mean number of cattle pats per wind turbine along the string of wind turbines (r_p = 0.34, n = 69, P < 0.001). Increased rodent control intensity appeared to increase the variation in the degree of ground squirrel clustering at wind turbines (Figure 6-29).

Alternatively, the degree of clustering of desert cottontail burrows at wind turbines was greater than it was for ground squirrels, and it differed significantly according to level of rodent control intensity (ANOVA F = 4.175; df = 2, 30; P = 0.026) (Figure 6-30). Based on post-hoc LSD tests, it tended to be greater (P = 0.054) in areas lacking rodent control ($\bar{x}$ = 4.82) compared to those with intermittent control ($\bar{x}$ = 1.29), and significantly greater in areas of intense control ($\bar{x}$ = 4.59) compared to intermittent control.

The degree of clustering of all fossorial animal burrows at wind turbines did not differ significantly according to level of rodent control intensity (ANOVA F = 0.847, df = 2, 30, P = 0.439) (Figure 6-31). No burrowing owl burrows were found within 15 m of wind turbines, so this species displayed no clustering at wind turbines and no variation in clustering according to rodent control intensity.

The density of pocket gopher burrow systems within 15 m of wind turbines differed significantly among areas of different intensities of rodent control (ANOVA F = 4.71; df = 2, 31; P < 0.05). Pairwise LSD post-hoc tests indicated pocket gopher density within 15 m of wind turbines was significantly greater in the areas of intermittent rodent control ($\bar{x}$ = 11.9 burrows/ha) than in the areas of no control ($\bar{x}$ = 0.9 burrows/ha) and intense control ($\bar{x}$ = 4.0 burrows/ha) (Figure 6-32A).

The density of pocket gopher burrow systems out to 90 m of wind turbines tended to differ between levels of rodent control (ANOVA F = 2.52; df = 2, 31; P < 0.10). Pairwise LSD post-hoc tests indicated it tended to be greater in the areas of intermittent control ($\bar{x}$ = 3.6 burrows/ha) than in areas of no control ($\bar{x}$ = 1.5 burrows/ha) (Figure 6-32B). Pocket gopher density in the

intermittently controlled area was more than twice that found on the areas with no rodent control, and within 15 m of wind turbines it was twelve times greater. Gopher burrow system density adjusted by the mean per rodent control intensity did not relate significantly to any other variables we measured on physiographic conditions or types of wind turbine.

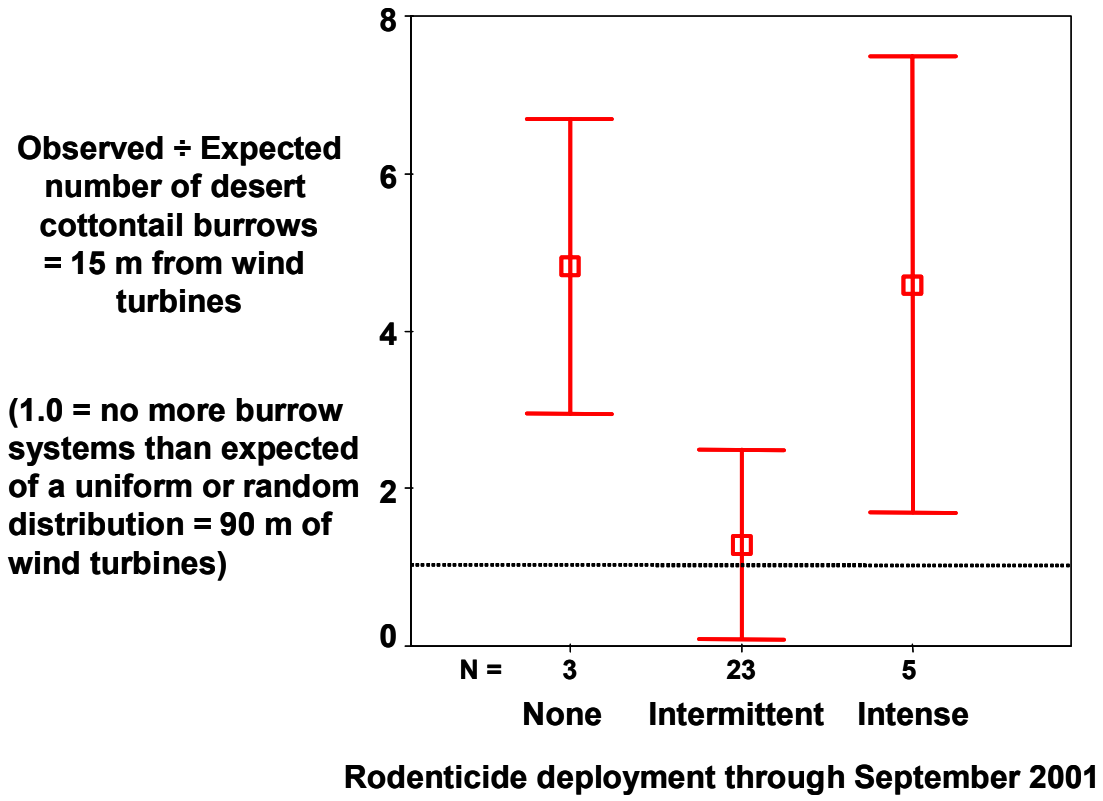


Figure 6-30. Relationship between degree of clustering of desert cottontail burrow systems around wind turbines and the intensity of rodent control applied in the area

The density of ground squirrel burrow systems within 15 m of wind turbines tended to differ between areas by rodent control intensity (ANOVA $F = 2.59$; $df = 2, 31$; $P < 0.10$). Pairwise LSD post-hoc tests indicated ground squirrel burrow system density within 15 m of the turbine was greatest where rodenticide was not deployed ($\bar{x} = 9.7$) and least where rodenticide was most intensely deployed ($\bar{x} = 1.0$) (Figure 6-32A).

The density of ground squirrel burrow systems within 90 m of wind turbines differed significantly among areas of different rodent control intensity (ANOVA $F = 3.38$; $df = 2, 31$; $P < 0.05$). Pairwise LSD post-hoc tests indicated ground squirrel burrow system density within 90 m was greatest where rodenticide was not deployed ($\bar{x} = 10.0$) and least where rodenticide was most intensely deployed ($\bar{x} = 1.5$) (Figure 6-32B).

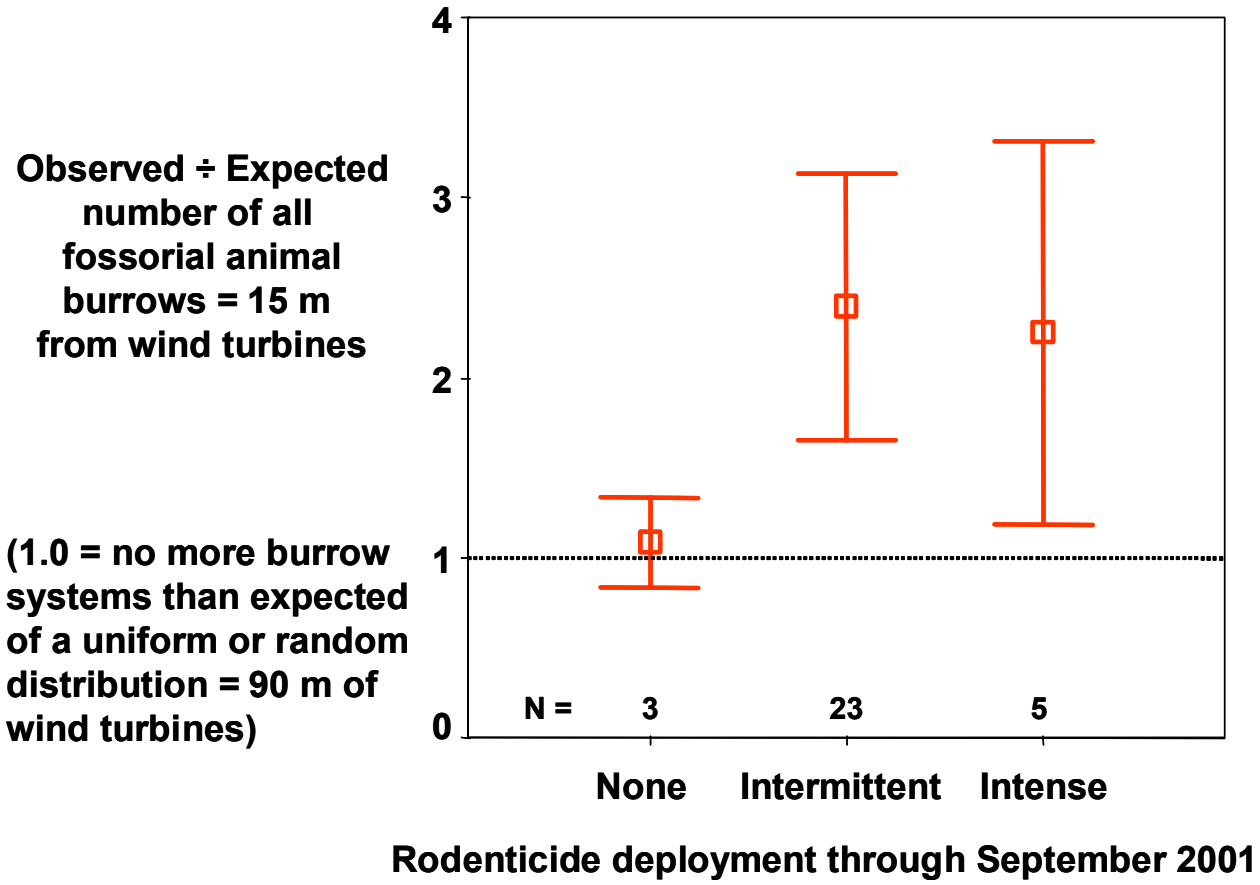


Figure 6-31. Relationship between degree of clustering of burrow systems of all fossorial mammal species around wind turbines and the intensity of rodent control applied in the area

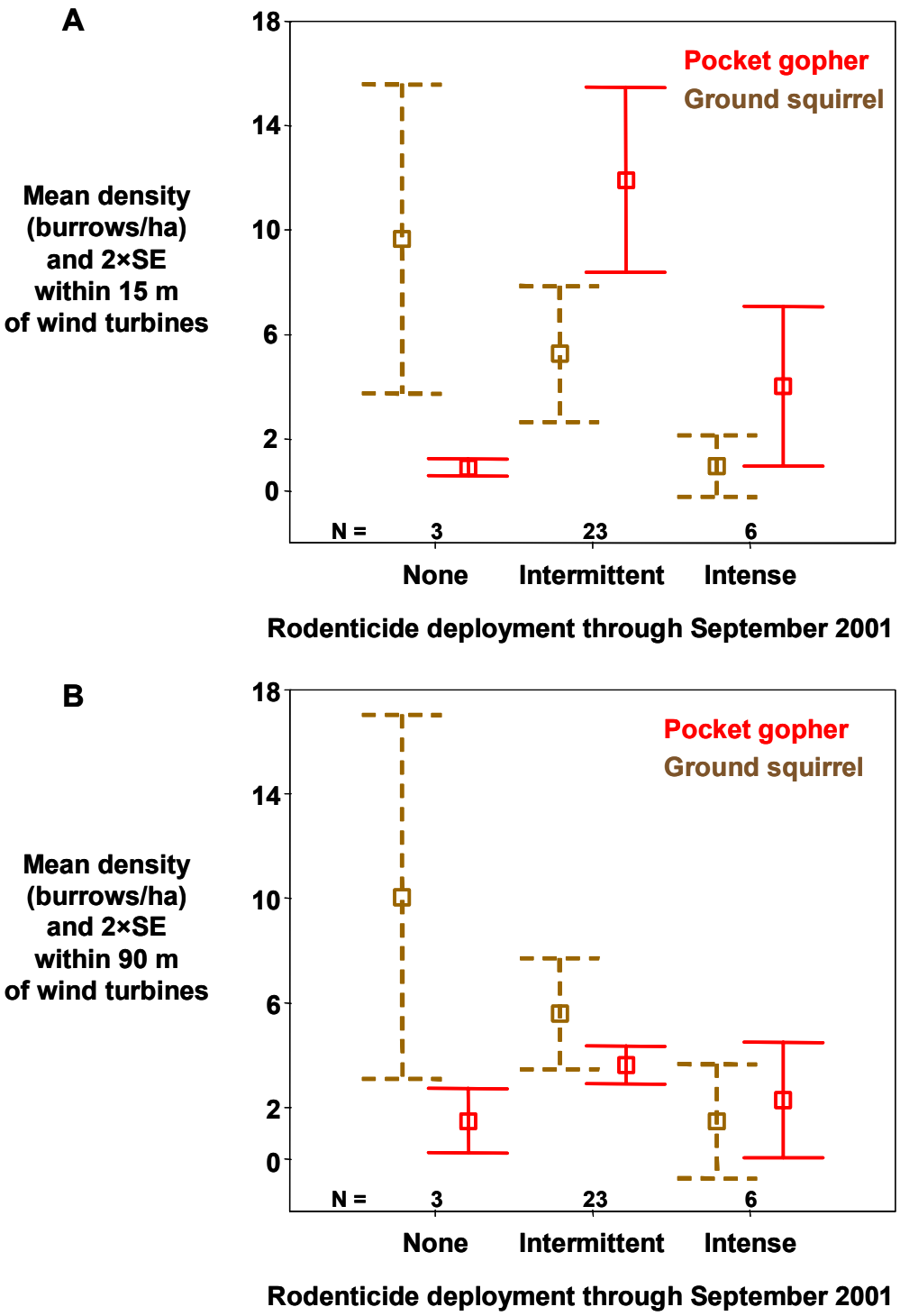


Figure 6-32. Relationship between mean density of pocket gopher and ground squirrel burrow systems within 15 m (A) and 90 m (B) of wind turbines and the intensity of rodent control applied in the area

Ground squirrel burrow system density in the intense rodent control areas averaged only 14% of the average density where no rodent control was implemented. Ground squirrel burrow system density adjusted by the mean per rodent control intensity did not relate significantly to any other variables we measured on physiographic conditions or turbine types.

Neither within 15 m or 90 m did the density of desert cottontail burrows differ significantly among levels of rodent control intensity.

The density of burrow systems of all species studied varied significantly by intensity of rodent control (ANOVA $F = 3.65$; $df = 2, 31$; $P < 0.05$), and post-hoc LSD tests suggested areas of intermittent control maintained higher densities of all fossorial animal species burrows ($\bar{x} = 9.6$) than did areas of intense control ($\bar{x} = 4.1$) (Figure 6-33). The density of burrow systems of all species studied tended to differ by intensity of rodent control (ANOVA $F = 3.04$; $df = 2, 31$; $P < 0.10$). Post-hoc LSD tests suggested areas of intense control ($\bar{x} = 4.3$) were significantly less dense than areas of intermittent control ($\bar{x} = 9.5$) or no control ($\bar{x} = 11.8$).

6.3.4 Relationships Between Raptor Mortality and Small Mammal Burrow Distributions

Figures 6-34 through 6-44 illustrate animal burrow distributions around some groups of wind turbines, as examples. Figures 6-34 through 6-36 depict the distributions of burrow systems of fossorial animals in some of the areas receiving no rodent control through 2001. Figures 6-37 through 6-41 depict burrow distributions in some of the areas treated intermittently with rodent poison during the entire study period and prior to the study. Figures 6-42 through 6-44 depict burrow distributions in some of the areas subjected to intense rodent abatement efforts during and preceding our study. Estimates of mortality generated for those groups of wind turbines in the figures are provided as examples of how mortality related to abatement efforts and resulting distributions of raptor prey species.

In areas of no rodent control through 2001, raptor mortality decreased, with increasing density of ground squirrel burrow systems within 90 m of wind turbines (Figure 6-45). In areas of intermittent control, raptor mortality did not relate significantly to ground squirrel burrow density, but in areas of intense control it increased rapidly with increasing ground squirrel density out to 90 m (Figure 6-45). These patterns were driven most strongly by red-tailed hawk and burrowing owl mortality. They were also evident when raptor mortality was compared to the density of ground squirrel burrow systems within 15 m of wind turbines (Figure 6-46); however, the regression slope estimated for the intensely controlled areas was steeper within this distance domain than it was for the 90-m radius.

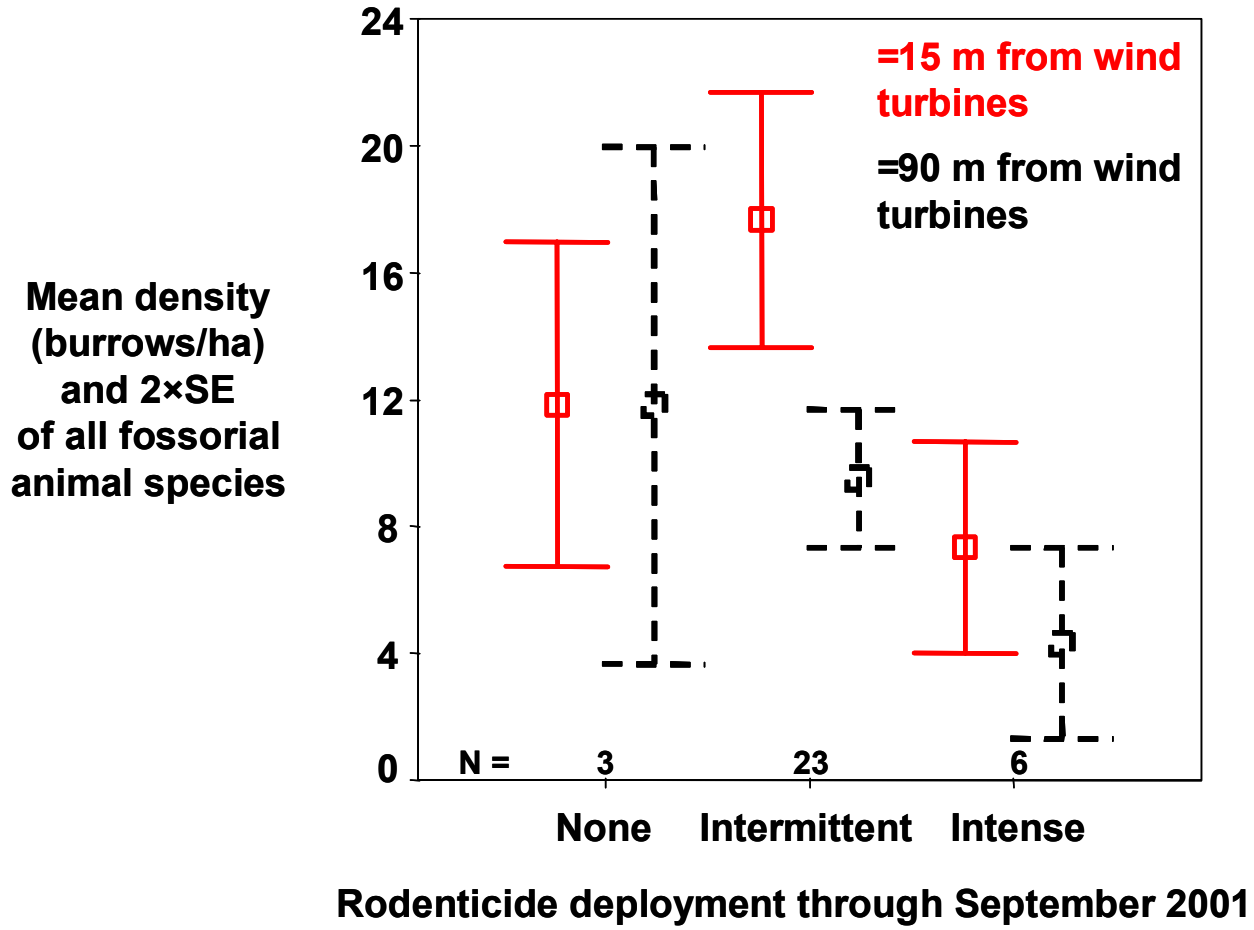


Figure 6-33. Relationship between mean density of burrow systems of all fossorial mammal species within 15 m and 90 m of wind turbines and the intensity of rodent control applied in the area

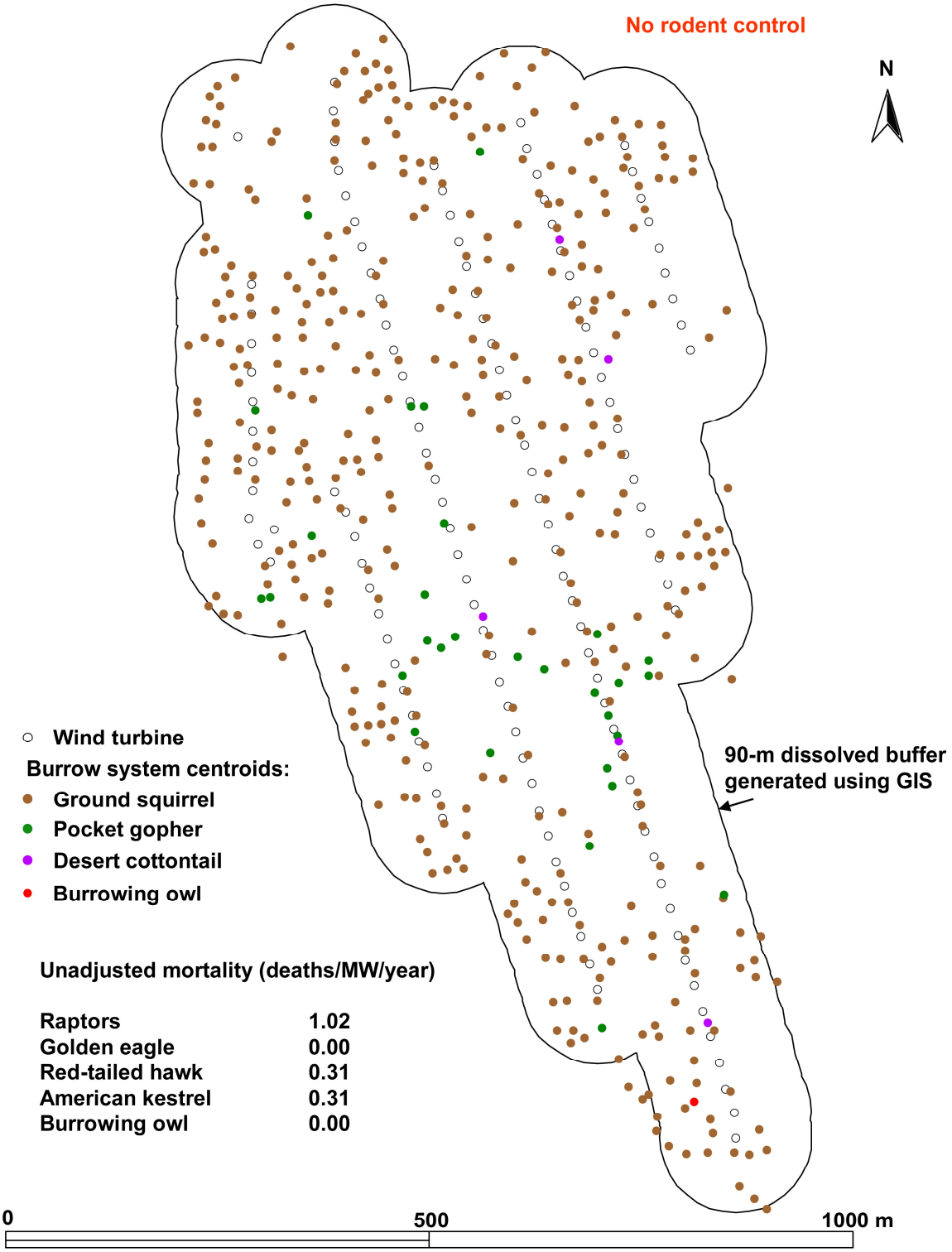


Figure 6-34. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the Mountain House area where rodent control was not applied until 2002

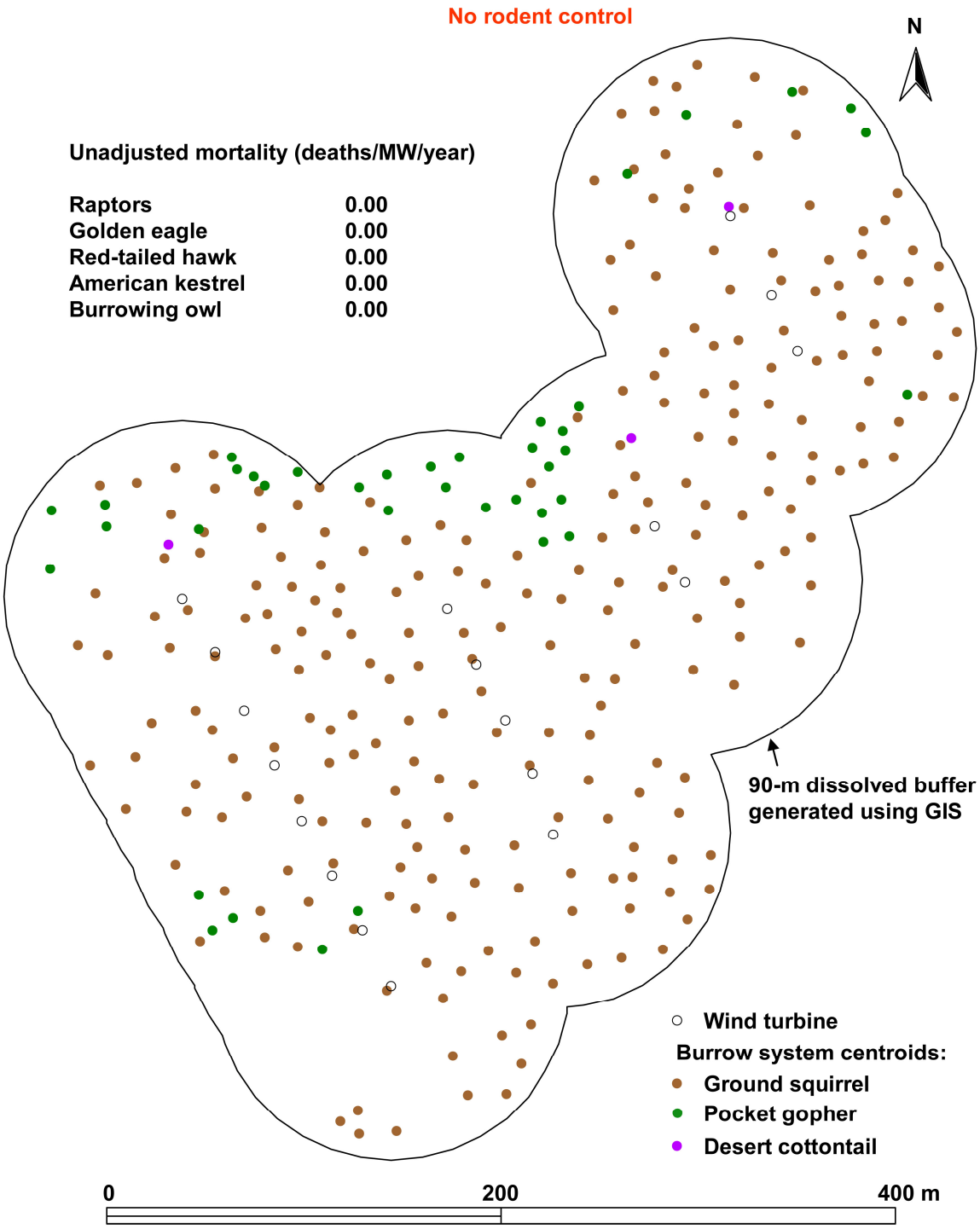


Figure 6-35. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the Midway area where rodent control was not applied until 2002

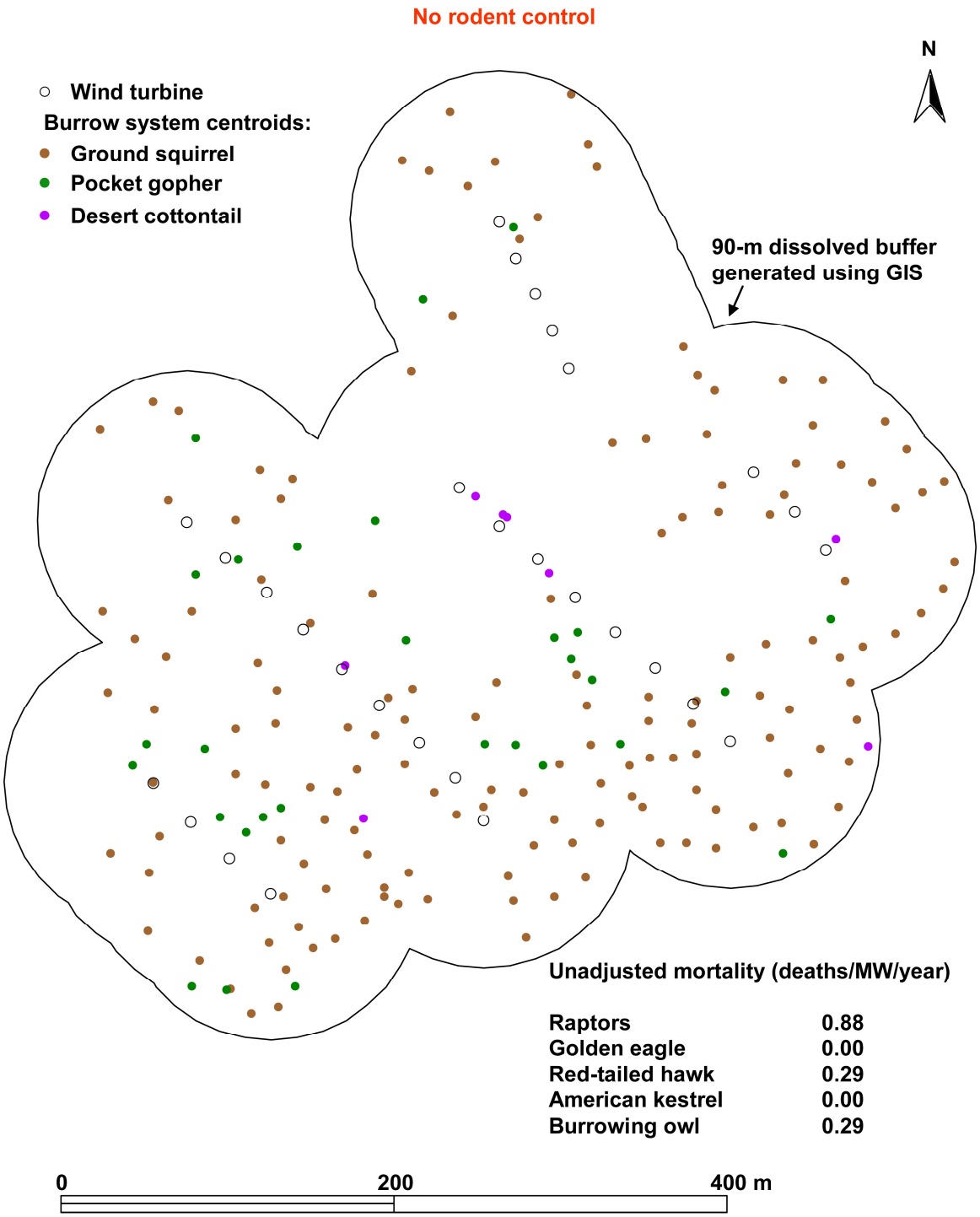


Figure 6-36. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the east-central area of the APWRA and where rodent control was not applied until 2002

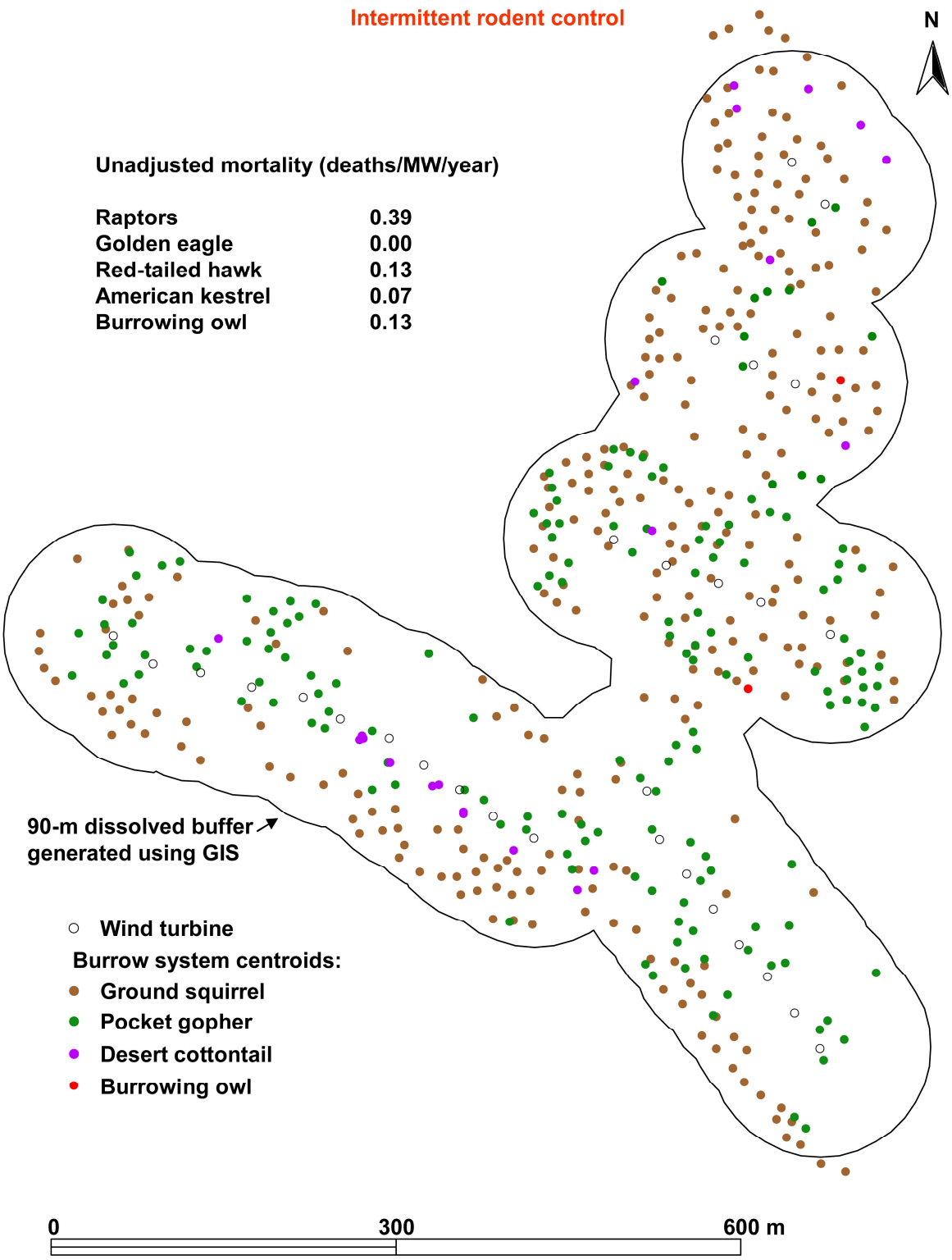


Figure 6-37. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the central aspect of EnXco's turbines and where rodent control was applied intermittently

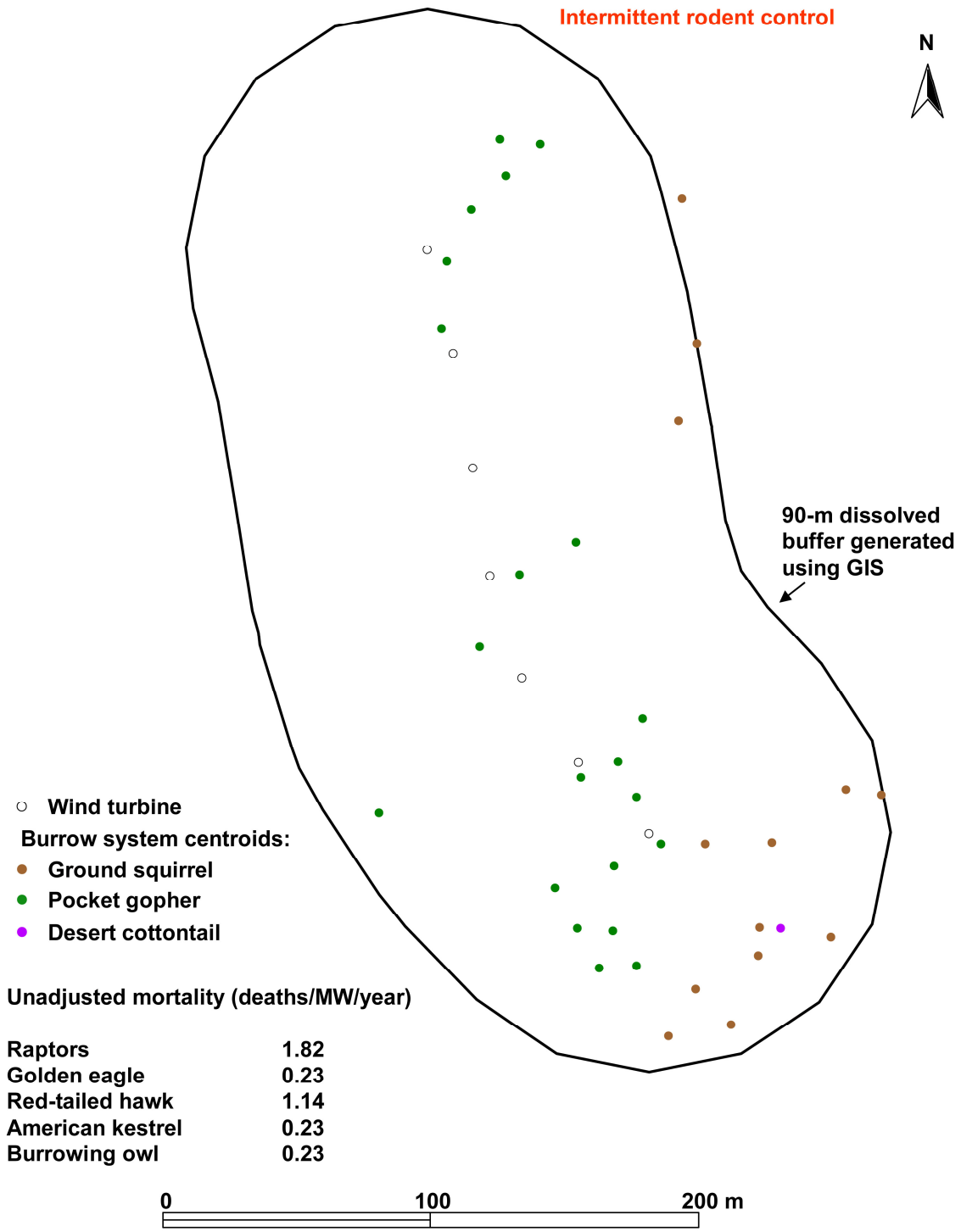


Figure 6-38. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines on the northern fringe of EnXco's turbine field and where rodent control was applied intermittently

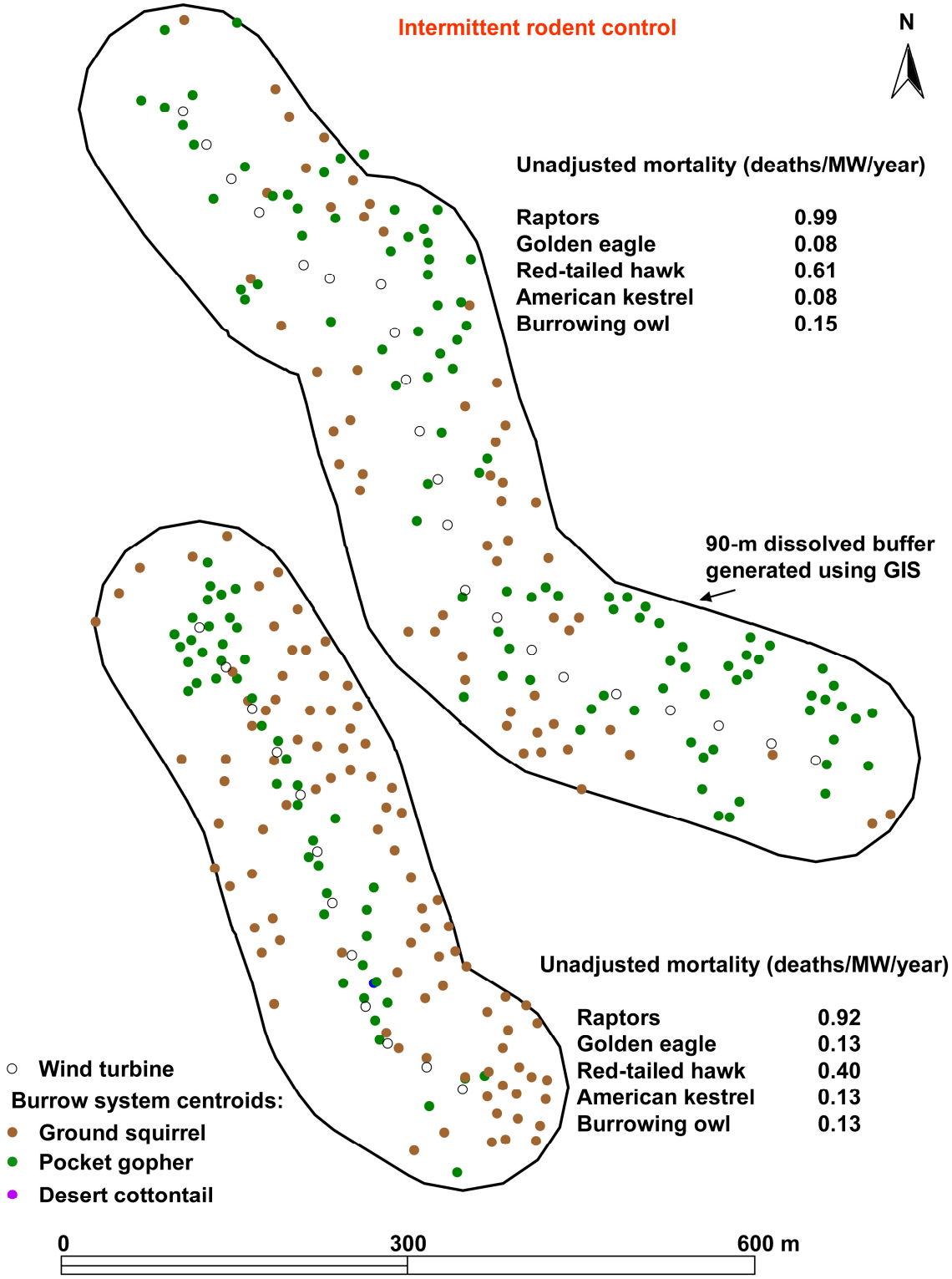
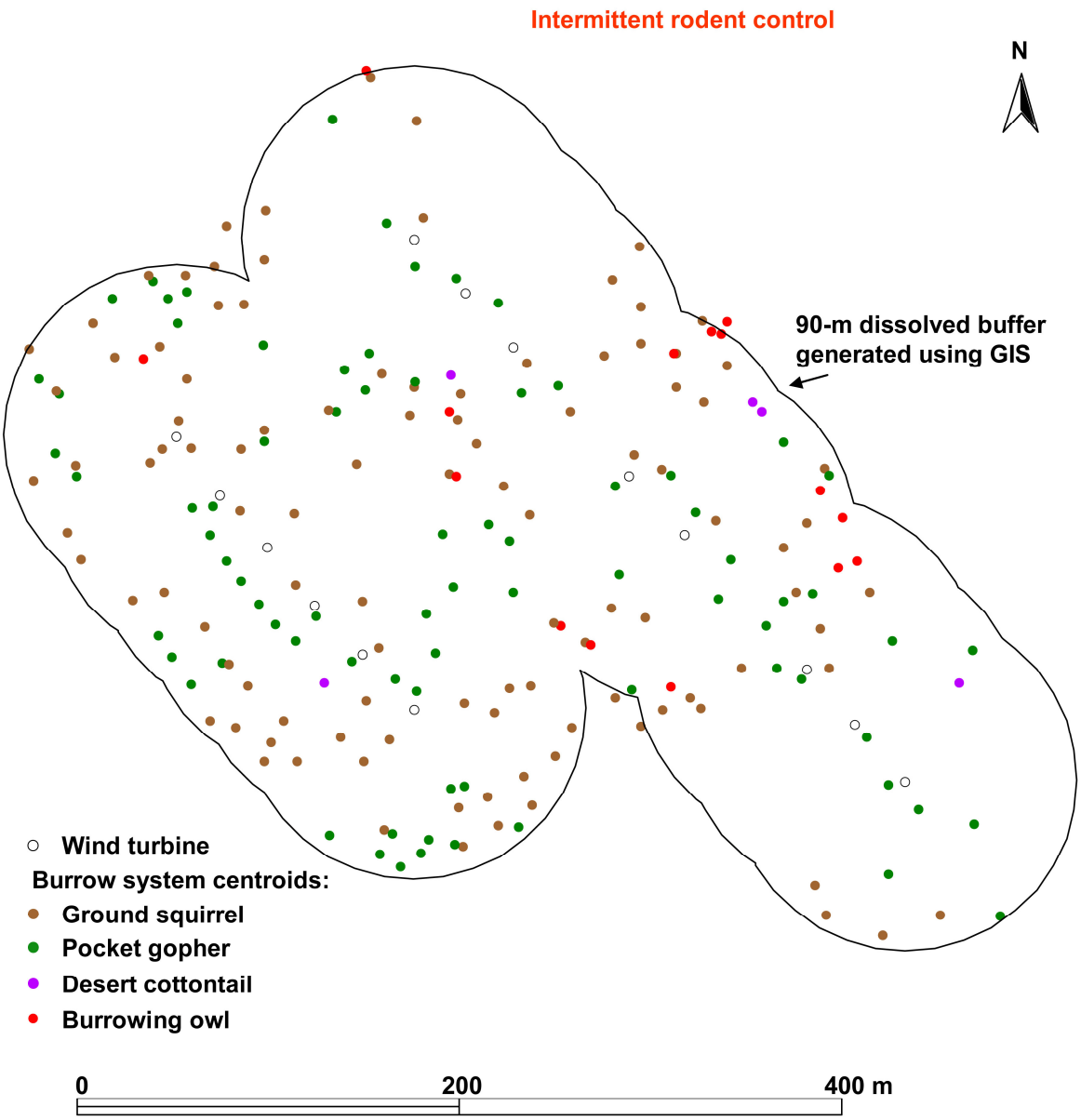


Figure 6-39. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the northern aspect of EnXco's turbine field and where rodent control was applied intermittently



Unadjusted mortality (deaths/MW/year)

Raptors	**0.42**
Golden eagle	**0.00**
Red-tailed hawk	**0.14**
American kestrel	**0.00**
Burrowing owl	**0.28**

Figure 6-40. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the central aspect of EnXco's turbine field and where rodent control was applied intermittently

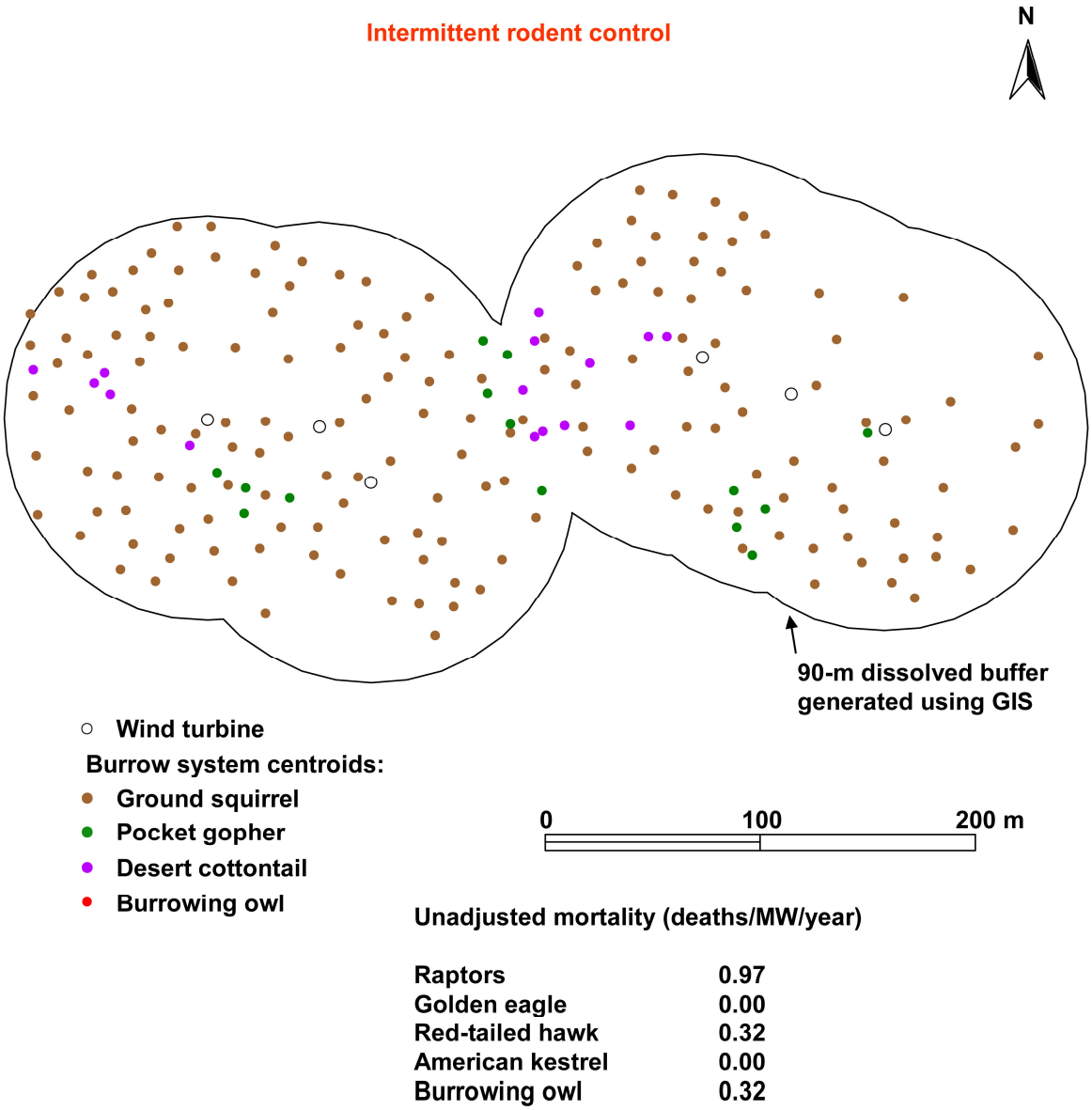


Figure 6-41. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the southern aspect of EnXco's turbine field, and where rodent control was applied intermittently

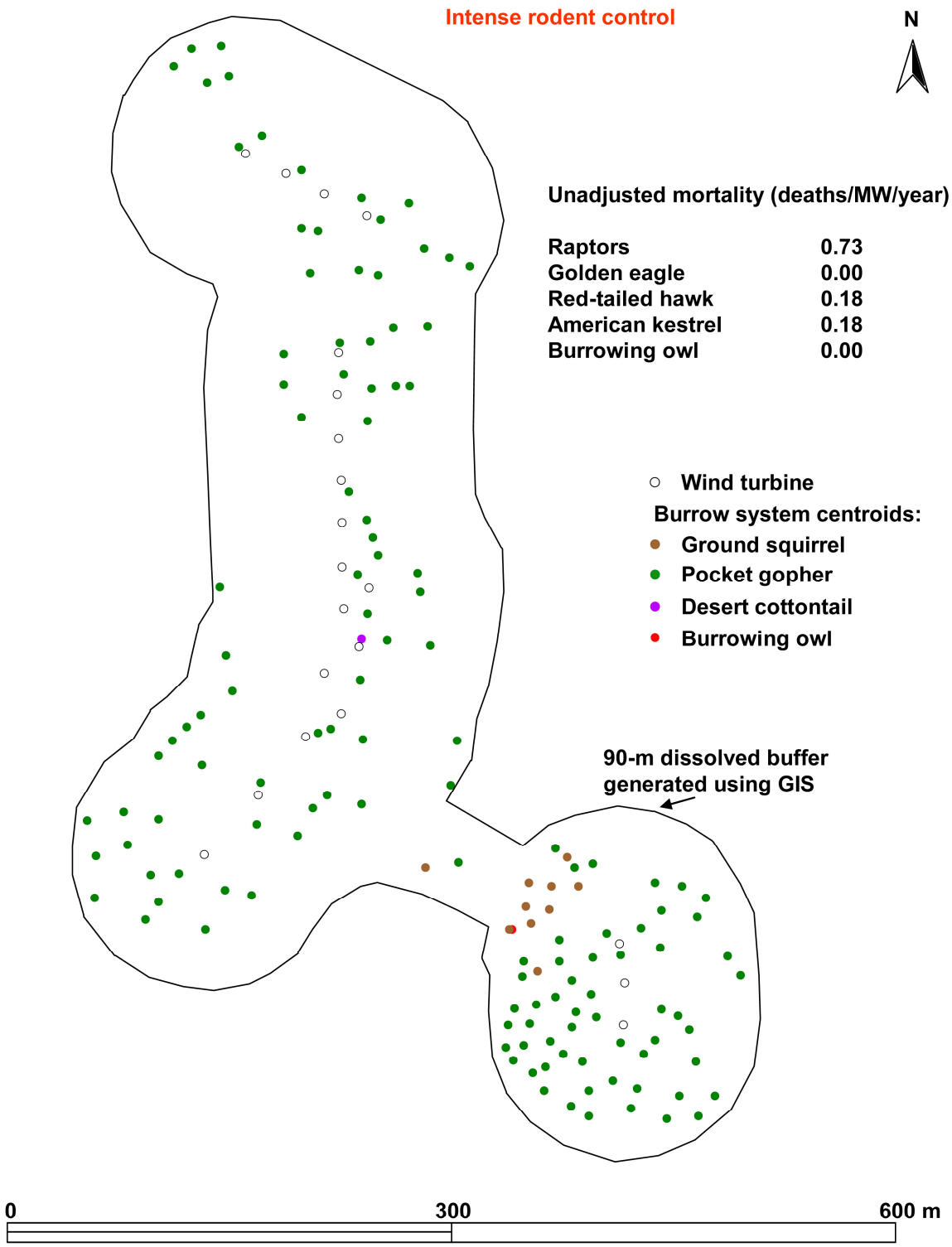


Figure 6-42. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in the Patterson Pass area and where rodent control was applied intensively

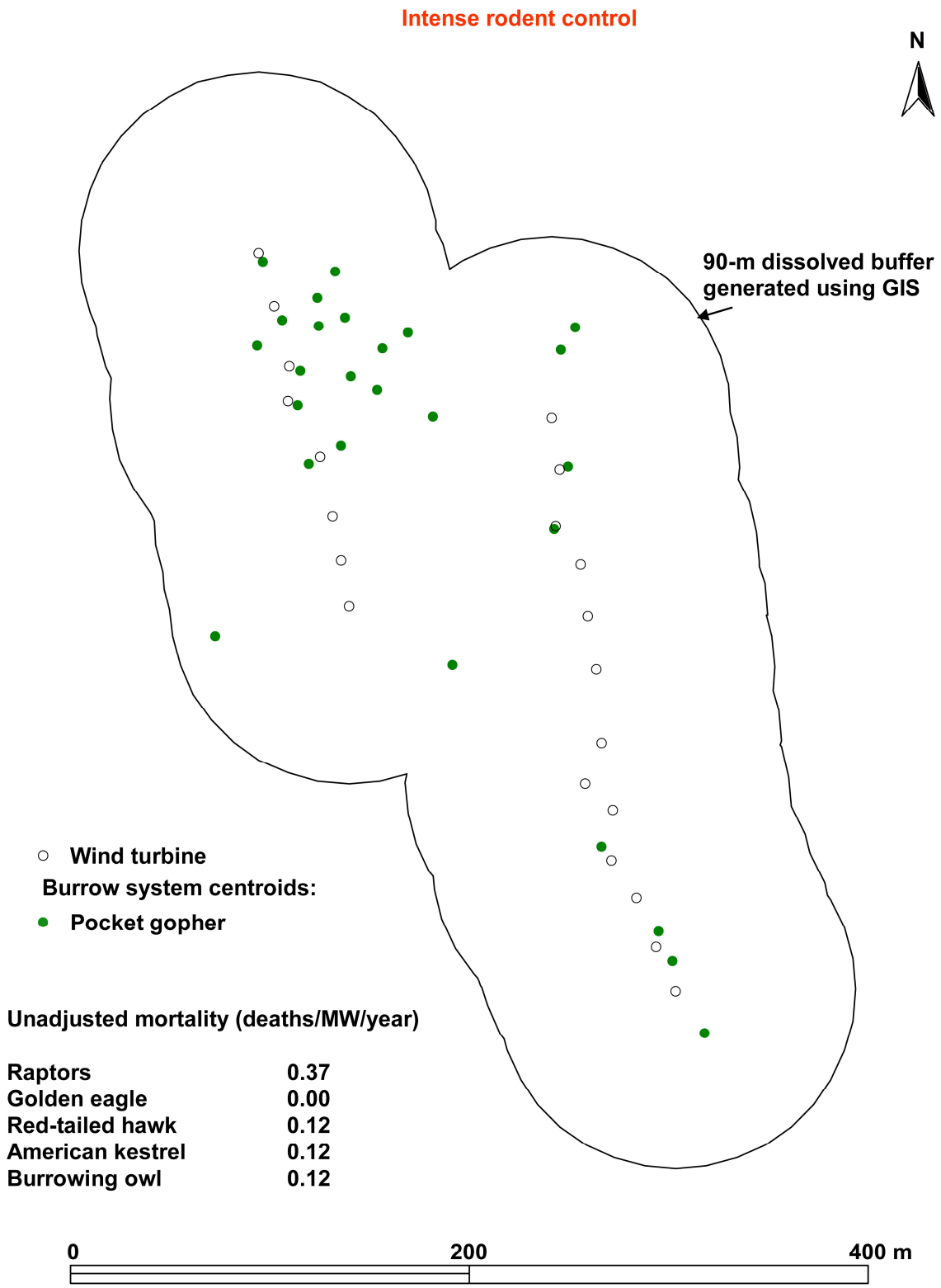


Figure 6-43. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines in center of the APWRA, and where rodent control was applied intensively

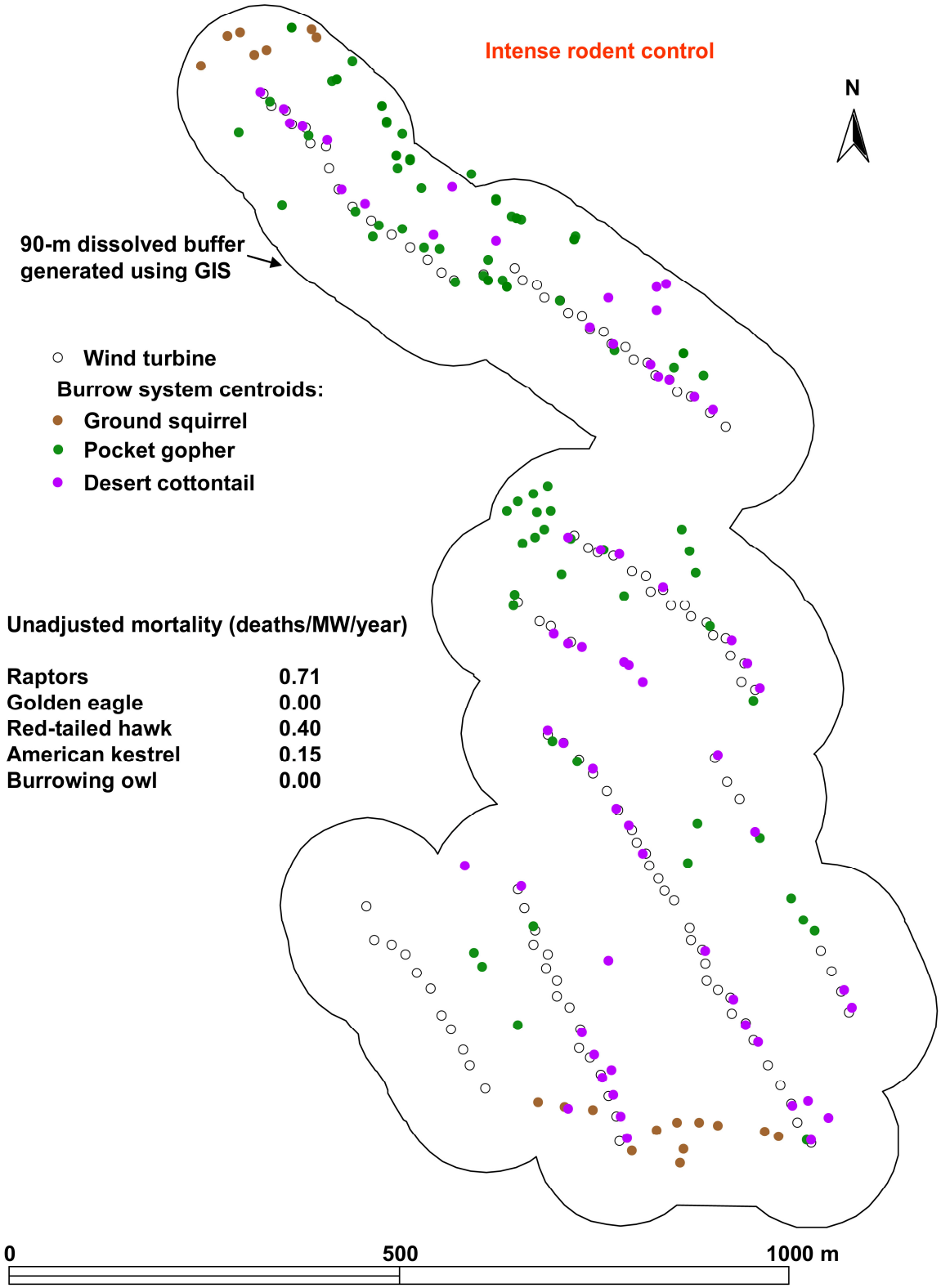
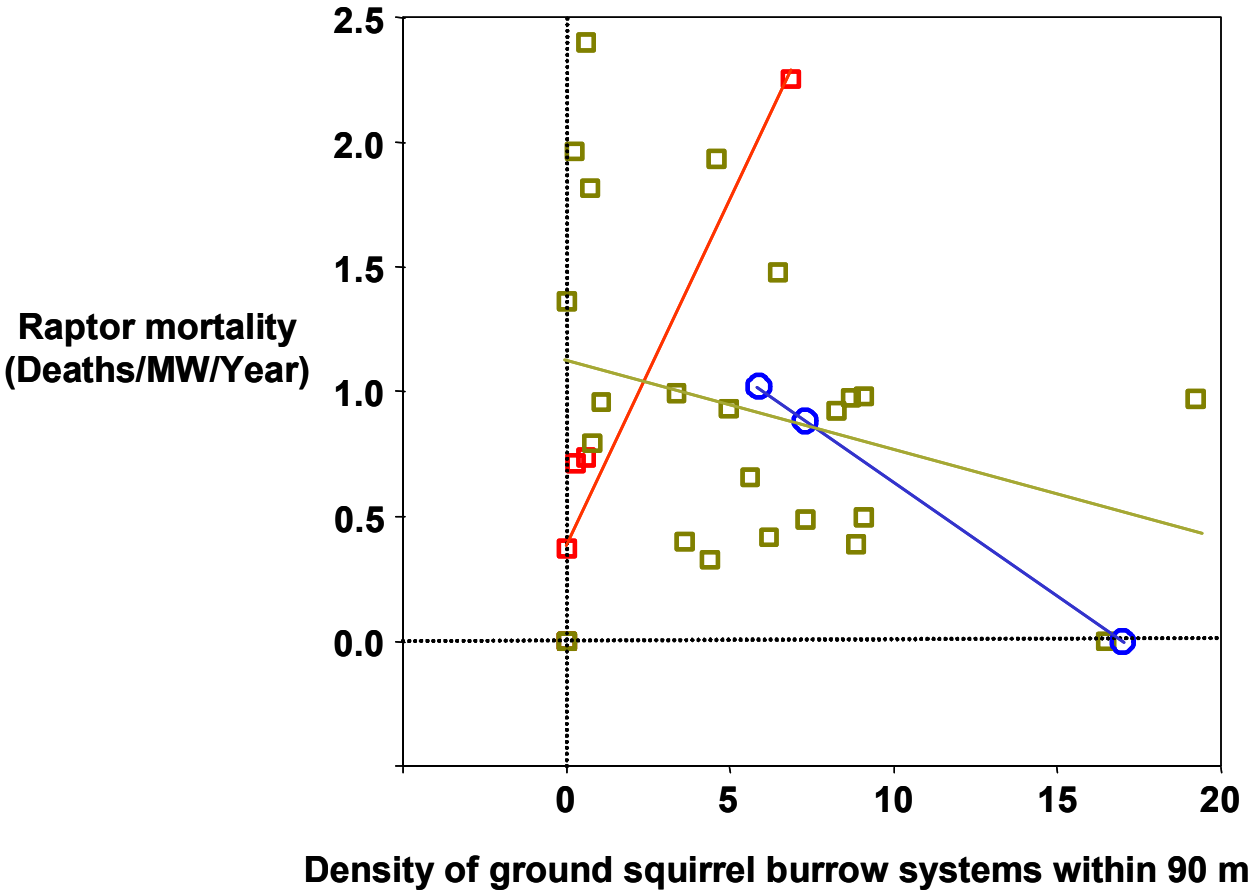
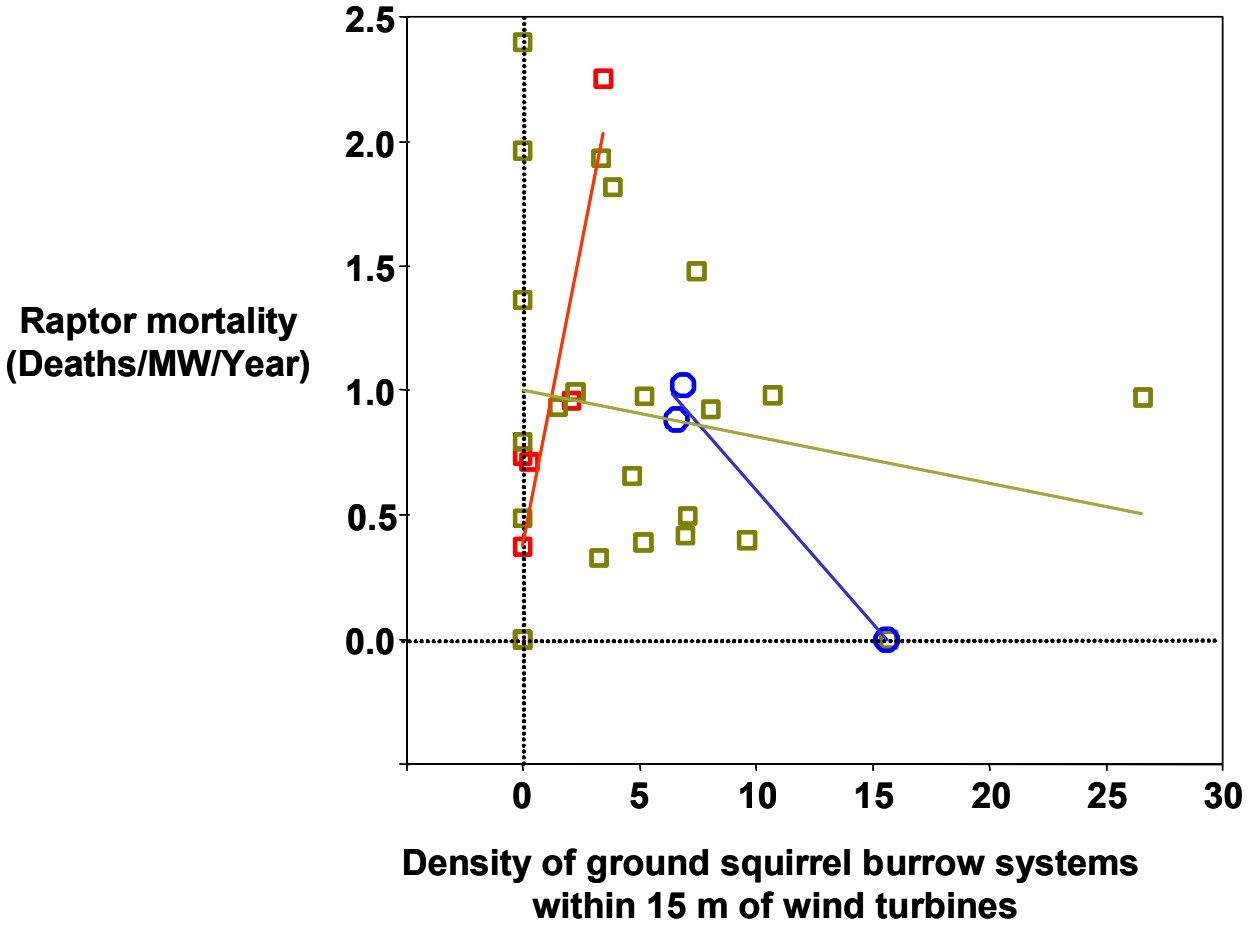


Figure 6-44. Spatial distribution of fossorial mammal burrow systems within 90 m of wind turbines formerly operated by Enron, and where rodent control was applied intensively



No rodent control $Y = 1.553 - 0.092X$, $r^2 = 1.00$, RMSE = 0.00, P = 0.004
Intermittent control $Y = 1.105 - 0.037X$, $r^2 = 0.08$, RMSE = 0.65, P = 0.194
Intense control $Y = 0.438 + 0.273X$, $r^2 = 0.90$, RMSE = 0.28, P = 0.004

Figure 6-45. Raptor mortality related to the density of ground squirrel burrow systems within 90 m differently depending on rodent control context, increasing with ground squirrel density in areas of intense rodent control, and declining with ground squirrel density in areas of no control



No rodent control $Y = 1.663 - 0.106X$, $r^2 = 0.98$, RMSE = 0.12, P = 0.095
Intermittent control $Y = 0.997 - 0.019X$, $r^2 = 0.03$, RMSE = 0.67, P = 0.428
Intense control $Y = 0.378 + 0.477X$, $r^2 = 0.82$, RMSE = 0.37, P = 0.013

Figure 6-46. Raptor mortality related to the density of ground squirrel burrow systems within 15 m differently depending on rodent control context, increasing with ground squirrel density in areas of intense rodent control, and tending to decline with ground squirrel density in areas of no control

Raptor mortality measured throughout the study period associated significantly with the density of burrow systems of all fossorial species, as well as with the density of burrow systems of ground squirrels out to 90 m (Table 6-2). Mortality was greatest in areas of moderate density of all species and of ground squirrels, and least in areas of highest densities of desert cottontail. It also tended to associate with the degree of clustering of desert cottontail burrows within 15 m of wind turbines relative to within 90 m (Table 6-2), where no desert cottontails within 15 m associated with more raptor fatalities. Raptor mortality was most responsive to intermediate densities of all fossorial species within 15 m of wind turbines, where this attribute could account for 12% of all raptor fatalities.

Table 6-2. Associations between raptors killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of all species to 90 m **				
0–5 burrow systems/ha	59	65.67	0.90	-4
5–10 burrow systems/ha	79	59.68	1.32	12
10–22.5 burrow systems/ha	27	39.64	0.68	-8
Density of ground squirrels to 90 m *				
0–2 burrow systems/ha	74	77.28	0.96	-2
3–7 burrow systems/ha	68	54.47	1.25	8
7–19.2 burrow systems/ha	23	33.25	0.69	-6
Clustering of cottontail burrows at turbines [t]				
0 burrows/ha	83	70.84	1.17	7
2.6–10.9 burrows/ha	82	93.19	0.88	-7

Raptors killed within a year of the burrow mapping efforts tended to associate with moderate ground squirrel density out to 90 m from wind turbines (Table 6-3). Raptor mortality also tended to associate with highest densities of all fossorial species within 15 m of wind turbines, and associated significantly with the highest densities of pocket gophers within 15 m of wind turbines and lowest desert cottontail densities in this zone (Table 6-3). Raptor mortality within a year of burrow mapping was most responsive to high pocket gopher density within 15 m of wind turbines, where this attribute could account for 17% of all near-term raptor fatalities.

Golden eagle mortality throughout the study period associated significantly with the density of burrow systems of all fossorial species out to 90 m, and it was most responsive to intermediate density of burrow systems. This intermediate density of burrow systems of all fossorial species could account for 37% of all golden eagle fatalities in the sample (Table 6-4). Golden eagle mortality also associated with greater densities of pocket gophers out to 90 m from wind turbines and with the absence of desert cottontails within 15 m of wind turbines (Table 6-4).

In comparison, golden eagles killed within one year of the burrow mapping efforts tended to associate with intermediate pocket gopher densities out to 90 m (Table 6-5). Golden eagle kills were most responsive to the absence of desert cottontails within 15 m of wind turbines, where this

attribute could account for 46% of all near-term golden eagle fatalities in the sample. However, we had only a small sample of golden eagle fatalities found within a year of burrow mapping.

Table 6-3. Associations between raptors killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of ground squirrels to 90 m [t]				
0–2 burrow systems/ha	32	34.19	0.94	-3
3–7 burrow systems/ha	35	27.07	1.29	10
7–19.2 burrow systems/ha	9	14.74	0.61	-8
Density of desert cottontails to 90 m *				
0 burrows/ha	29	21.30	1.36	10
0.2–0.7 burrows/ha	35	33.54	1.04	2
0.8–1.7 burrows/ha	12	21.16	0.57	-12
Density of all species to 15 m [t]				
0–10 burrow systems/ha	35	39.99	0.88	-7
10–17 burrow systems/ha	23	25.30	0.91	-3
18–45 burrow systems/ha	18	10.71	1.68	10
Density of pocket gophers to 15 m **				
0–4 burrow systems/ha	34	40.32	0.84	-8
5–12 burrow systems/ha	14	20.84	0.67	-9
13–37 burrow systems/ha	28	14.84	1.89	17
Density of desert cottontails to 15 m *				
0 burrows/ha	41	29.18	1.41	16
0.4–1.7 burrows/ha	19	21.43	0.89	-3
2.3–4.7 burrows/ha	16	25.40	0.63	-12
Clustering of ground squirrels at turbines [t]				
0 burrow systems/ha	19	13.19	1.44	8
0.3–1.0 burrow systems/ha	35	43.68	0.80	-11
1.1–5.2 burrow systems/ha	22	18.57	1.19	5
Clustering of desert cottontails at turbines **				
0 burrows/ha	41	28.61	1.43	16
2.6–10.9 burrows/ha	35	46.82	0.75	-16

Table 6-4. Associations between golden eagles killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of all species to 90 m *				
0–5 burrow systems/ha	1	4.38	0.23	-31
5–10 burrow systems/ha	8	3.98	2.01	37
10–22.5 burrow systems/ha	2	2.64	0.76	-6
Density of pocket gophers to 90 m *				
0–2 burrow systems/ha	1	4.95	0.20	-36
2–4 burrow systems/ha	6	2.98	2.01	27
4.3–7.6 burrow systems/ha	4	3.06	1.31	9
Clustering of desert cottontails at turbines *				
0 burrows/ha	8	4.72	1.69	30
2.6–10.9 burrows/ha	3	6.21	0.48	-29

Table 6-5. Associations between golden eagles killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of pocket gophers to 90 m [t]				
0–2 burrow systems/ha	1	2.98	0.34	-33
2–4 burrow systems/ha	4	1.48	2.69	42
4.3–7.6 burrow systems/ha	1	1.54	0.65	-9
Density of desert cottontails to 15 m [t]				
0 burrows/ha	5	2.30	2.17	45
0.4–1.7 burrows/ha	0	1.69	0	-28
2.3–4.7 burrows/ha	1	2.00	0.50	-17
Clustering of desert cottontails at turbines *				
0 burrows/ha	5	2.26	2.21	46
2.6–10.9 burrows/ha	1	3.70	0.27	-45

Red-tailed hawk mortality measured throughout the study period associated significantly with the density of all fossorial species within 90 m of wind turbines, where intermediate densities could account for 10% of all red-tailed hawk fatalities in our sample (Table 6-6). It was also significantly greater in areas of low to intermediate ground squirrel densities within 90 m of wind turbines, and at wind turbines with lower desert cottontail densities within 15 m (Table 6-6). Red-tailed hawk mortality correlated positively with clustering of burrow systems of all species studied at wind turbines ($r_p = 0.50$, $n = 32$, $P < 0.01$), and tended to correlate with the clustering of pocket gopher burrow systems at wind turbines ($r_p = 0.33$, $n = 32$, $P < 0.10$).

Table 6-6. Associations between red-tailed hawks killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of all species to 90 m *				
0–5 burrow systems/ha	35	32.64	1.07	3
5–10 burrow systems/ha	38	29.66	1.28	10
10–22.5 burrow systems/ha	9	19.70	0.46	-13
Density of ground squirrels to 90 m [t]				
0–2 burrow systems/ha	42	38.41	1.09	4
3–7 burrow systems/ha	32	27.07	1.18	6
7–19.2 burrow systems/ha	8	16.52	0.48	-10
Density of desert cottontails to 15 m *				
0 burrows/ha	46	35.69	1.29	13
0.4–1.7 burrows/ha	10	18.50	0.54	-10
2.3–4.7 burrows/ha	26	27.82	0.93	-2
Clustering of desert cottontails at turbines *				
0 burrows/ha	46	35.20	1.31	13
2.6–10.9 burrows/ha	36	46.31	0.78	-13

Red-tailed hawk mortality measured within a year of burrow mapping efforts was significantly greater at turbines lacking desert cottontails out to 90 m, and it was significantly greater at wind turbines with higher densities of all species within 15 m of wind turbines, and especially of pocket gophers within 15 m (Table 6-7). It was also greater where desert cottontails were lacking within 15 m of wind turbines (Table 6-7). It was most responsive to pocket gopher density within 15 m of wind turbines, which accounted for 32% of the near-term red-tailed hawk fatalities in our sample. Measured within a year of the date upon which burrows were mapped, red-tailed hawk mortality also correlated with clustering of burrow systems of all species studied at wind turbines ($r_p = 0.55$, $n = 32$, $P < 0.01$), and correlated with the clustering of pocket gopher burrow systems at wind turbines ($r_p = 0.43$, $n = 32$, $P < 0.05$).

Table 6-7. Associations between red-tailed hawks killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of desert cottontails to 90 m *				
0 burrows/ha	16	9.25	1.73	20
0.2–0.7 burrows/ha	13	14.56	0.89	-5
0.8–1.7 burrows/ha	4	9.19	0.44	-16
Density of all species to 15 m **				
0–10 burrow systems/ha	14	17.37	0.81	-10
10–17 burrow systems/ha	7	10.99	0.64	-12
18–45 burrow systems/ha	12	4.65	2.58	22

Table 6-7. (cont'd)

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of pocket gophers to 15 m **				
0–4 burrow systems/ha	13	17.51	0.74	-14
5–12 burrow systems/ha	3	9.05	0.33	-18
13–37 burrow systems/ha	17	6.45	2.64	32
Density of desert cottontails to 15 m *				
0 burrows/ha	21	12.67	1.66	25
0.4–1.7 burrows/ha	7	9.30	0.75	-7
2.3–4.7 burrows/ha	5	11.03	0.45	-18
Clustering of desert cottontails at turbines **				
0 burrows/ha	21	12.42	1.69	26
2.6–10.9 burrows/ha	12	20.33	0.59	-25

American kestrel mortality measured throughout the study tended to be least where pocket gopher density out to 90 m was also least, and this level of pocket gopher density could account for 23% of the American kestrel fatalities in our sample (Table 6-8).

American kestrel mortality measured within a year of burrow mapping efforts tended to be greatest where pocket gophers were fewest within 90 m and where there was an intermediate level of clustering of desert cottontails within 15 m of wind turbines (Table 6-9). Scarcity of pocket gophers could account for 39% of the near-term American kestrel fatalities in our sample.

Table 6-8. Associations between American kestrels killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of pocket gophers to 90 m [t]				
0–2 burrow systems/ha	13	8.55	1.52	23
2–4 burrow systems/ha	1	5.15	0.19	-22
4.3–7.6 burrow systems/ha	5	5.29	0.94	-2
Clustering of desert cottontails at turbines [t]				
0 burrows/ha	4	8.16	0.49	-22
2.6–10.9 burrows/ha	15	10.73	1.40	22

Table 6-9. Associations between American kestrels killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of pocket gophers to 90 m [t]				
0–2 burrow systems/ha	8	4.47	1.79	39
2–4 burrow systems/ha	0	2.23	0	-25
4.3–7.6 burrow systems/ha	1	2.31	0.43	-15
Clustering of all species at turbines [t]				
0–1.25 obs/expected burrows ≤ 15 m	0	1.72	0	-19
1.26–2.00 obs/expected burrows ≤ 15 m	6	3.04	1.97	33
2.01–7.19 obs/expected burrows ≤ 15 m	3	4.17	0.72	-13

Burrowing owl mortality measured throughout the study was greater at wind turbines surrounded by higher densities of all fossorial species within 90 m, but especially with intermediate densities (Table 6-10). It was disproportionately greater at wind turbines with intermediate densities of ground squirrel and desert cottontail burrow systems within 90 m, and it tended to be greater at the highest densities of ground squirrel burrow systems within 15 m of wind turbines (Table 6-10). It was also significantly greater at wind turbines with burrowing owl burrows located within 90 m, and the occurrence of these burrows could account for 23% of the burrowing owl fatalities in our sample (Table 6-10).

Burrowing owl mortality measured within a year of burrow mapping efforts also was greatest at turbines with intermediate densities of burrow systems of all fossorial species within 90 m, and these densities could account for 43% of the variation in burrowing owl fatalities in our sample (Table 6-11). It tended to be greater at highest ground squirrel densities within 15 m of wind turbines and was significantly greater where desert cottontails were absent within 90 m and within 15 m (Table 6-11). Near-term burrowing owl mortality was significantly greater at wind turbines with burrowing owl burrows within 90 m, and this condition could account for 28% of the fatalities in our sample (Table 6-11).

Table 6-10. Associations between burrowing owls killed throughout the study period and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of all species to 90 m *				
0–5 burrow systems/ha	4	10.75	0.37	-25
5–10 burrow systems/ha	15	9.77	1.54	19
10–22.5 burrow systems/ha	8	6.49	1.23	6
Density of ground squirrels to 90 m **				
0–2 burrow systems/ha	5	12.65	0.40	-28
3–7 burrow systems/ha	17	8.91	1.91	30
7–19.2 burrow systems/ha	5	5.44	0.92	-2
Density of desert cottontails to 90 m [t]				
0 burrows/ha	9	8.75	1.03	1
0.2–0.7 burrows/ha	15	10.10	1.49	18
0.8–1.7 burrows/ha	3	8.16	0.37	-19
Density of ground squirrels to 15 m [t]				
0 burrow systems/ha	2	4.81	0.42	-10
0.3–5.2 burrow systems/ha	14	15.88	0.88	-7
6.6–26.6 burrow systems/ha	11	6.30	1.75	17
Clustering of ground squirrels at turbines *				
0 burrow systems/ha	2	4.65	0.43	-10
0.3–1.0 burrow systems/ha	13	16.76	0.78	-14
1.1–5.2 burrow systems/ha	12	5.43	2.21	24
Density of burrowing owls to 90 m *				
0 burrows/ha	12	18.16	0.66	-23
0.02–0.88 burrows/ha	15	8.84	1.70	23

Table 6-11. Associations between burrowing owls killed within a year of burrow mapping and particular ranges of density and clustering of fossorial animal species

Variable and Attribute	Observed number	Expected number	Obs ÷ Exp number	Accountable percent
Density of ground squirrels to 90 m **				
0–2 burrow systems/ha	2	6.30	0.32	-31
3–7 burrow systems/ha	11	4.99	2.21	43
7–19.2 burrow systems/ha	1	2.72	0.37	-12
Density of desert cottontails to 90 m *				
0 burrows/ha	7	3.92	1.78	22
0.2–0.7 burrows/ha	7	6.18	1.13	6
0.8–1.7 burrows/ha	0	3.90	0	-28
Density of ground squirrels to 15 m [t]				
0 burrow systems/ha	2	2.53	0.79	-4
0.3–5.2 burrow systems/ha	4	7.49	0.53	-25
6.6–26.6 burrow systems/ha	8	3.98	2.01	29
Density of desert cottontails to 15 m *				
0 burrows/ha	9	5.37	1.67	26
0.4–1.7 burrows/ha	5	3.95	1.27	8
2.3–4.7 burrows/ha	0	4.68	0	-33
Clustering of all species at turbines [t]				
0–1.25 obs/expected burrows ≤ 15 m	0	2.67	0	-19
1.26–2.00 obs/expected burrows ≤ 15 m	8	4.73	1.69	23
2.01–7.19 obs/expected burrows ≤ 15 m	6	6.49	0.92	-4
Clustering of ground squirrels at turbines [t]				
0 burrow systems/ha	2	2.43	0.82	-3
0.3–1.0 burrow systems/ha	5	8.05	0.62	-22
1.1–5.2 burrow systems/ha	7	3.42	2.05	26
Clustering of desert cottontails at turbines *				
0 burrows/ha	9	5.27	1.71	27
2.6–10.9 burrows/ha	5	8.63	0.58	-26
Density of burrowing owls to 90 m *				
0 burrows/ha	5	8.88	0.56	-28
0.02–0.88 burrows/ha	9	5.12	1.76	28

6.3.5 Relationships Between Bird Mortality and Rodent Control

Burrowing owl mortality was significantly greater on the ranch where rodent control was intermittently applied (Table 6-12). However, the mortality of every other species except mallard did not relate significantly to intensity of rodent control. Most likely the mallard's significant relationship of mortality with rodent control intensity was only spurious, because it is difficult to explain how rodent control would affect mallard mortality.

6.4 DISCUSSION

Our study refutes several hypotheses about the relationships between wind turbines, rodent control, and rodent distribution and abundance. For example, it appears that ground squirrel distribution was not extended by the wind turbine access roads or disturbed soils related to the wind farm at the Altamont Pass, as had been suggested by Colson (1995) and Morrison (1996). In fact, ground squirrels appear to avoid the 15-m zone around the wind turbines, which is where the access roads and soil disturbances principally occur. Pocket gophers, however, were attracted to this zone where soils were disturbed, and this species typically occurred there two to four times more often than expected by a uniform distribution of gopher burrow systems within the entire search area.

Table 6-12. Summary of mortality estimates by rodent control intensity in the APWRA from May 1998 through September 2002

Species or Taxonomic group	Mean mortality (fatalities/MW/year)				
	Rodent control through 2002			ANOVA F-value (df = 2,445)	P-value
	None (120 strings, 118.02 MW)	Intermittent 87 strings, 65.33 MW)	Intense (240 strings, 206.3 MW)		
Golden eagle	0.1267	0.0709	0.1037	0.10	0.901
Red-tailed hawk	0.3747	0.3095	0.2164	0.69	0.504
American kestrel	0.1317	0.0561	0.1010	5.14	0.599
Burrowing owl	0.0137	0.1632	0.0871	4.45	0.012
Great horned owl	0.0144	0.0053	0.0152	0.31	0.737
Barn owl	0.0456	0.0984	0.0286	1.82	0.165
Mallard	0.0059	0.1034	0.0303	3.26	0.039
Rock dove	0.4631	0.2939	0.1823	2.43	0.089
European starling	0.1149	0.0361	0.1864	0.94	0.393
Horned lark	0.0134	0.0238	0.0188	0.25	0.782
Western meadowlark	0.1727	0.1500	0.2559	0.42	0.649
House finch	0.0000	0.0361	0.0266	1.32	0.268
Raptor	1.2092	1.1359	1.0346	0.23	0.793
TOTAL	2.0123	1.6827	1.6746	0.41	0.665

Hunt (2002) accurately predicted that ground squirrel control would reduce the abundance of ground squirrels. On lands with intense rodent control, almost no ground squirrel burrow systems remain. But on a ranch where rodent control was applied less intensively, ground squirrel abundance increased from 1999 through 2001. This result is not consistent with what was expected to occur there.

Each year we witnessed the applications of the poison bait on portions of the APWRA. We observed high mortality of ground squirrels and desert cottontails, whose carcasses lay upon the ground or in rock piles and were scavenged by raptors. The remains or odors associated with dead animals were openly evident during the two weeks following the poison bait applications. However, despite our observations of widespread mortality of squirrels due to control implemented intermittently on one particular ranch, the density of ground squirrel burrow systems increased from 1999 through 2001. We believe that subadult ground squirrels quickly immigrated from surrounding areas, or from unaffected colonies on this ranch, and occupied the abandoned burrow systems.

Intermittent rodent control associated with an increased density of pocket gopher burrow systems out to 90 m from the wind turbines and with increased degrees of clustering of gopher burrow systems around the wind turbines. Pocket gopher density and distribution responded to rodent control almost opposite the density and distribution of ground squirrels; whereas ground squirrel density and degree of clustering decreased in areas of rodent control, the density and degree of clustering of pocket gophers increased. The response of pocket gophers may be an unintended consequence of the rodent control program in the APWRA, and this consequence may exacerbate the bird mortality problem by effectively concentrating sign of fossorial rodents among wind turbines because sign is removed from locations farther away from the wind turbines. The response of pocket gophers to the rodent control program was consistent with this species' responses to abatement efforts in forest clear cuts (Smallwood 1999) and in alfalfa stands (Smallwood et al. 2001), again demonstrating that a simplistic abatement approach may not achieve desired results due to the ecological complexity of this species.

The significant correlation between pocket gopher burrow system clustering at wind turbines and cattle pat abundance may indicate a complex ecological relationship in which cattle more intensively use some wind turbines for shade and consequently where they more intensively graze down the grass and defecate. The increased abundance of cattle pats near these wind turbines may fertilize plants to the advantage of forbs, including leguminous plants, which appear to flourish near wind turbines. Pocket gophers may be attracted to the near-zone of wind turbines partly due to the food plants available there. Cattle pats also create concentrations of grasshoppers and other prey items for smaller raptors such as burrowing owls and American kestrels. Also, several *Buteo* species such as red-tailed hawks and Swainson's hawks are known to gorge on grasshoppers when they are extraordinarily abundant.

Table 6-13 summarizes the significant relationships we found between small mammal burrow systems and variables measured in this study. The distribution and abundance of small mammal species in the APWRA, and the underlying reasons for their distribution and abundance, are more complicated than previously imagined. Our study certainly did not fully characterize the factors affecting small mammal distribution and abundance. In the field we observed many tantalizing

indicators suggesting larger patterns that warrant further investigation, but for which we lacked the time and resources to pursue. For example, we observed desert cottontails burrowing under wind turbine pads (Photo 6-5), but we did not have the opportunity to identify, and therefore more widely characterize, the conditions associated with this burrowing activity.

Table 6-13. Summary of significant relationships between factors measured in our study and small mammal distribution and abundance

Dependent Variable	Magnitude and Direction of Significant Effects
Pocket gopher clustering at turbines	3.4 × greater in areas of intermediate control
	increased with percent of wind turbines in canyon (r = 0.27)
	decreased with more desert cottontail fecal pellets (r = -0.32)
	increased with more cattle pats 20-40 m from turbines (r = 0.49)
	increased with more cattle pats along turbine string (r = 0.51)
	3 × greater on west and southwest slopes
Ground squirrel clustering at turbines	decreased with greater elevation (r = -0.32)
	increased with more cattle pats along turbine string (r = 0.34)
Desert cottontail clustering at turbines	3.6 × less in areas of intermittent rodent control
Pocket gopher density within 15 m	12 × greater in areas of intermittent rodent control
Pocket gopher density within 90 m	2 × greater in areas of intermittent rodent control
Ground squirrel density within 15 m	10 × in areas of no control compared to intense control
Ground squirrel density within 90 m	6.7 × in areas of no control compared to intense control

Photo 6-5. Desert cottontails burrowed under some wind turbine pads.

Based on the inter-annual comparisons of mortality presented in Chapter 3, there was no compelling evidence that the rodent control program succeeded in reducing mortality of raptors or all birds. Even for those species and species groups for which significant decreases in mortality occurred during the study, they were preceded by significant increases in mortality during a time period several years into the rodent control program. Also, the implementation of rodent control at the SeaWest-owned turbines failed to cause declines in raptor mortality by the end of the first year of the program (2002).

Based on the analysis of data presented in this chapter, rodent control does not appear to reduce raptor use of the APWRA and, therefore, it is not an effective tool for reducing raptor mortality. The spatial distribution of an animal species is influenced by multiple factors, including the strong effects of social organization, which are rather rigid and unresponsive to local changes in the distribution and abundance of prey items (Smallwood 2002). Smallwood (2002) summarized cases where animal species were shown to rely more on gestalt and sociality in spacing themselves out in their environment, and to not always rely upon prey enumeration.

We found that raptor mortality was greater in areas with intermediate densities of ground squirrel burrow systems within 90 m, as well as with intermediate densities of burrow systems of all fossorial mammal species. It was greater at wind turbines with greatest densities of pocket gopher burrow systems within 15 m, which also corresponded with areas subjected to intermittent rodent control. These patterns were true for mortality of golden eagle, red-tailed hawk, and more or less for burrowing owl.

Burrowing owl mortality was greater where burrowing owls resided within 90 m of wind turbines. It is possible that burrowing owls more often reside near wind turbines following poisoning of ground squirrels because the vacated burrows will be more available to burrowing owls. Repetitive intense control would likely eliminate this pattern, however, because vacant squirrel burrows eventually collapse and become unavailable to burrowing owls. In fact, we did not find evidence of burrowing owl residency of burrows within the areas of intense control.

During the period of our study, consultants contracted by the owners performed and reported on an investigation of rodenticide use in relation to golden eagle and red-tailed hawk fatalities. Our results differ significantly with those reported in Kerlinger and Curry (2003), who concluded that the rodent control program has achieved its objectives by reducing raptor mortality. The reasons for our differences in results are summarized in Appendix B.

Even had the monitoring and experimental design of the Kerlinger and Curry (2003) study not been flawed (see Appendix B), the conflicting results presented by the owner's consultants is further evidence that the rodent control program is not meeting its goal. Kerlinger and Curry (2003) reported mortality estimates generated from the WRRS during the time period 1989 to 2002 that were 1.7 times greater for red-tailed hawk and 2.3 times greater for golden eagle than Kerlinger and Curry (1998) reported for the time period 1989 to 1991.

We note that the longer time period of the WRRS includes the shorter, earlier time period of 1989–1991, so the increase in mortality must have been even greater than 1.7- and 2.3-fold for red-tailed hawk and golden eagle, respectively. However, Kerlinger and Curry (1998) reported nearly

identical mortality estimates for red-tailed hawk and golden eagle during 1989 to 1997 as Kerlinger and Curry (2003) reported for the period 1989 to 2002. They reported 0.00581 golden eagles/turbine/year during the entire period compared to 0.00602 golden eagles/turbine/year during the period ending in 1997, or an increase of 0.7 (3.5%) golden eagles per year, including the last five years. They reported 0.0101 red-tailed hawks/turbine/year during the entire period, compared to 0.01081 red-tailed hawks /turbine/year during the period ending in 1997, or a decrease of 2.4 (6.8%) red-tailed hawks per year, including the last five years. These comparisons refute claims that the rodent control program has reduced raptor mortality.

In addition, rodent control likely threatens four special-status species commonly observed in the APWRA. Two such species are the California red-legged frog (Photo 6-6) and the California tiger salamander, both listed as threatened under the federal Endangered Species Act (Photo 6-7). These species are losing fossorial mammal burrows as refuge sites, while the rodent control proceeds to reduce the abundance and distribution of small mammals. Rodent control also threatens the existence of the endangered San Joaquin kit fox, a species for which use was last documented in the APWRA during the early 1990s (Photo 6-8). San Joaquin kit fox are sensitive to anti-coagulant poisons such as the chlorophacinone being used in the APWRA. The loss of ground squirrel burrow systems to rodent control also depletes a critical habitat element of burrowing owl, which is a Species of Special Concern in California.

Photo 6-6. A California red-legged frog found in the APWRA (photo by Brian Karas)

Photo 6-7. A California tiger salamander found in the APWRA (photo by Brian Karas)

Photo 6-8. The broadcasting of rolled oats laced with chlorophacinone poses a hazard to the San Joaquin kit fox, a species that was documented to use the APWRA. Wind turbine installation in the APWRA originally required mitigation measures for San Joaquin kit fox conservation.

In conclusion, we recommend the cessation of rodent control programs in the APWRA. Research is needed, however, that explores alternative means of managing the spatial distribution of small mammals in the APWRA. Chapter 9 includes suggested alternatives, and other ideas might be found in Van Vuren and Smallwood (1996).

Intermittent rodent control appears to be contributing to greater raptor mortality and might be increasing burrowing owl residency within close proximity to wind turbines. Intense rodent control was associated with fewer golden eagle fatalities in areas of intense rodent control but the association is not strong enough to warrant its continued use. Additionally, golden eagle mortality throughout the APWRA did not change between years when rodent control was conducted. The rodent control efforts effectively reduced small mammal densities but they probably adversely affected four special-status species and other non-sensitive wildlife using the area. They fail to noticeably reduce raptor mortality in general, which was their intended purpose.

CHAPTER 7

BIRD FATALITY ASSOCIATIONS AND PREDICTIVE MODELS FOR THE APWRA

7.1 INTRODUCTION

A major step toward reducing bird fatalities at wind energy generating facilities will be to identify and understand the causal factors of the fatalities. Because collisions with wind turbines are rarely observed, inferences must be drawn from patterns discernable from carcass locations found near wind turbines. Other investigators have studied such patterns (see below), but with little success, largely because of small sample sizes. Our study in the APWRA created a large enough sample size of fatalities to reveal relatively robust patterns. These patterns have resulted in the development of a predictive model based on the causal factors underlying the observed fatalities.

A robust empirical foundation is needed to attribute reliable causative factors to the bird fatality problem at wind energy generating facilities. Published and unpublished reports of the problem are replete with conclusions of the causal factors, but few are reliably based on scientific sampling, adequate sample sizes, and/or hypothesis testing (unpublished data). Many conclusions from reports are contradictory to those of other reports and some are used inappropriately to support management actions and optimistic impact estimates of proposed wind energy generating facilities or changes in existing wind energy generating facilities. The more commonly cited causal factors are cited below.

Researchers have argued that particular species or functional groups of species are inherently susceptible to collision with wind turbine blades due to typical behaviors such as migration through the area, or due to particular foraging or breeding strategies (Rogers et al. 1976; Estep 1989; Howell and DiDonato 1991; Howell and Noone 1992; Orloff and Flannery 1992, 1996; Colson 1995; Erickson et al. 1999; Hoover 2001; Strickland et al. 2001a,b; Rugge 2001; Thelander and Rugge 2001, Hunt 2002, Johnson et al. 2002) or body size (1996a,b). Some researchers have also argued that susceptibility is linked to intensity of the use of the site or numerical abundance (Howell and Noone 1992; Cade 1995; Colson 1995; Morrison 1998; Erickson et al. 1999; Anderson et al. 2001; Kerlinger and Curry 2000; Thelander and Rugge 2000a,b; Ugoretz et a. 2000; Rugge 2001; Strickland et al. 2001b); while others have concluded otherwise (Orloff and Flannery 1992, 1996; Hunt 2002).

Some have argued that all types of wind turbine and tower combinations kill birds or that the type of tower or wind turbine does not relate to bird mortality (Anderson et al. 2001; Johnson et al. 2002). Others have concluded that horizontal lattice towers (e.g., at KCS-56s) are responsible for a disproportionate number of fatalities (Orloff and Flannery 1996; Curry and Kerlinger 2000; Rugge 2001; Hunt 2002)—a conclusion that has been related to the increased perching opportunities on horizontal lattice towers, which are thought to increase the number of fatalities (Howell and DiDonato 1991; Orloff and Flannery 1992; Cade 1995; Colson 1995; Curry and Kerlinger 2000; Kerlinger and Curry 2000; Strickland et al. 2001b; Hunt 2002). However, Rugge (2001) found that

birds more frequently perch on wind turbines with tubular towers, and Thelander and Rugge (2001) found that mortality was no less on tubular towers.

Rogers et al. (1976) concluded that taller towers are more dangerous to birds; whereas, Hunt (2002) concluded that taller towers are likely safer for golden eagles. Orloff and Flannery (1996) found that tower height did not relate to bird mortality, and Strickland et al. (2000b) safely concluded that the most dangerous wind turbines will be those whose rotor swept height band corresponds with the frequency of bird flights in it.

Tucker (1996b) predicted that larger-diameter rotors would be safer, which was a conclusion adopted by Kerlinger and Curry (2001). However, Orloff and Flannery (1996) found that wind turbines with larger rotor-swept areas killed more birds, and Howell (1997) concluded that the size of the rotor-swept area does not matter. Because larger-diameter rotors have been associated with slower blade motion, conclusions regarding blade tip speed correspond with those of rotor diameters. Tucker (1996b) predicted that wind turbines with slower blade tips are safer, which was also the opinion of Kerlinger and Curry (2001). However, Orloff and Flannery (1996) found that blade tip speed does not matter.

Rogers et al. (1976) predicted that wind turbines with increased rotor solidity pose greater threats to birds, where rotor solidity is the degree to which the length, depth, and speed of the blades pose an obstacle to birds flying through the rotor plane. However, Orloff and Flannery (1996) found that rotor solidity did not relate to bird mortality.

Considerable attention has been focused on the visibility of the moving turbine blades, and their lack of contrast with the background sky (Howell and DiDonato 1991; Cade 1995; Tucker 1996b; Curry and Kerlinger 2000; McIsaac 2001). Some wind turbine blades in the APWRA were painted in various patterns as a remedy and were said to be safer (Howell et al. 1991), but Orloff and Flannery (1992) found no effect. Hodos et al. (2001) reported that raptors experience motion smear, which is the inability to see the moving blades because their images moving across the birds' retinas are too large and fast to be processed by the brain. He proposed blade painting schemes to reduce motion smear, but these remain untested in the field.

Researchers concluded that wind turbines pose an obstacle to bird flights, so the more wind turbines present, the greater the threat of the wind farm to birds (Winkelman 1992; Colson 1995; Howell 1997; Hunt et al. 1998; Kerlinger and Curry 2000). Wind turbine congestion also might relate to bird mortality (Orloff and Flannery 1992). Other tall structures in the wind farm might divert flying birds into the rotor planes of operating wind turbines (Kerlinger and Curry 2001). However, Orloff and Flannery (1992) found no relationship between bird fatalities and wind turbine congestion, inter-turbine spacing, or the density of all structures around each wind turbine. Orloff and Flannery (1992) also found that bird mortality did not relate significantly to the turbine row's length, orientation, or whether it was part of a wind wall.

Orloff and Flannery (1992) found that wind turbines installed in rows (i.e. "turbine strings") forming local edges were no less dangerous than were other wind turbines.

Investigators have differed on whether fatalities are proportionately more common at mid-row wind turbines (Howell et al. 1991; Howell and Noone 1992; Anderson et al. 2001) or end-row

wind turbines (Winkelman 1992; Orloff and Flannery 1992, 1996; Curry and Kerlinger 2000). Gaps in wind turbine rows have also been identified as more dangerous to birds (Curry and Kerlinger 2000; Thelander and Rugge 2001. On the other hand, Smallwood et al. (2001) found that neither ends of rows or gaps killed more birds, and Thelander and Rugge (2000a,b, 2001) concluded no more birds die at end-of-row turbines than at others.

Rogers et al. (1976) suggested that wind turbines are more dangerous on ridge crests or hill peaks, and Colson (1995) also suggested that wind turbines on ridge crests are more dangerous. Wind turbines have been considered more dangerous when located on ridge saddles or shoulders of hills (Howell and DiDonato 1991; Howell et al. 1991; Colson 1995; Curry and Kerlinger 2000), on the edges of rims (Strickland et al. 2000a), or in canyons (Orloff and Flannery 1992, 1996; Colson 1995; Kerlinger and Curry 1999). Orloff and Flannery (1992) and Rugge (2001) concluded that wind turbines at higher elevations killed more birds.

Orloff and Flannery (1992) also concluded that more raptors than non-raptors were killed at wind turbines on steep slopes, and that wind turbines with two steep slopes within 154 m also killed more raptors. Curry and Kerlinger (2000) concurred that steeper slope are more dangerous to birds, and Rugge (2001) concurred that greater topographic complexity was more dangerous. However, Orloff and Flannery (1992) concluded slope aspect was insignificant, but Rugge concluded it was significant when examined at a species-specific level.

Some researchers feel that the development of wind energy generating facilities also attracts small mammals, which then attract predatory birds to the wind farm (Hunt and Culp 1997; Hoover 2001; Curry and Kerlinger 2000; Kerlinger and Curry 2001; Hunt 2002). Roads built to access the wind turbines are thought to extend the range of distribution of ground squirrels (Colson 1995; Morrison 1996) and pocket gophers (Smallwood et al. 2001). Hunt (2002) claimed ground squirrels are more abundant where the wind turbines are located. Smallwood et al. (2001) reported golden eagle fatalities to be more common at wind turbines with at least three ground squirrel burrows within 55 m. Researchers have contended that raptors become preoccupied with hunting prey animals and therefore they inadvertently run into moving wind turbine blades (Smallwood et al. 2001; Hunt 2002). However, Hoover (2001) and Hoover et al. (2001) reported that red-tailed hawks are not attracted to ground squirrel colonies, and Orloff and Flannery (1992) reported that raptor mortality was unrelated to ground squirrel abundance.

Hunt (2002) claimed that golden eagle radio-locations from a telemetered population were more common on land parcels where rodenticides were not deployed. Cattle grazing have been thought to lower the average vegetation height, thus favoring ground squirrels (Morrison 1996). Cattle carcasses were identified as a possible attraction to golden eagles (Hoover 2001). Janss and Clave (2000) suggested carrion could attract raptors to a wind farm, and carrion is abundant in the APWRA due to the frequent deaths of cattle that are left to decompose *in situ*. Also, carrion abundance increases during the fall after the most intense ground squirrel control efforts are conducted. It is at that time that poisoned squirrels litter the hillsides, and dead squirrels and desert cottontails are clustered in and around the rock piles constructed near some turbine strings. Lastly, Kerlinger and Curry (2000) claimed that land used for cattle grazing does not attract raptors, although they provided no quantitative evidence or explanation of how they came to this conclusion.

Other factors associated with bird fatalities at wind energy generating facilities include inclement weather (Colson 1995; Johnson et al. 2002), particular seasons (Rugge 2001; Hunt 2002), and the rotor wake pushing birds into the ground (Winkelman 1995).

Most of these suggested causal factors were addressed in this study. We represented the factors with measured variables, and related them to the distribution of bird fatalities in the APWRA Our objective was to systematically test hypotheses stemming from the conclusions put forth by previous research efforts in the APWRA (and summarized in the preceding paragraphs). To do so required compiling an extensive database on bird fatalities. The ultimate aim of these association analyses was to formulate predictive models of fatalities for each of several bird species of interest.

7.2 METHODS

Methods used for fatality searches are described in Chapter 3, Section 3.2, Methods.

We collected data on each fatality along with the associated season, tower type, turbine type, tower location within the string, the aspect of the slope on which the string of turbines was situated, and attributes of the physical relief of the study plot. Except for season and weather, these same variables were recorded for all wind towers in our study area, whether or not birds were ever reported killed there. We used a global positioning system (GPS) device to record these attribute data.

7.2.1 Variables

We defined seasons of the year as spring (March 1 through May 31), summer (June 1 through September 25), fall (September 26 through November 15) and winter (November 16 through the end of February). We attributed fatalities to season of the year after projecting the actual fatality event from the date of discovery to the estimated number of days since the fatality had likely occurred. For example, if we found a carcass on October 30 and we estimated number of days since death as 45, then we attributed the fatality to September 15, which would be during summer. For estimating the association of mortality with season of the year, we only used fatalities estimated to have occurred within 90 days and to have been caused by collisions with wind turbines.

We attributed each wind turbine according to its rated output and model of manufacture. Each model and size combination also included a suite of physical characteristics such as rotor diameter and blade tip speed. The relationship between each of these variables and bird mortality usually was similar to the relationships between the other physical attributes of the wind turbine and bird mortality, because the suite of variables characteristic of each wind turbine model/size shared considerable variation.

In Chapter 1, Table 1-1 we summarized the wind turbine attributes of the wind turbines included in our sample in the APWRA. Rotor diameter equals the distance through the center and to the

extremes of the rotor plane. Tip speed equals the speed of movement of the rotor at the outer tip of the blade. We tracked this variable in kilometers per hour (kph), but converted it to meters per second (m/s) for deriving the variables below.

We calculated the window of opportunity (i.e., time) when birds could fly through the rotor plane at the tips of the blades while the rotor operated at normal speed. This window was calculated as follows:

$$\text{Window} = C \div T \cdot B,$$

where C is the circumference of the rotor plane (or $2\pi r$, where r is the radius of the rotor plane, or one half the rotor diameter), T is the tip speed in m/s, and B is the number of blades on the rotor. This variable measured the number of seconds intervening blade sweeps at a particular location at the edge of the rotor plane. The values for the wind turbines in the APWRA ranged from 0.273 to 0.695 seconds. Thus, any bird taking 0.7 seconds or longer to clear the rotor plane of a normally operating wind turbine would almost certainly be injured or killed.

We calculated the area of the rotor plane swept per second by the wind turbine's blades:

$$\text{Swept rate} = TrB \div 2,$$

which, after cancellations of terms, was derived from the function:

$$\text{Swept rate} = (T/C) \cdot AB,$$

and A is the area of the rotor plane in square meters (m^2). This variable characterizes the magnitude to which the sky is disrupted by the operation of the wind turbine, or the extent that the rotor plane is an obstacle to flying birds. It is measured in m^2/s.

Blade color schemes included white, black stripes on white background, red tips, and green tips.

Tower height is measured as the distance, in meters, from the ground to the rotor. For comparison purposes, we excluded vertical axis turbines from our test of the effect of tower height on bird mortality. In one set of tests, we included vertical axis turbines, and in another set we excluded them because the movement of the blades was fundamentally different from that of the horizontal axis turbines.

Tower type was characterized, but tower type and turbine type were sometimes confounded. We compared bird mortality between vertical axis towers/turbines to both tubular and lattice towers supporting horizontal axis turbines. We performed this simplified comparison to test whether perching relates to bird mortality. Perching was assumed to be less likely on vertical axis and tubular towers than on lattice towers, although perching can occur on any tower.

We mapped the perimeters of artificially made rock piles and related bird mortality to the incidence of these piles, which had been constructed as a mitigation measure during installation of the turbines. The rocks were removed from wind turbine laydown areas and piled near the

wind turbines. They were intended as den habitat for prey species of San Joaquin kit fox. We noticed that ground squirrels and desert cottontails frequently used these rock piles. It occurred to us that rock piles might draw raptors, because they tended to concentrate prey species. The incidence of rock piles at each turbine string was characterized as none, less, or equal to 0.25 piles per turbine, and > 0.25 piles per turbine.

An edge index for the wind turbine/tower laydown area was measured from the string transect while viewing the 40-m radius from the wind turbine. The index categories were: 0 = no vertical or lateral edge within 40 m of the wind turbine; 1 = some lateral edge such as the presence of a dirt road other than just the service road found at all of the wind turbines, or the presence of a cleared area adjacent to vegetated area, or area tilled for pipeline, etc.; 2 = lots of lateral edge; 3 = some vertical edge such as a road cut, road embankment, or cut into the hillside for creating a flat laydown area; 4 = lots of vertical edge, covering half or more of the area within 40 m of the wind turbine; and 5 = lots of vertical and lateral edge within 40 m of the wind turbine. The edge index was measured to test whether raptors spent disproportionate amounts of time near wind turbines with greater lateral and vertical edge, presumably for improved foraging opportunities. If such was the case, then they had a higher likelihood of being killed by operating wind turbines.

The position of each turbine in the APWRA was classified as "edge" for all those wind turbines facing a landscape devoid of wind turbines outside the APWRA, as "local edge" for all those adjacent to large spaces within the APWRA where no wind turbines occur, and as "interior" for all those not at the APWRA edge or local edge.

7.2.2 Analysis

The statistics presented here satisfy our objectives, as well as the assumptions of the corresponding hypothesis tests. For example, correlation analyses are summarized by the coefficient of determination, R^2, when prediction is the ultimate objective. They are summarized by Pearson's correlation coefficient, r_p, when the objective is simply to summarize the degree of correlation. We report weak and non-significant correlations when doing so meets our objectives, or when the measures of effect are informative despite the non-significance of the test.

Because R^2 is based on two independent factors (i.e., the steepness of the regression slope and the precision of the data relative to the regression line), we often also include the root mean square error (RMSE), which measures the latter. R^2 alone is an inefficient summary statistic for some of our hypothesis tests.

Although we use ANOVA to test some hypotheses in this study, several key assumptions of ANOVA cannot be met due to the absence of block design or related controls on treatment replication or interspersion. Even though we are studying an anthropogenic system, ours is a non-manipulative study. Our "replicates" and our degrees of interspersion of "treatments" were established by the placement of wind towers by the industry prior to our study. As a mensurative

study, the chi-square family of statistical tests is, therefore, most efficient for testing many of our hypotheses (Smallwood 1993, 2002).

For all hypotheses tested, we relied on the α-level of significance of 0.05. However, we also took note of P-values less than 0.1 as indicative of trends worthy of further research or consideration. The observed/expected values derived from χ^2 tests are used as measures of effect, and need to be interpreted based on the P-value of the test, whether the expected number of observations was larger than 5 (smaller than 5 is generally regarded as unreliable), and the magnitude of the ratio. These latter considerations for assessing the significance of particular observed/expected values we leave to the reader.

For association analyses, expected values were calculated by multiplying the total number of fatalities by the incidence of the environmental element being compared in the measured set. The incidence was the proportion of the total search effort, or the sum of the time spans over which each wind turbine composing element *i* was searched, divided by the sum of the time spans over which all of the wind turbines were searched.

Search effort at the turbine level of analysis was calculated as:

$$\text{Turbine Search Effort} = Y_t \div \Sigma Y,$$

and,

$$\text{Incidence, } P_i = \Sigma \text{ (Turbine Search Effort of all wind turbines composing element } i\text{)},$$

and then,

$$\text{Expected} = N \times P_i,$$

where Y_t is the number of years during which fatality searches were performed for a given wind turbine, ΣY is the number of years of fatality searches across all wind turbines, and N represents the total number of fatalities compared within the measured set of environmental elements.

Search effort specific to season of the year was calculated as:

$$\text{Season-specific Turbine Search Effort, } Y_{t,s} = (S_s \div S_t) \times Y_t \,.$$

where S_s was the number of searches made at the wind turbine during a particular season and S_t was the total number of searches made at the wind turbine. This search effort was adjusted by the searches during the next season that could document fatalities < 90 days old and that occurred during this season:

$$\text{Adjusted Season-specific Turbine Search Effort} = Y_{t,s} + 0.5 \times Y_{t,s+1} \,,$$

where $Y_{t,s+1}$ represents the search effort at the turbine during the following season. Essentially, we added half of the next season's search effort to the targeted season search effort. The sum of the

adjusted season-specific turbine search effort values was divided into the sum of all these values across seasons in order to arrive at a proportion of the total search effort that was made per season across the APWRA.

Tests for relationships between bird fatalities and rodent burrow distributions were performed at the turbine string level of analysis, because we felt that our representations of burrow distributions were more robust at this level. Performing the analysis at this level introduced an additional complication of search effort, because turbine strings varied in length (i.e., number of wind turbines) and cumulative rotor swept area (we term this "windswept area"), as well as the number of years devoted to searching the wind turbines.

Figure 7-1A illustrates the strong relationship between fatalities and search effort at the string level of analysis ($r_p = 0.74$, $N = 472$, $P < 0.01$), requiring that fatality rates be adjusted by search effort. Therefore, the relative search effort devoted to each turbine string was calculated as:

$$\text{String Search Effort } (m^2 \cdot \text{years}) = N_t \times R \times Y,$$

where N_t is the number of wind turbines in the string, R is the mean rotor swept area in m^2, and Y is the number of years the string was searched.

Figure 7-1B illustrates the inverse power relationship between a fatality rate and search effort, which casts doubt on the reliability of a simple conversion of fatalities to fatality rates (mortality) for inter-string (or inter-site) comparisons and hypothesis testing. This relationship resembles the patterns in estimates of animal density related to the sizes of the area used to make the estimates (Blackburn and Gaston 1996; Smallwood and Schonewald 1996), rendering their comparisons inappropriate among study sites of varying sizes.

A more appropriate approach to factoring in differential search effort for comparing the frequencies of fatalities is to estimate expected frequencies of fatalities based on the measured set of fatalities relative to that of the element of the wind farm being associated with the fatalities (Smallwood 1993, 2002). The incidence of the compared element in the string within the measured set of searches across all the strings was calculated as:

$$\text{Effort}_i \div \Sigma \text{ Effort},$$

and was the basis upon which expected χ^2 values were estimated at the string level of analysis.

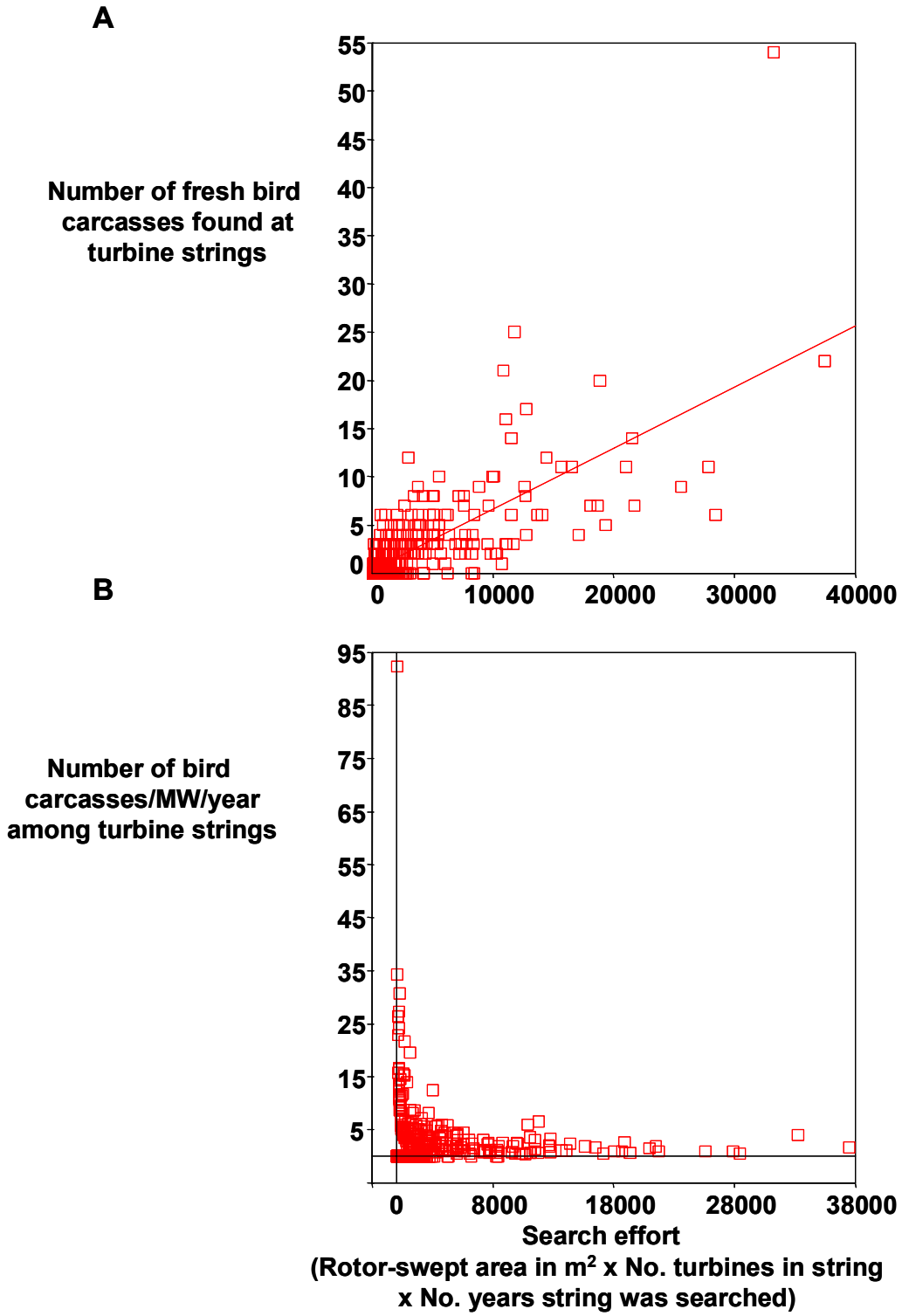


Figure 7-1. The number of fresh bird carcasses found at wind turbine strings was a linear function of carcass search effort (A) and turbine-caused bird mortality was an inverse power function of search effort (B).

7.2.3 Measures of Effect

In-depth examination of test results was based on two measures of effect. The first was the observed-divided-by-expected values, which measures the number of fatalities at that element of the measured set as a multiple of what would be expected from a uniform or random distribution of fatalities throughout the measured set. The second was the percentage of total fatalities that can be attributed to the variable's attribute in question, and is measured as the following:

$$\text{Accountable Mortality} = (\text{Observed} - \text{Expected}) \div \text{Total fatalities} \times 100\%.$$

This measure is similar to the one used in Smallwood and Erickson (1995). Positive values express the percent of the total fatalities likely killed at wind turbines due to the attribute associated with the value, and negative values express the percent of the total that were expected to have been killed if fatalities were random, but that were not killed. Thus accountable mortality ranged from -100% to 100% of the fatalities attributable to a particular category of an association variable.

7.2.4 Predictive Model

Accountable mortality values were the weightings applied to the models developed for each of twelve species. The values used were restricted to variables with significant chi-square tests for association, which were based on expected cell values mostly > 5 and which were either categorical in nature (e.g., tower type) or showed gradients in accountable mortality along a continuum (i.e., along categories that expressed a continuum, such as elevation or rotor diameter). For those variables included in the model, accountable mortality values were summed across the variables to arrive at a score:

$$\text{Predicted Impact} = \Sigma \text{ accountable mortality}.$$

Predicted impact values > 0 represented wind turbines more likely to kill individuals of the species in question. Negative or zero values represented wind turbines less likely to kill individuals of the species in question. Predicted impacts were additional to impacts that we could not account for based on the data we collected, which probably included a baseline level of impacts that were random or due simply to the fact that all wind turbines pose an inherent danger to birds because they are tall structures with moving parts into which birds can collide.

Model predictions of impact were compared to the impact we measured, where in this case the impact was the number of fatalities we recorded at the particular wind turbine. We assessed the effectiveness of the model by the percent correct classification of the wind turbines that killed birds. We also assessed the model based on the percentage of wind turbines predicted to cause greater impact (i.e., predicted impact > 0) but at which we found no fatalities during our study. It is reasonable to assume that these wind turbines will more likely kill birds, even though we did not find them yet, and this percentage informs of the level of effort needed to modify wind turbines and range management practices to substantially reduce collisions involving that species.

Lastly, we examined the percentage of the fatalities associated with the correct classification of wind turbines as those more likely to cause an impact. This percentage informs of the degree to which mortality could be reduced per species by modifying conditions expressed by the variables composing the model, assuming no interaction effects between predictor variables.

7.3 RESULTS

7.3.1 Sample Characteristics

Our sample of wind turbines and our sampling effort included mostly KCS-56 and Bonus turbines (Figure 7-2). Our sample and sampling effort of towers included mostly lattice and tubular towers (Figure 7-3). Our sample included a wide range of rotor plane areas swept per second during ordinary wind turbine operations (416 to 1246 m^2/s), although many of the wind turbines sampled swept a larger area per second (Figure 7-4). The area in the rotor plane swept per second, as well as the window of time birds could fly through the rotor plane at the blade tips, was more a function of rotor diameter than of tip speed (Figures 7-5 and 7-6).

Similarly, our sample included a wide range of tower heights, ranging from 14.0 to 43.1 m (Figure 7-7). Our sample, however, was influenced largely by 18.5 and 24.6-m towers, those supporting KCS-56 and Bonus turbines, respectively. Most of the wind turbines in our sample of turbines were designed to face the wind, but a considerable number also faced away from the wind (Figure 7-8).

The majority of the wind turbines in our sample were situated in the interior of turbine strings (Figure 7-9), and the majority was situated in the interior of the wind farm (Figure 7-10). Most were on hill slopes, ridgelines, and ridge crests (Figure 7-11), and only a relatively few wind turbines occurred within canyons (Figure 7-12). Nearly a third of the wind turbines in our sample were installed on peaks, ridge crests, and plateaus, to which no slope aspect applied, and relatively few turbines occurred on southwest and west-facing slopes (Figure 7-13).

The wind turbines ranged in elevation from 61 m to 532 m above sea level, and most occurred within two sub-ranges of elevation, from 120 to 220 m and from 280 to 450 m (Figure 7-14A). Our search effort applied to the wind turbines was more evenly distributed among elevations, however (Figure 7-14B). The wind turbines in our sample averaged 7˚ of slope, and they were right-skewed in frequency of occurrence in the sample (Figure 7-15A) but more evenly represented in the search effort (Figure 7-15B).

The number of wind turbines within 300 m of each wind turbine averaged 25, and ranged from 3 to 71 with a right-skewed frequency distribution (Figure 7-16A). The search effort generally corresponded with the frequency distribution (Figure 7-16B).

More than half of the wind turbines in our sample were within areas where rodent control was applied intensively by 2002; whereas, many of the wind turbines recently added to our sample were located on ranches where rodent control had not been conducted (Figure 7-17).

Fall was the least-sampled season of the year (Figure 7-18).

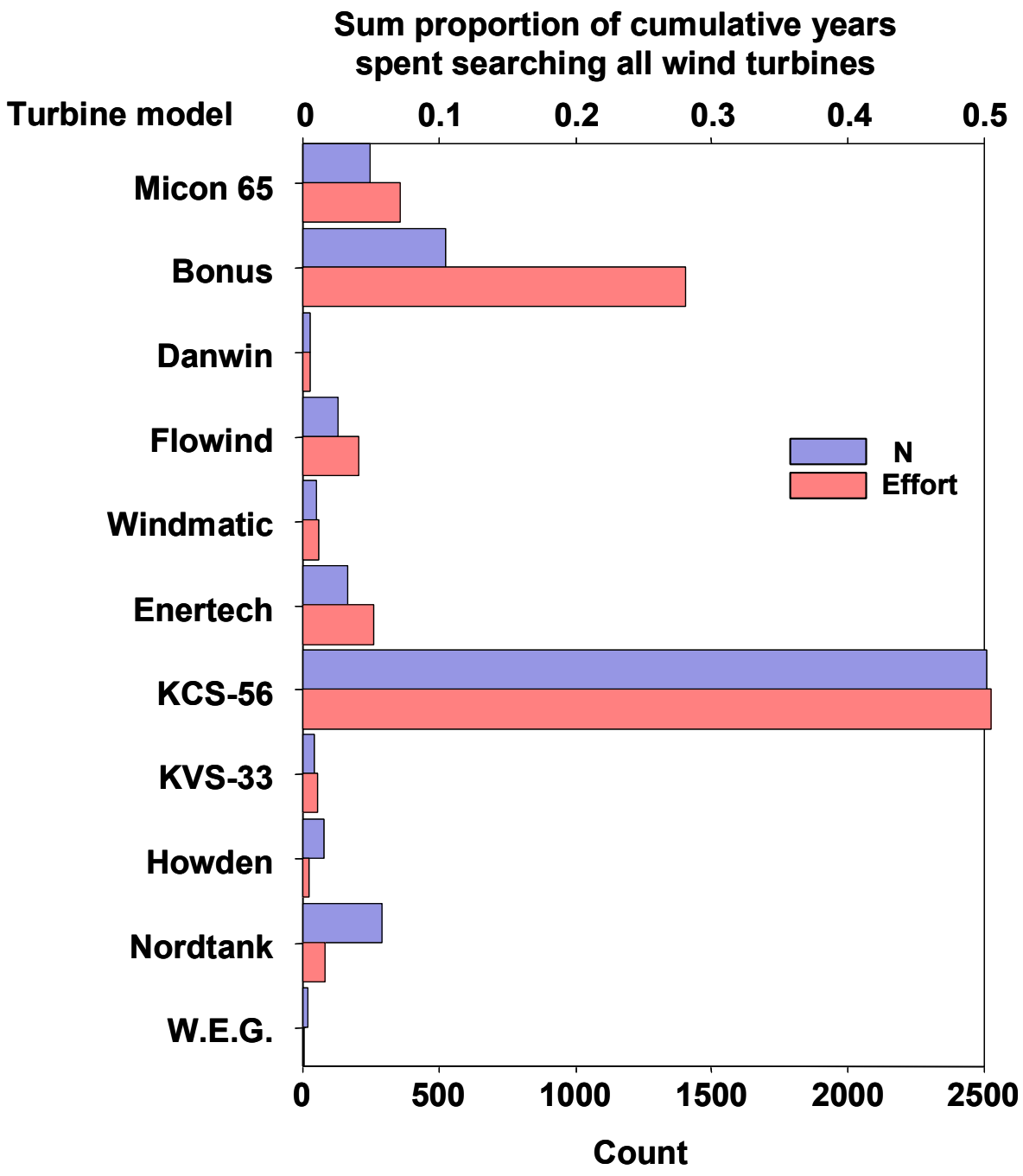


Figure 7-2. Frequency distributions of wind turbine models and search effort at those models in our sample in the APWRA

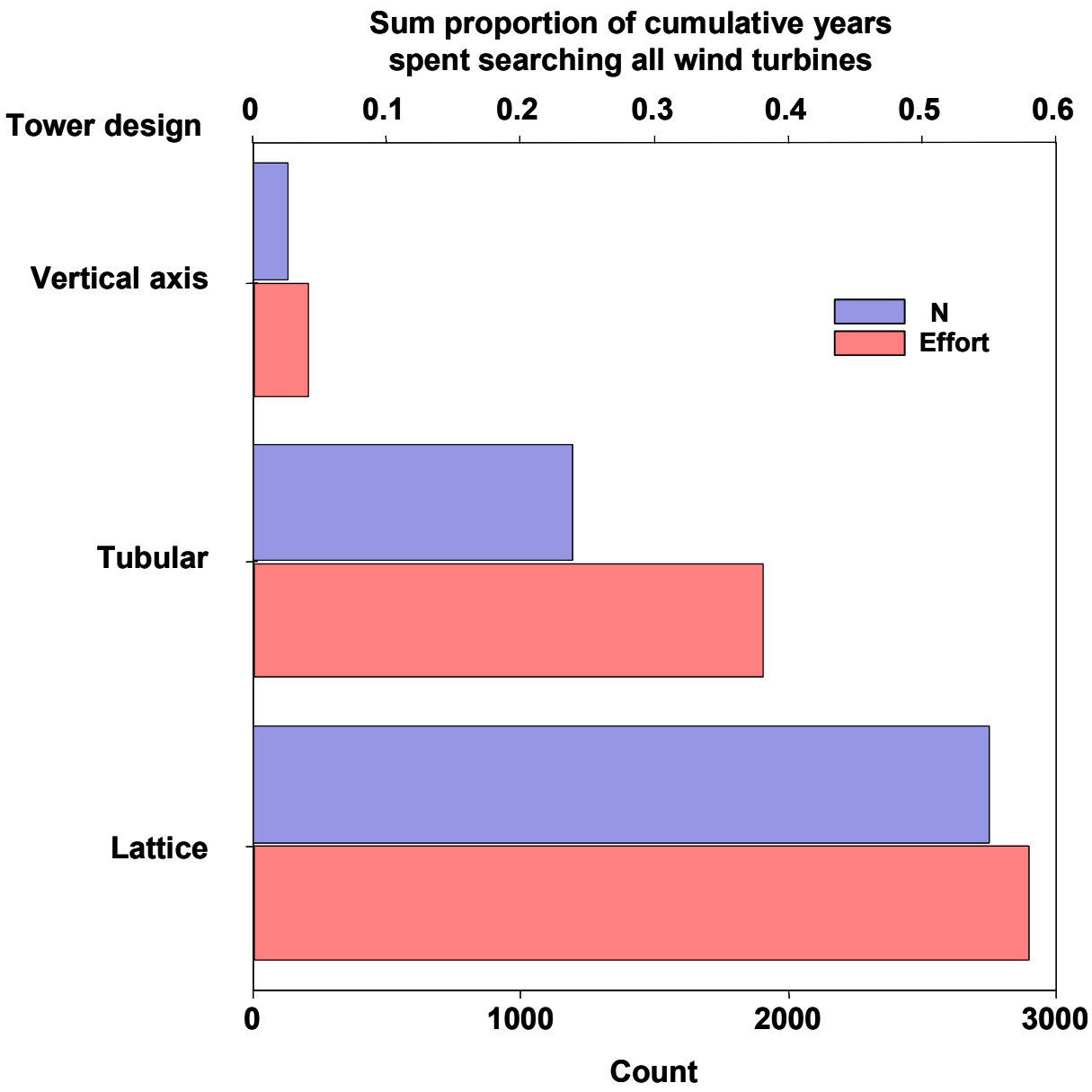


Figure 7-3. Frequency distributions of wind tower types and search effort at those tower types in our sample in the APWRA

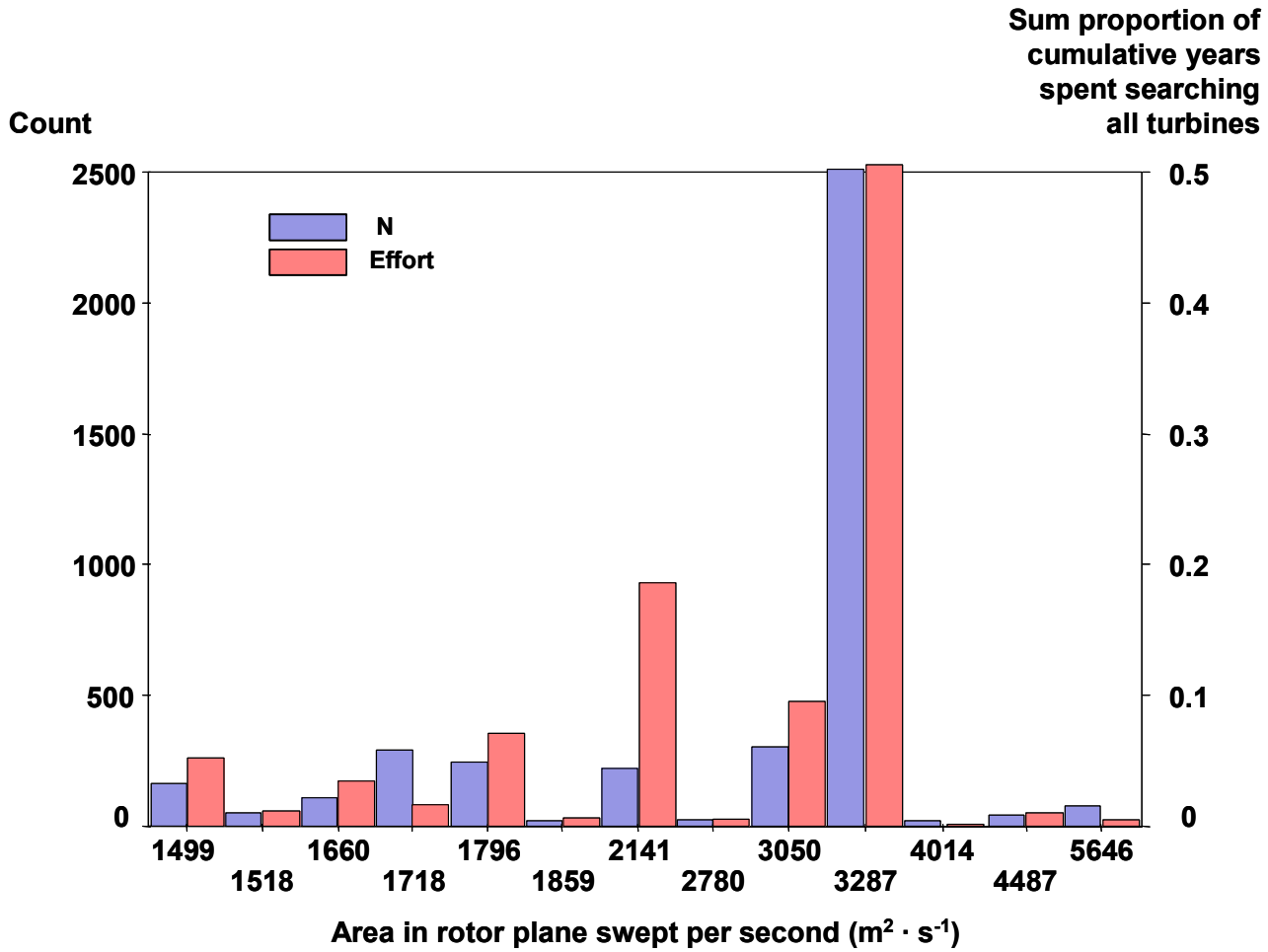


Figure 7-4. Frequency distributions of rotor swept area and search effort at those rotor swept areas characteristic of wind turbines in our sample in the APWRA

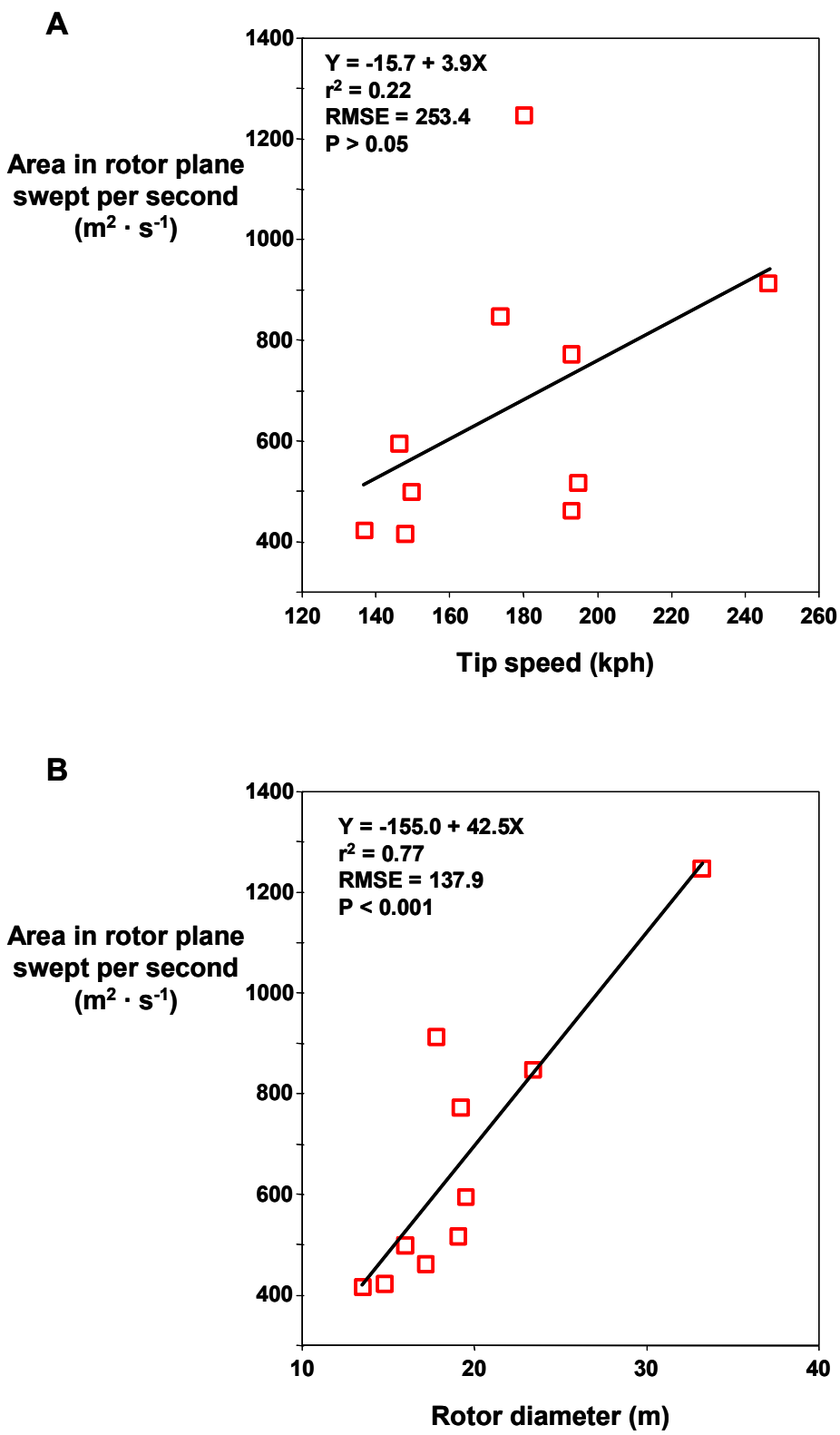


Figure 7-5. The rotor swept area swept per second was a linear function of blade tip speed among the wind turbine models in the APWRA (A), but it was more responsive and precisely related to rotor diameter (B).

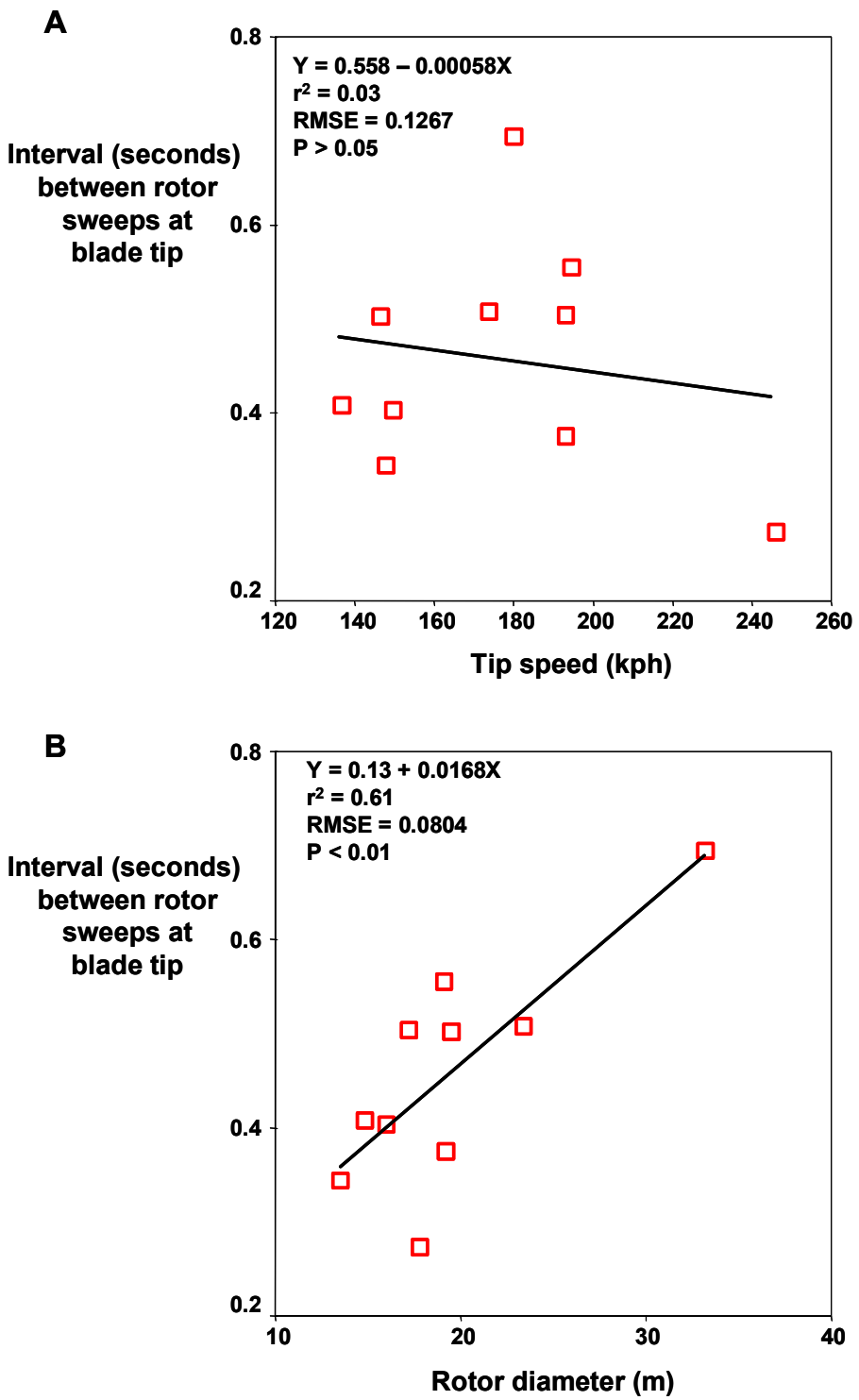


Figure 7-6. The time period intervening blade sweeps at the edge of the rotor place did not relate to blade tip speed (A), but it was a linear function of rotor diameter (B).

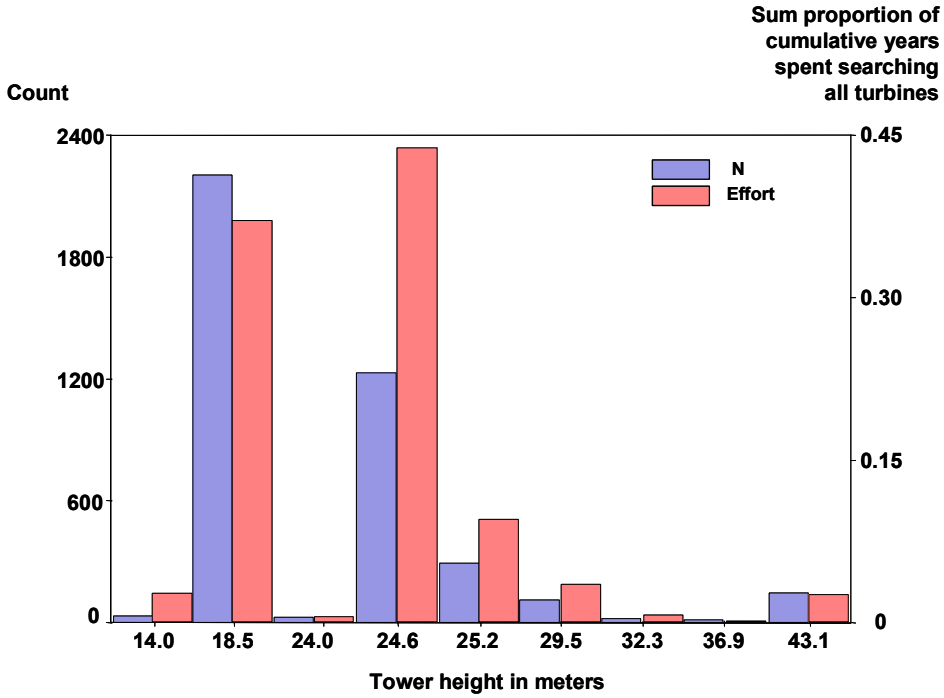


Figure 7-7. Frequency distributions of wind tower heights and search effort at those tower heights in our sample in the APWRA

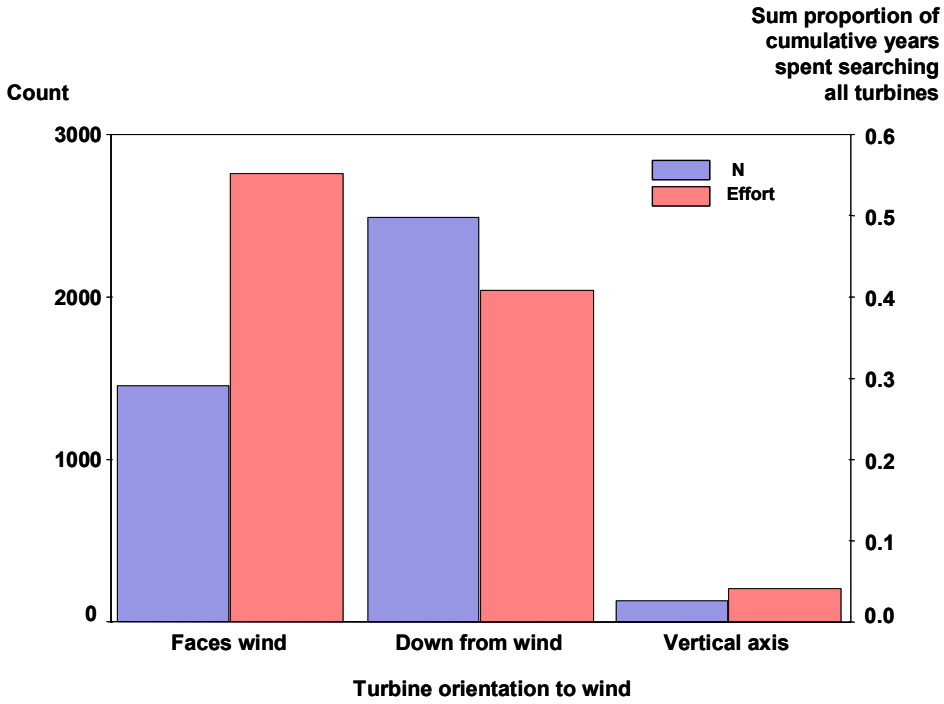


Figure 7-8. Frequency distributions of wind turbine orientations to the wind and search effort at those orientations among wind turbines in our sample in the APWRA

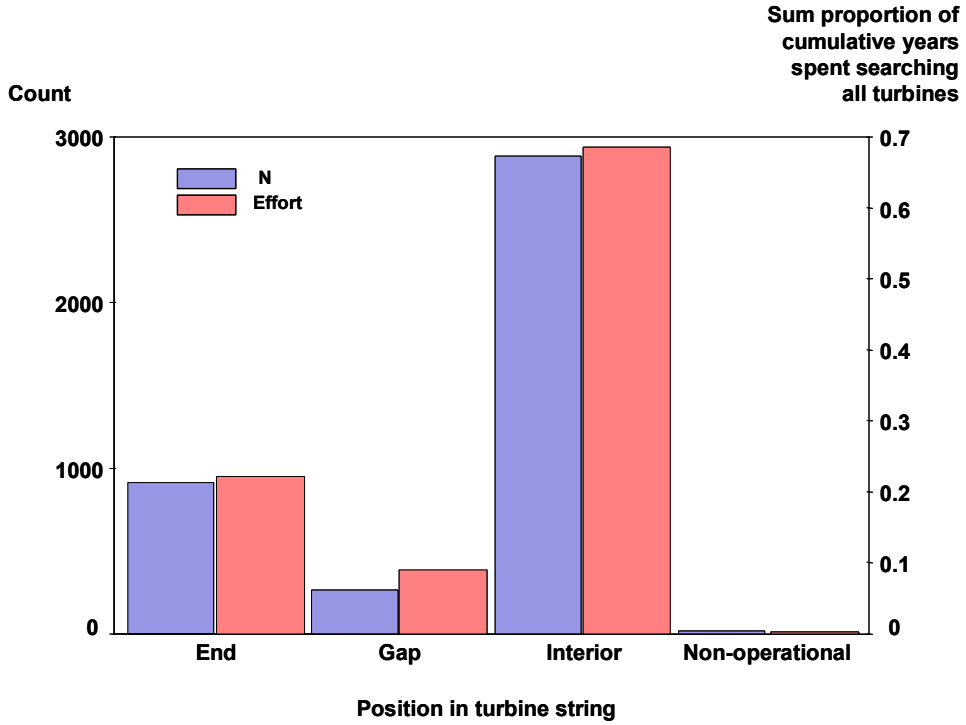


Figure 7-9. Frequency distributions of wind turbine positions in the string and search effort at positions in our sample in the APWRA

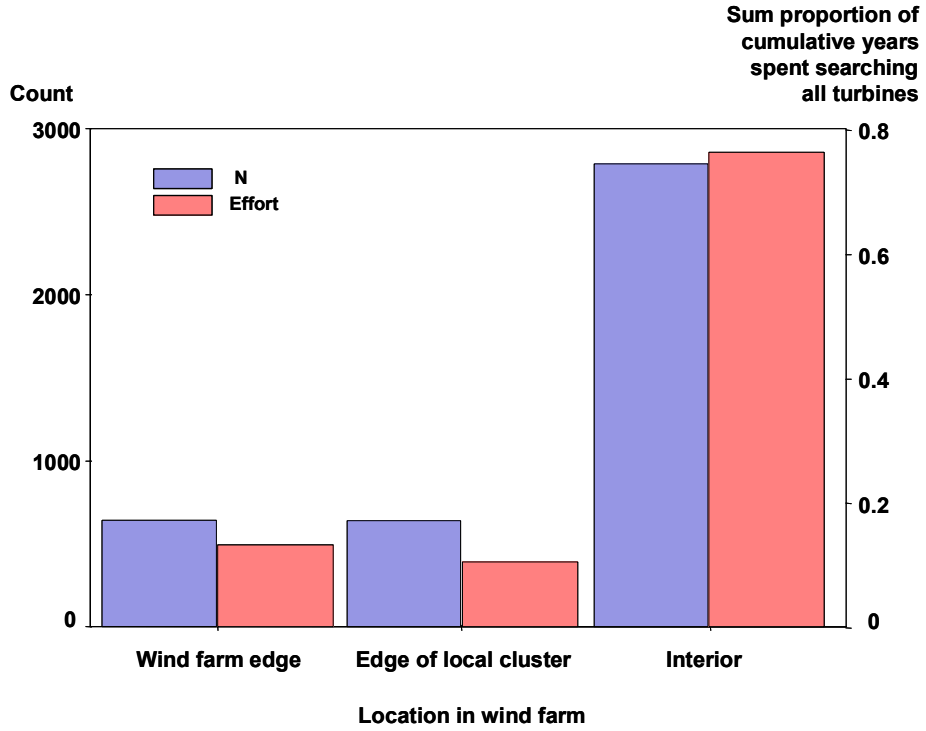


Figure 7-10. Frequency distributions of wind turbine locations in the wind farm and search effort at locations in the APWRA

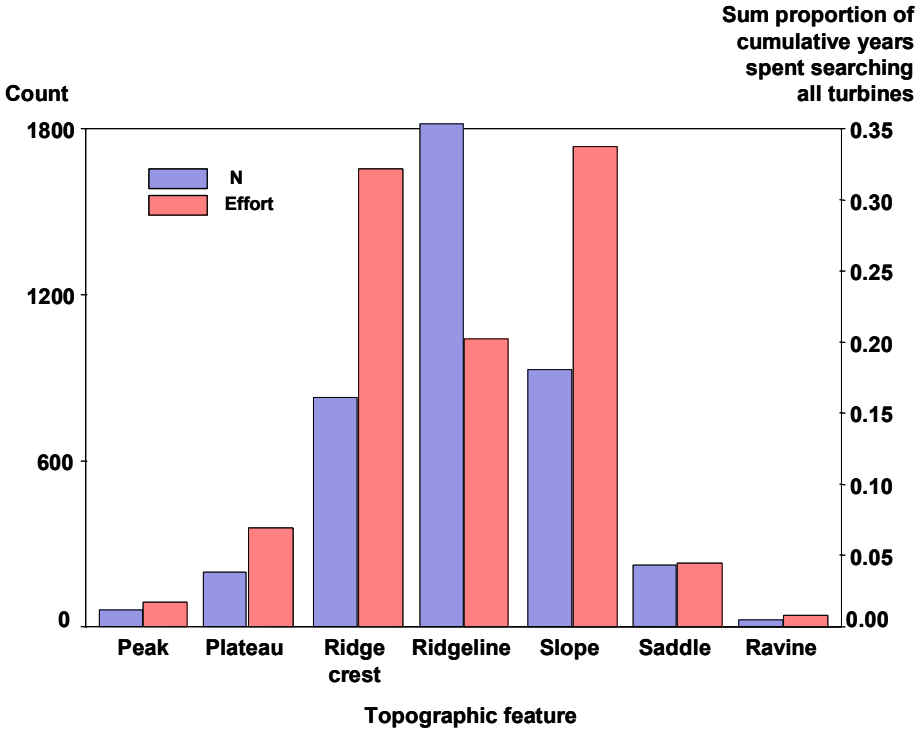


Figure 7-11. Frequency distributions of types of physical relief at wind turbines and search effort at these types of relief in the APWRA

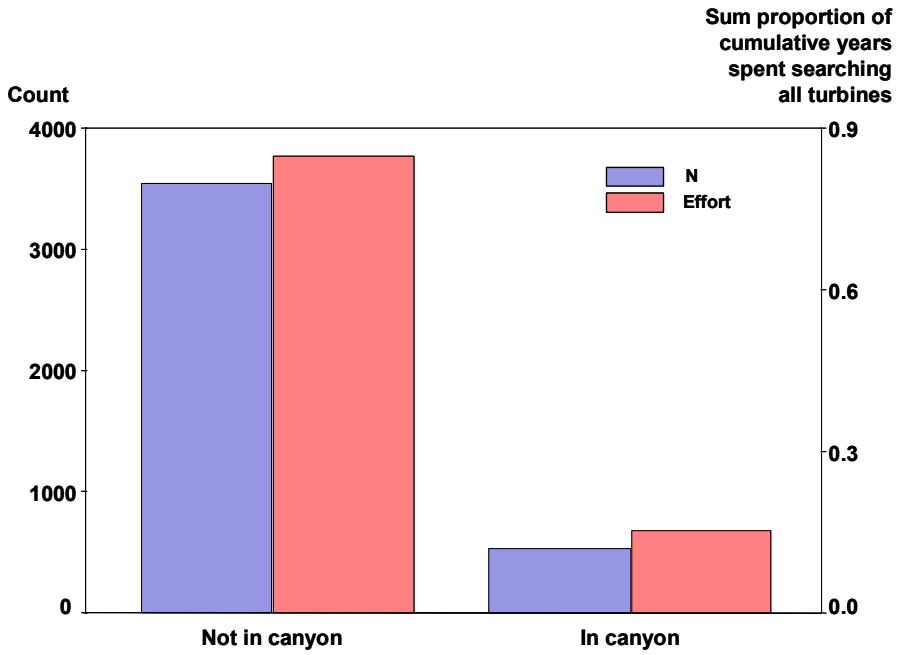


Figure 7-12. Frequency distributions of wind turbines in and out of canyons and search effort at these turbines in the APWRA

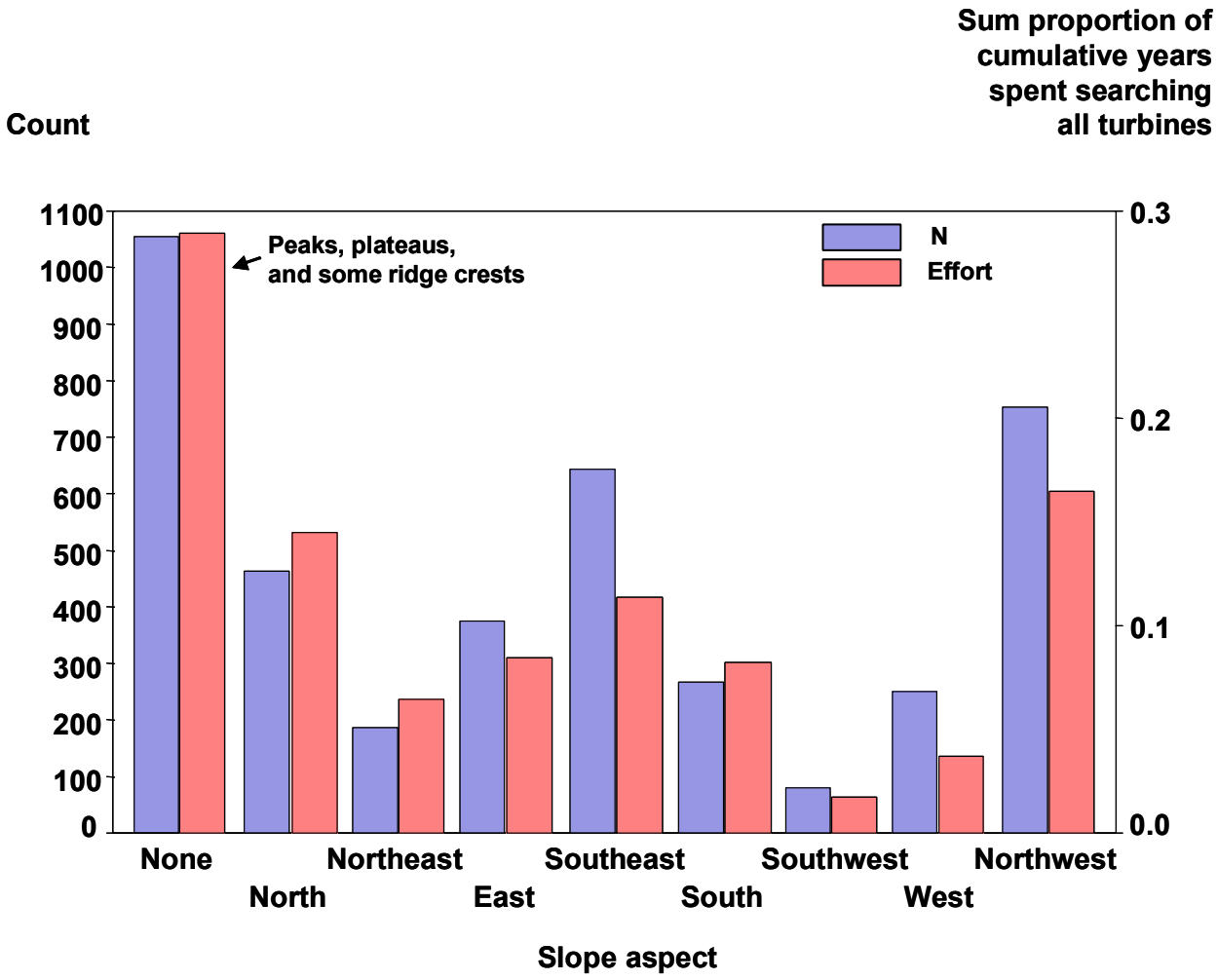


Figure 7-13. Frequency distributions of wind turbines and search effort at these turbines among slope aspects in the APWRA

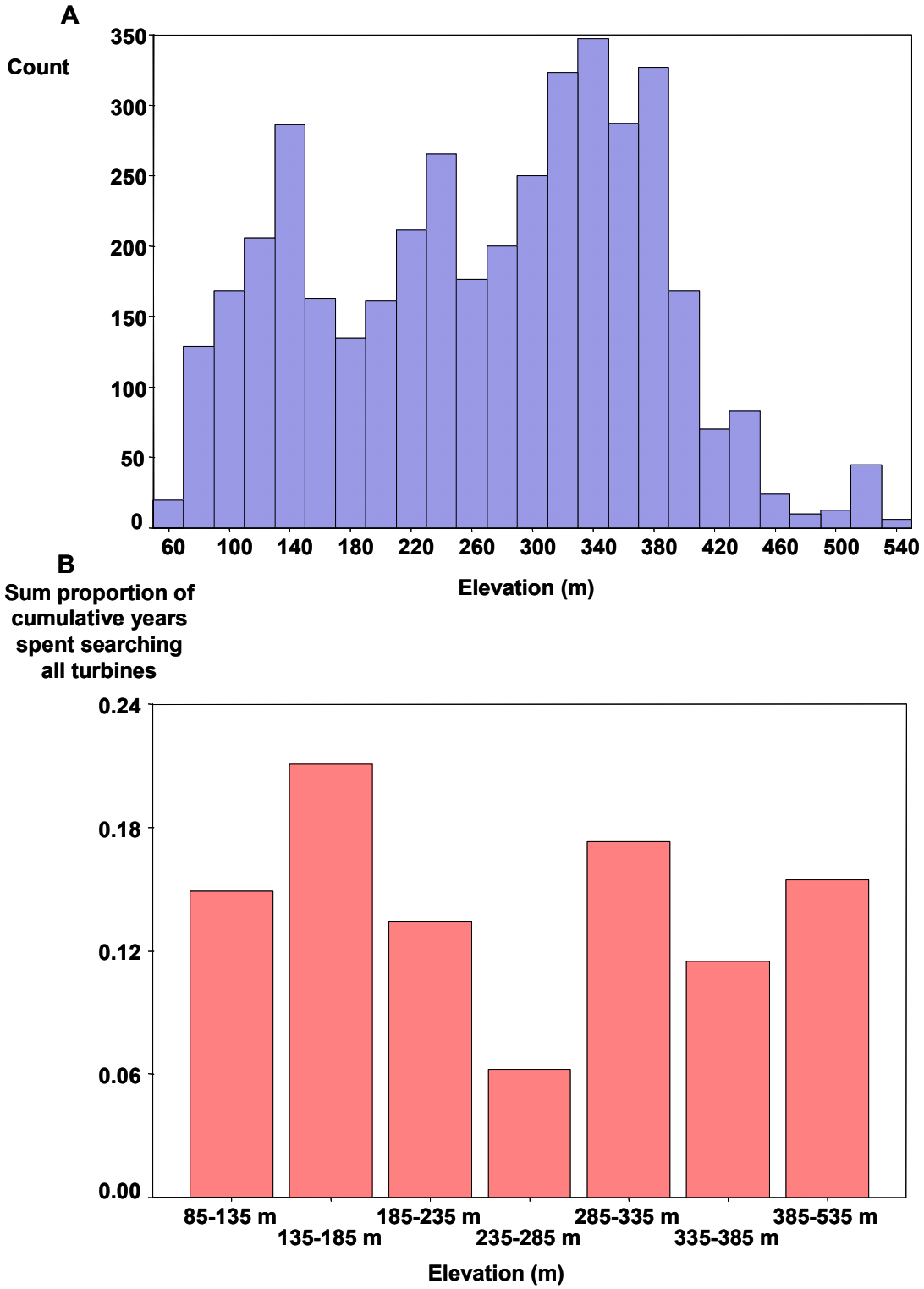


Figure 7-14. Frequency distributions of wind turbines (A) and search effort (B) at these turbines among elevations in the APWRA

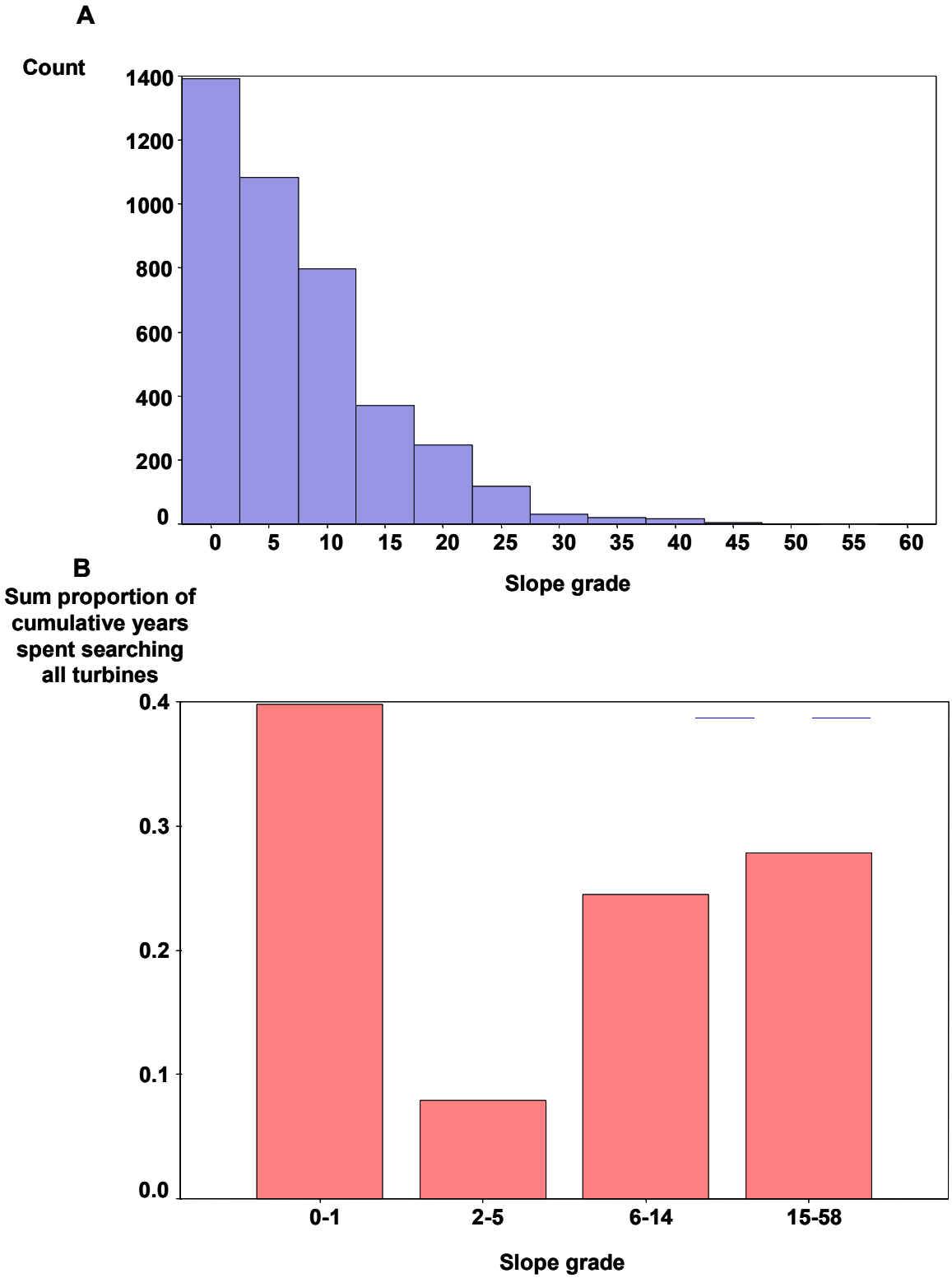


Figure 7-15. Frequency distributions of wind turbines (A) and search effort (B) at these turbines among slope grades in the APWRA

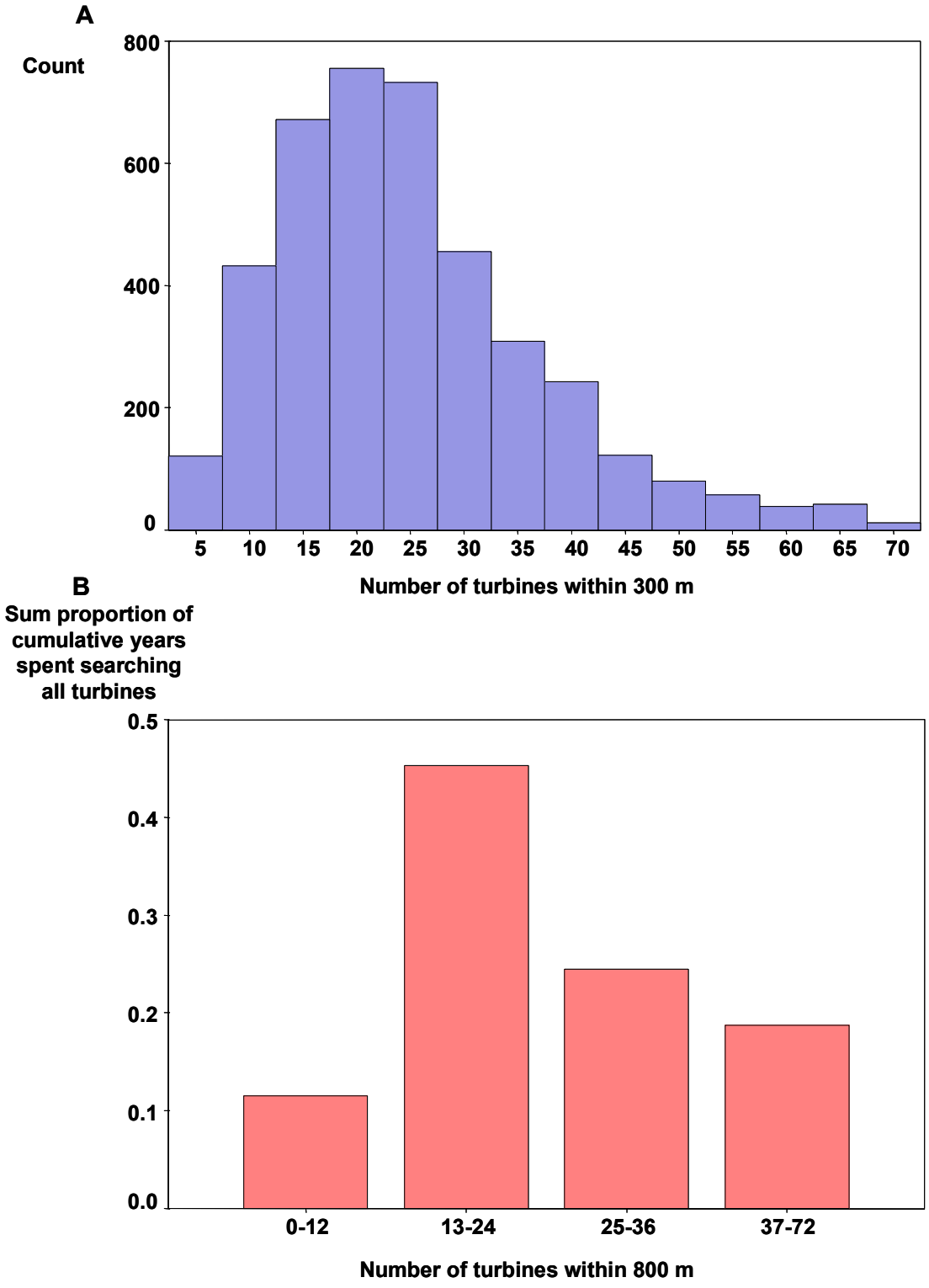


Figure 7-16. Frequency distributions of wind turbines (A) and search effort (B) at these turbines among counts of other wind turbines within 300 m of each wind turbine in the APWRA

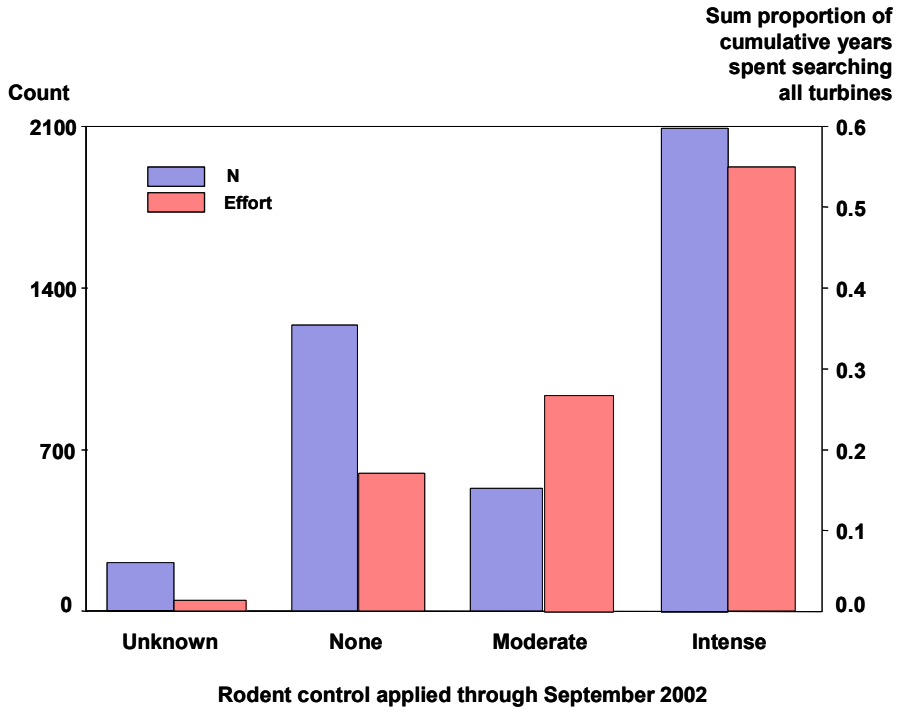


Figure 7-17. Frequency distributions of wind turbines and search effort at these turbines among levels of rodent control intensity applied in the APWRA

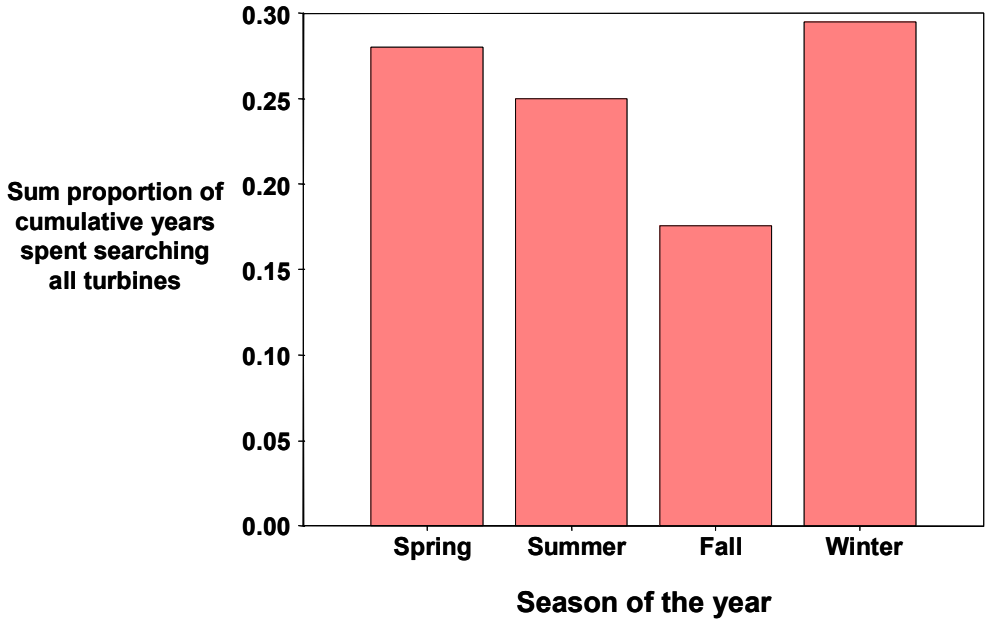


Figure 7-18. Frequency distribution of search effort at these turbines during the four seasons of the year

7.3.2 Fatality Associations

Tables 7-1 through 7-3 list the chi-square test values and their levels of statistical significance. Some variables were repeated in Table 7-3 because we aggregated the original categories into a smaller set of categories. The differences between the test results in these cases are evident in their degrees of freedom (df). For these variables, original categories were not included in Tables 7-1 and 7-2 because the smaller sample sizes of fatalities did not warrant testing of the number of original categories in the variables. When variables were aggregated in Table 7-3, only results from the aggregated categories were used in predictive model development.

Table 7-1. Chi-square values of association between the number of fatalities of raptor species and independent variables, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005; and GOEA = golden eagle, RTHA = red-tailed hawk, AMKE = American kestrel, BUOW = burrowing owl, BAOW = barn owl, and GHOW = great-horned owl

Predictor Variable	df	GOEA	RTHA	AMKE	BUOW	BAOW	GHOW
Turbine model	10	17.98 [t]	20.70*	78.59**	44.59**	7.23	5.47
Turbine size	8	15.41 [t]	16.62*	74.42**	33.89**	7.07	4.82
Rotor diameter [a]	5	3.67	24.69**	50.89**	17.28**	5.21	4.5
Tip speed [a]	2	1.44	8.43*	1.94	26.75**	1.67	3.32
Window [a]	2	0.66	2.19	0.72	27.43**	5.86 [t]	3.45
Rotor-swept area/sec [a]	3	4.83	9.72*	40.71**	24.83**	2.70	4.08
Tower type	2	2.34	6.74*	2.71	34.37**	0.56	1.87
Tower height [a]	4	11.47*	9.34 [t]	3.22	24.41**	6.17	5.03
Orientation to wind	2	8.81*	6.42*	2.25	21.24**	0.54	2.09
Blade color scheme	4	4.59	21.50**	35.37**	1.69	24.13**	3.76
Perch guard	1	3.44 [t]	14.12**	0.20	0.76	0.54	3.34 [t]
Derelict turbine	2	0.22	4.87 [t]	3.22	3.39	2.92	0.70
Low reach of blades [a]	4	21.74**	5.78	12.42*	22.01**	2.52	6.64
High reach of blades [a]	3	15.05**	16.29**	2.69	9.79*	3.82	4.04
Whether in wind wall	1	6.64*	0.14	0.07	9.05**	0.13	0.10
Position in string	3	9.95*	15.77**	1.23	28.05**	6.82 [t]	1.95
Position in farm	2	8.25*	18.96**	2.59	3.21	7.70*	1.38
Turbine congestion	3	10.42*	17.44**	2.12	6.04	10.75*	1.24
Elevation	6	9.78	11.56 [t]	14.5*	57.78**	8.05	10.27
Slope grade	3	6.79	9.26 [t]	2.37	2.08	11.80*	1.89
Physical relief	6	17.39*	9.99	10.93 [t]	5.67	9.15	19.5**
Whether in canyon	1	6.56*	38.42**	0.00	2.25 [t]	24.79**	1.31
Slope aspect	8	10.84	19.50*	9.69	10.49	24.05**	7.03
Slope aspect	4	7.76	11.56*	4.32	1.38	17.93**	3.84
Edge index	5	47.56**	31.48**	3.33	7.21	1.86	3.49
Rock piles	2	1.01	3.30	4.12	2.75	1.22	3.73
Rodent control	3	9.32*	7.61 [t]	2.16	23.45**	6.02	4.61
Rodent control	3	11.09*	10.06*	2.52	23.42**	5.32	4.91
Cattle pats, grass	3	2.67	9.20*	0.13	7.29 [t]	18.40**	8.99*
Cattle pats, turbines	3	7.12 [t]	3.18	3.98	9.87*	3.30	1.17
Cottontails, grass	2	0.27	5.14 [t]	0.48	0.35	0.33	1.68
Cottontails, turbines	2	0.16	5.40 [t]	0.57	2.49	3.45	1.07
Vegetation height	3	8.00*	3.90	3.52	0.63	3.89	1.03
Season of the year	3	3.29	32.70**	8.83*	26.21**	5.87	3.59

[a] Categories of variable were aggregated to reduce degrees of freedom.

Table 7-2. Chi-square values of association between the number of fatalities of non-raptor species and independent variables, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005; and MALL = mallard, WEME = western meadowlark, HOLA = horned lark, MODO = mourning dove, RODO = rock dove, and EUST = European starling

Predictor Variable	df	MALL	WEME	HOLA	MODO	RODO	EUST
Turbine model	10	25.02*	31.02**	5.99	65.36**	92.63**	22.70*
Turbine size	8	31.55**	25.10**	17.25*	55.67**	58.75**	19.13*
Rotor diameter [a]	5	29.14**	16.53*	14.65*	32.50**	60.11**	17.66**
Tip speed [a]	2	20.49**	19.48**	5.98 [t]	10.82**	19.23**	2.43
Window [a]	2	14.78**	18.59**	2.20	28.73**	37.57**	12.13**
Rotor-swept area/sec [a]	3	2.21	12.48*	9.82*	18.73**	19.83**	12.29*
Tower type	2	18.43**	16.17**	3.47	5.36 [t]	5.36 [t]	0.86
Tower height [a]	4	8.17 [t]	14.45*	3.43	3.47	19.06**	4.83
Orientation to wind	2	8.94*	12.33**	0.34	2.20	19.43**	1.75
Blade color scheme	4	0.81	6.29	0.56	1.63	4.78	8.28 [t]
Perch guard	1	0.36	1.05	0.25	0.37	16.50**	0.74
Derelict turbine	2	1.35	4.44	4.97 [t]	4.78 [t]	3.80	0.05
Low reach of blades [a]	4	8.76 [t]	12.93*	1.81	5.54	64.44**	6.12
High reach of blades [a]	3	13.4**	8.81*	11.02*	1.48	44.6**	6.49 [t]
Whether in wind wall	1	5.38*	4.81*	0.54	5.55*	4.83*	3.60 [t]
Position in string	3	20.43**	10.43*	9.20*	12.68*	3.82	0.30
Position in farm	2	2.40	1.45	2.33	8.37*	19.99**	0.70
Turbine congestion	3	9.81*	2.72	2.08	5.83	23.19**	2.26
Elevation	6	32.74**	24.64**	2.35	50.99**	80.86**	12.99*
Slope grade	3	14.58*	15.24**	5.75	4.02	10.46*	3.23
Physical relief	6	13.19*	7.50	0.87	15.43*	65.04**	10.15
Whether in canyon	1	33.59**	16.62**	0.76	3.31 [t]	1.30	0.17
Slope aspect	8	13.71 [t]	6.29	7.22	21.49*	30.19**	5.46
Slope aspect	4	5.44	1.38	0.38	15.80**	24.95**	1.15
Edge index	5	4.26	6.32	6.18	10.09 [t]	13.06*	3.42
Rock piles	2	1.48	0.67	0.62	2.85	2.86	1.28
Rodent control	3	18.52**	5.52	0.76	17.32**	12.67*	11.38*
Rodent control	3	16.20**	5.67	0.62	14.62**	11.84*	8.03*
cattle pats, grass	3	3.00	1.30	0.84	1.99	11.37*	1.88
cattle pats, turbines	3	9.98*	3.71	3.61	4.22	16.68**	2.56
Cottontails, grass	2	2.03	0.82	0.24	4.22	12.14**	2.24
Cottontails, turbines	2	5.48 [t]	16.31**	2.84	3.85	20.92**	8.81*
Vegetation height	3	6.58 [t]	3.47	2.97	1.98	20.88**	2.69
Season of the year	3	9.70*	14.65**	10.53*	33.02**	45.75**	1.07

[a] Categories of variable were aggregated to reduce degrees of freedom.

Table 7-3. Chi-square values of association between the number of fatalities of bird species and independent variables, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Predictor Variable	df	Hawks	Raptors	All birds
Turbine model	10	23.48*	41.50**	70.06**
Turbine size	8	15.89*	38.63**	66.71**
Rotor diameter [a]	5	23.29**	40.58**	53.99**
Tip speed	11	35.99**	51.07**	68.41**
Tip speed [a]	2	6.41*	11.56**	12.34**
Window	12	36.2**	51.56**	71.35**
Window [a]	2	2.13	7.11*	20.07**
Rotor-swept area/sec	12	36.2**	51.56**	71.35**
Rotor-swept area/sec [a]	3	7.23 [t]	17.10**	15.90**
Tower type	2	7.89*	8.18*	23.82**
Tower height	8	23.66**	24.27**	25.39**
Tower height [a]	4	11.97*	10.90*	19.57**
Orientation to wind	2	9.09*	1.48	6.83*
Blade color scheme	4	23.65**	32.90**	20.29**
Perch guard	1	10.99**	7.33*	12.45**
Derelict turbine	2	4.58	0.30	1.49
Low reach of blades	16	32.84*	53.60**	82.49**
Low reach of blades [a]	4	6.44	6.98	16.14**
High reach of blades	17	32.96*	53.62**	82.55**
High reach of blades [a]	3	14.02**	15.99**	4.98
Whether in wind wall	1	0.15	6.10*	15.26**
Position in string	3	20.39**	52.95**	75.33**
Position in farm	2	12.96**	23.50**	33.56**
Turbine congestion	3	14.41**	24.73**	5.17
Elevation	6	11.97 [t]	14.74*	114.83**
Slope grade	4	9.77*	9.44 [t]	14.59*
Physical relief	6	8.95	19.91**	41.31**
Whether in canyon	1	32.50**	47.22**	41.49**
Slope aspect	8	19.95*	28.57**	27.18**
Slope aspect	4	9.82*	15.52**	19.71**
Edge index	5	26.99**	45.06**	31.57**
Rock piles	2	2.47	4.00	4.97 [t]
Rodent control	3	7.74 [t]	13.38**	20.34**
Rodent control	3	8.96*	16.91**	21.10**
Cattle pats, grass	3	11.43*	4.54	1.90
Cattle pats, turbines	3	2.77	5.66	4.23
Cottontails, grass	2	6.85*	3.42	6.57*
Cottontails, turbines	2	5.13 [t]	2.49	8.56*
Vegetation height	3	5.7	7.83*	11.42*
Season of the year	3	30.81**	49.50**	65.26**

[a] Categories of variable were aggregated to reduce degrees of freedom.

Appendix C presents the χ^2 tests between the distribution of bird fatalities and factors measured in the APWRA for particular species. Appendix B presents the tests for groups of species, including all hawks, all raptors, and all bird species combined. In considering these test values, we also considered the percentage of expected values < 5—the greater the percentage, the less reliable the test result. The test values were similar across wind turbine attributes, including wind turbine model, its rated speed, typical tip speed, rotor diameter, the window of time between blade sweeps of the same location at the blade tips, and the area in the rotor plane that is swept per second. Therefore, we attempted to identify the strongest association between the fatalities of a given species and turbine attributes, and we used only this strongest association in the predictive model.

Figures 7-19 through 7-21 depict the locations of wind turbines where golden eagles, red-tailed hawks, and burrowing owls had been found killed.

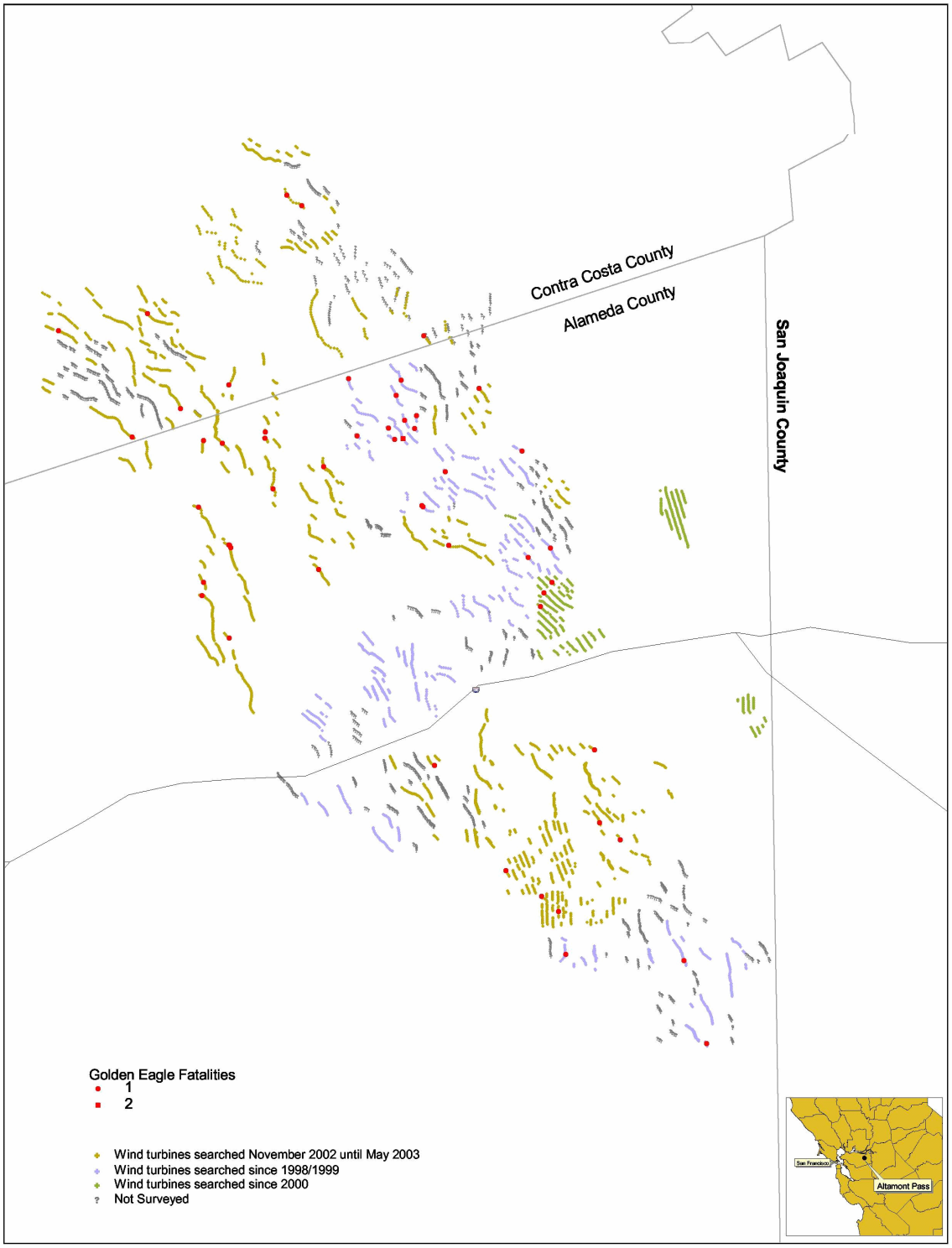


Figure 7-19. Golden eagle fatalities relative to search effort applied to wind turbines in the APWRA

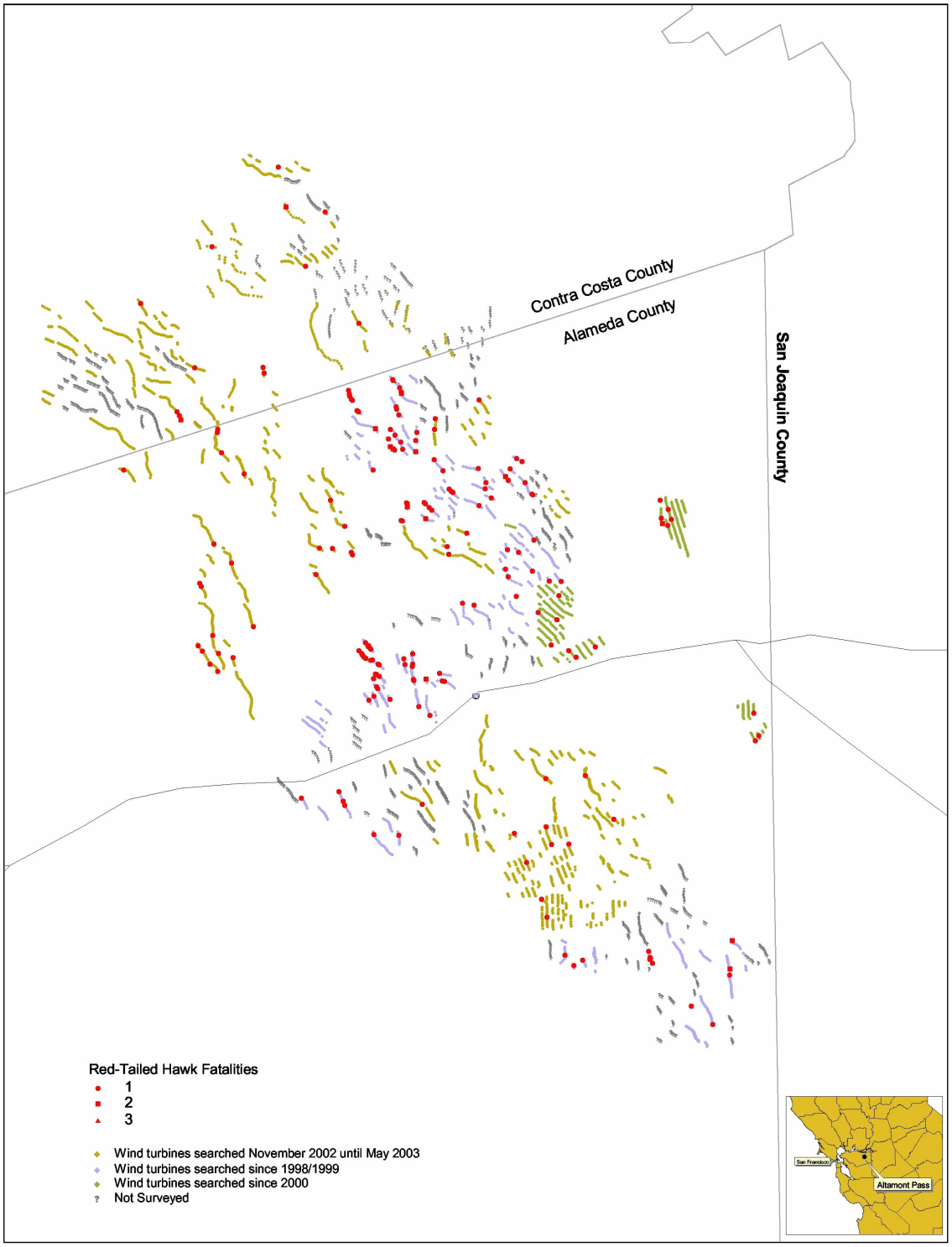


Figure 7-20. Red-tailed hawk fatalities relative to search effort applied to wind turbines in the APWRA

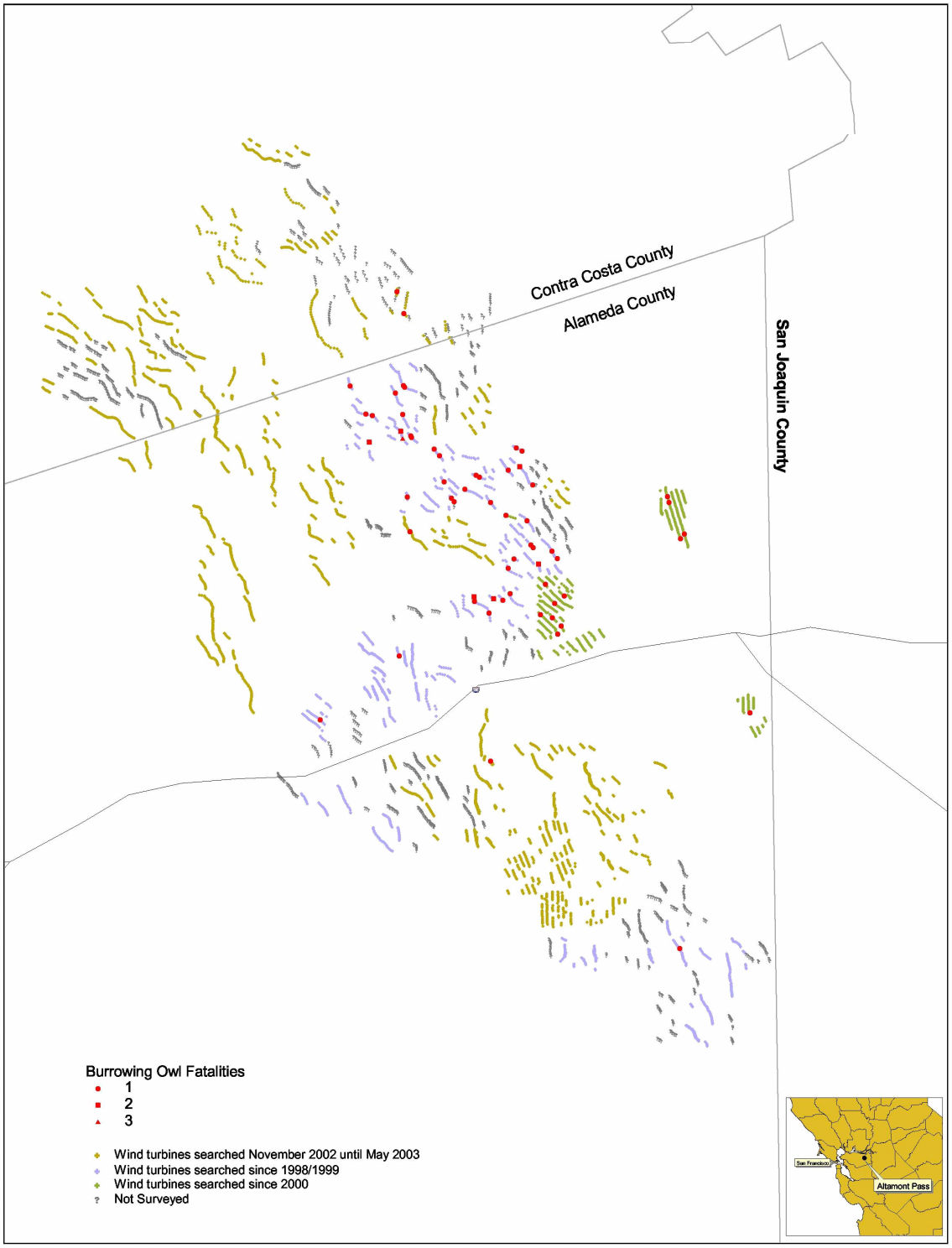


Figure 7-21. Burrowing owl fatalities relative to search effort applied to wind turbines in the APWRA

Wind Turbine Attributes

Table 7-4 presents the directions and magnitudes of the χ^2 test results involving wind turbine attributes, most of which were used for model development. Variables not used for model development included rated speed of the wind turbine, turbine size (rated power output), and turbine model. Bonus turbines associated with a greater than expected number of golden eagle fatalities, as well as fatalities of American kestrel, burrowing owl, mallard, western meadowlark, and mourning dove (Table 7-4). KVS-33 turbines killed more than the expected number of American kestrels, and KCS-56 turbines killed more than the expected number of golden eagles and American kestrels. Enertech and Flowind turbines also killed more than the expected number of burrowing owls, and Windmatic turbines took a disproportionate toll on mourning doves. Micon turbines killed more than the expected number of mourning doves, as well as European starlings and Rock doves.

Table 7-4. The directions and magnitudes of the associations between wind turbine-caused fatalities and attributes of the turbine or tower, and identified from the most reliable statistical test results.

Species	Magnitude of increase in mortality
Wind turbine model	
Golden eagle	5% at KCS-56, 3% at Bonus, 3% at Howden
Red-tailed hawk	6% at Bonus, 2% at Nordtank
American kestrel	11% at KVS-33, 5% at KCS-56, 3% at Nordtank
Burrowing owl	17% at Bonus, 10% at Flowind, 4% at Micon, 3% at Enertech
Mallard	26% at Bonus, 11% at Micon
Western meadowlark	11% at Bonus, 4% at Nordtank, 4% at Flowind
Mourning dove	25% at Micon, 5% at Windmatic, 5% at Howden
Rock dove	16% at Micon
European starling	9% at Micon, 4% at Nordtank
All hawks	6% at Bonus
All raptors	5% at Bonus
All birds	5% at Micon, 2% at Bonus
Rotor Diameter	
Red-tailed hawk	10% at turbines with larger rotor diameters
Rock dove	15% at turbines with smaller rotor diameters
All hawks	9% at turbines with the largest rotor diameters
All raptors	7% at turbines with the largest rotor diameters
Tip speed	
Mourning dove	25% at turbines with slowest tip speeds
All hawks	5% at turbines with intermediate tip speeds
All raptors	5% at turbines with intermediate tip speeds
All birds	5% at turbines with intermediate to slowest tip speeds

Table 7-4. (cont'd)

Species	Magnitude of increase in mortality
Seconds per rotor sweep at blade tip	
Burrowing owl	30% at turbines with longer time per rotor sweep at blade tip
Barn owl	10% at turbines with longest time per rotor sweep at blade tip
Mallard	32% at turbines with longer time per rotor sweep at blade tip
Western meadowlark	22% at turbines with longer time per rotor sweep at blade tip
All raptors	5% at turbines with longer time per rotor sweep at blade tip
All birds	5% at turbines with longer time per rotor sweep at blade tip
Rotor-swept area/sec.	
American kestrel	10% at turbines with larger area swept/second
Horned lark	25% at turbines with low-medium area swept/second
European starling	17% at turbines with least area swept/second
All hawks	7% at turbines with larger area swept/second
All raptors	3% at turbines with larger area swept/second
All birds	4% at turbines with least area swept/second
Rotor orientation	
Rock dove	15% at turbines with rotor blades facing wind
All hawks	9% at turbines with rotor blades facing wind
All birds	4% at turbines with rotor blades facing wind
Tower type	
Red-tailed hawk	7% at tubular towers
Burrowing owl	19% at tubular towers, 10% at vertical axis towers
Mallard	35% at tubular towers
Western meadowlark	15% at tubular towers, 4% at vertical axis towers
Mourning dove	18% at tubular towers
All hawks	7% at tubular towers
All raptors	6% at tubular towers
All birds	7% at tubular towers
Blade color scheme	
Red-tailed hawk	2% at turbines with red stripes/tips on blades
American kestrel	5% at turbines with black stripes, 3% at turbines with colored blade tips
Barn owl	3% at turbines with red stripes/tips on blades
European starling	4% at turbines with colored blade tips
All hawks	3% at turbines with red stripes/tips on blades
All raptors	2% at turbines with colored blade tips
All birds	2% at turbines with colored blade tips

Table 7-4. (cont'd)

Species	Magnitude of increase in mortality
Perch deterrent	
Golden eagle	3% at towers with perch deterrents
Red-tailed hawk	3% at towers with perch deterrents
Great horned owl	4% at towers with perch deterrents
Rock dove	3% at towers with perch deterrents
All hawks	2% at towers with perch deterrents
Tower height	
Burrowing owl	16% at towers of medium height
All hawks	10% at towers of medium height
All raptors	6% at towers of medium height
All birds	5% at towers of medium height
Height of lowest blade reach	
Golden eagle	25% at turbines with lower reaches of blades
Rock dove	24% at turbines with fairly high reach of blades
All birds	3% at turbines with fairly high reach of blades
Height of highest blade reach	
Red-tailed hawk	9% at turbines with *highest* reaches of blades
Mallard	23% at turbines with *highest* reaches of blades
Horned lark	27% at turbines with *medium* reaches of blades
Western meadowlark	13% at turbines with *higher* to highest reaches of blades
European starling	14% at turbines with *lowest* reaches of blades
All hawks	8% at turbines with *highest* reaches of blades
All raptors	6% at turbines with *highest* reaches of blades

At the multi-species level of analysis, Bonus turbines killed disproportionately more hawks, raptors, and all birds (Table 7-4). Micon turbines killed disproportionately more birds than any other wind turbine model. KCS-56 turbines killed fewer than the expected number of raptors and all birds.

Larger rotor diameters associated with disproportionately more fatalities of red-tailed hawks, all hawks, and all raptors; whereas, shorter diameter wind turbines killed substantially more than the expected number of rock doves (Table 7-4).

Wind turbines with slower-moving blades associated with a significantly larger proportion of fatalities of mourning doves, all hawks, all raptors, and all birds considered together. Wind turbines with intermediate to longer windows of opportunity to fly through the rotor plane (i.e., 0.5–0.7 seconds) associated with a significantly larger proportion of fatalities of burrowing owl, mallard, and western meadowlark. Wind turbines with the longest windows of opportunity to fly through the rotor plane associated with a significantly larger proportion of barn owl fatalities.

At the multi-species level of analysis, wind turbines with longer windows of opportunity to fly through the rotor plane associated with a significantly larger proportion of fatalities of all raptors and all birds. The converse of the window of opportunity to fly through the rotor plane is the rate at which the rotor plane is swept.

Larger rotor areas swept per second associated with disproportionately more numbers of fatalities of American kestrel, all hawks, all raptors, and all birds; whereas, the intermediate and small rotor swept areas per second associated with disproportionately more horned lark and European starling fatalities.

Rotors facing the wind killed disproportionately more rock doves, all hawks, and all birds combined (Table 7-4). Tubular towers killed disproportionately more red-tailed hawks, burrowing owls, mallards, western meadowlarks, mourning doves, all hawks, all raptors, and all birds than expected by chance, whereas vertical axis turbines killed more burrowing owls and western meadowlarks than expected.

Wind turbines with blades painted colors other than white ended up killing disproportionately more red-tailed hawks, American kestrels, barn owls, European starlings, and all hawks, all raptors, and all birds (Table 7-4). We found no evidence for any species that indicated colored blade tips or striped blades associated with fewer than the expected number of fatalities.

Lattice towers with perch deterrents associated with increased mortality of golden eagle, red-tailed hawk, great-horned owl, rock dove, and all hawks (Table 7-4). Wind turbines with perch deterrents did not associate with less mortality for any species in the study area. Positive associations might have resulted for one or more reasons. It is possible that perch deterrents were put on lattice towers with a history of killing disproportionately more birds, and that the perch deterrents failed to eliminate mortality at these turbines. It is also possible that birds that are used to perching on lattice towers might approach them to perch on them and at the last moment discover the perch deterrents, which are simply chicken wire tied around horizontal structures normally used for perching. Upon discovering the perch deterrents, these birds might take evasive or corrective flights, which sometimes take them into the rotor plane.

Towers of intermediate height associated with disproportionately more fatalities of burrowing owl, all hawks, all raptors, and all birds (Table 7-4). Turbines with blades that reach lower toward the ground killed disproportionately more golden eagles, and those with lowest reaches that were relatively high compared to other turbines killed more than the expected number of rock doves and all birds considered together. Of all the wind turbine and tower attributes, the lowest reach of the turbine blades associated most strongly with golden eagle mortality.

Wind turbines with blades reaching highest into the sky killed disproportionately more red-tailed hawks, mallards, all hawks, and all raptors. Higher blade reaches also took disproportionately more western meadowlarks.

Wind Turbine Location Attributes

Wind turbine-caused fatalities of most species were more often than expected at wind turbines not belonging to wind walls, including golden eagle, burrowing owl, mallard, western meadowlark, European starling, all raptors, and all birds (Table 7-5). One exception was rock dove. Wind turbines with fewer other wind turbines occurring within 300 m killed disproportionately more golden eagles, red-tailed hawks, barn owls, mallards, and all hawks and all raptors combined (Table 7-5). Only rock doves were killed disproportionately more often at wind turbines within denser turbine fields.

Whereas adjacency of wind turbines to derelict turbines appeared to be a significant factor in our analysis of a smaller set of data (Smallwood and Thelander, in review), it did not appear to be a significant factor using the larger data set now available to us. Only horned lark and mourning dove were killed at wind turbines next to derelict wind turbines in disproportionate numbers (Table 7-5). Mourning doves also died disproportionately at derelict turbines, suggesting that at least this species collides with non-operating turbines and tower structures with fatal consequences.

Wind turbines at the ends of turbine rows killed more than the expected number of golden eagles, red-tailed hawks, burrowing owls, barn owls, mallards, western meadowlarks, and mourning doves, and wind turbines at the edges of gaps in the row killed more than the expected number of mallards and horned larks (Table 7-5). Overall, wind turbines at the ends of rows and at gaps killed disproportionately more hawks, raptors, and all bird species combined than did interior turbines (Table 7-5). Similarly, wind turbines at the edges of local clusters of wind turbines killed disproportionately more golden eagles, red-tailed hawks, barn owls, and mourning doves (Table 7-5). At the multi-species level of analysis, wind turbines at the edges of local clusters of wind turbines killed significantly more than the expected number of hawks, raptors, and all bird species combined.

Wind turbines on ridgelines killed disproportionately more golden eagles, American kestrels, and all raptors combined; whereas, those on plateaus killed disproportionately more great-horned owls, mallards, and mourning doves; and those on slopes also killed disproportionately more mallards and mourning doves (Table 7-5). Those in canyons killed disproportionately more golden eagles, red-tailed hawks, burrowing owls, barn owls, mallards, western meadowlarks, and mourning doves—as well as all hawks combined, all raptors, and all birds (Table 7-5). Wind turbines on slopes facing north or northwest killed disproportionately more red-tailed hawks and barn owls, as well as all hawks and all raptors combined (Table 7-5). Wind turbines on slopes facing southwest and west killed more than the expected number of mourning doves.

Wind turbines at mid elevation killed disproportionately more red-tailed hawks; whereas, those at highest and lowest elevations killed disproportionately more American kestrels. Those at the lowest elevations in the APWRA killed disproportionately more burrowing owls, mallards, western meadowlarks, mourning doves, rock doves, European starlings, and all raptors and all birds (Table 7-5). Those on steeper slopes killed disproportionately more golden eagles, red-tailed hawks, barn owls, and western meadowlarks; whereas, those on shallower slopes killed more rock doves (Table 7-5). At the interspecific level of analysis, wind turbines on steeper slopes also killed disproportionately more hawks, raptors, and all birds.

Within the first set of 1,526 wind turbines searched for carcasses, the presence of rock piles assembled near wind turbine strings associated with significantly more than the expected number of fatalities of golden eagle, red-tailed hawk, American kestrel, burrowing owl, barn owl, horned lark, western meadowlark, and rock dove (Smallwood and Thelander in review). However, adding the additional 2,548 wind turbines changed the relationship. With our larger sample size, the number of rock piles near wind turbines did not associate with the number of fatalities of any species we examined.

Table 7-5. The directions and magnitudes of the associations between wind turbine-caused fatalities and attributes of the turbine's location, and identified from the most reliable statistical test results

Species	Magnitude of increase in mortality
Whether in wind wall	
Golden eagle	12% at turbines *not* in wind walls
Burrowing owl	13% at turbines *not* in wind walls
Mallard	14% at turbines *not* in wind walls
Western meadowlark	8% at turbines *not* in wind walls
Mourning dove	14% at turbines *not* in wind walls
Rock dove	5% at turbines *in* wind walls
European starling	8% at turbines *not* in wind walls
All raptors	4% at turbines *not* in wind walls
All birds	4% at turbines *not* in wind walls
Whether adjacent to derelict turbine	
Horned lark	9% at turbines next to derelict turbines
Mourning dove	5% at turbines next to derelict turbines, 5% at derelict turbines
Position in turbine string	
Golden eagle	17% at the string end, 2% next to gaps
Red-tailed hawk	11% at the string end, 1% next to gaps
Burrowing owl	24% at the string end
Barn owl	6% at the string end, 3% next to gaps
Mallard	18% next to gaps, 14% at the string end
Horned lark	17% next to gaps, 4% at the string end
Western meadowlark	11% at the string end, 2% next to gaps
Mourning dove	25% at the string end
All hawks	13% at the string end or edge of gap
All raptors	14% at the string end or edge of gap
All birds	11% at the string end or edge of gap

Table 7-5. (cont'd)

Species	Magnitude of increase in mortality
Location in wind farm	
Golden eagle	12% at local cluster of turbines
Red-tailed hawk	9% at local cluster of turbines
Barn owl	12% at local cluster of turbines
Mourning dove	16% at edge of wind farm
Rock dove	8% at local cluster of turbines, 5% at edge of wind farm
All hawks	7% at local cluster of turbines
All raptors	7% at local cluster of turbines
All birds	6% at local cluster of turbines or at edge of wind farm
Wind turbine congestion	
Golden eagle	21% at turbines more sparsely distributed
Red-tailed hawk	8% at turbines more sparsely distributed
Barn owl	23% at turbines more sparsely distributed
Mallard	13% at turbines more sparsely distributed, 6% at most crowded turbines
Rock dove	17% at turbines more densely distributed
All hawks	7% at turbines more sparsely distributed
All raptors	8% at turbines more sparsely distributed
Physical relief	
Golden eagle	21% on ridgeline
American kestrel	10% on ridgeline, 5% on ridge crest
Great horned owl	21% on plateau, 5% in ravine, 2% on ridgeline
Mallard	12% on slope, 11% on plateau
Mourning dove	19% on slope, 11% on plateau
Rock dove	10% on plateau, 7% in saddle
All raptors	6% on ridgeline
All birds	3% on plateau, 2% on slope
Whether in a canyon	
Golden eagle	13% *in* canyon
Red-tailed hawk	15% *in* canyon
Burrowing owl	6% *in* canyon
Barn owl	26% *in* canyon
Mallard	36% *in* canyon
Western meadowlark	15% *in* canyon
Mourning dove	11% *in* canyon
All hawks	13% *in* canyon
All raptors	11% *in* canyon
All birds	7% *in* canyon

Table 7-5. (cont'd)

Species	Magnitude of increase in mortality
Slope aspect	
Red-tailed hawk	5% on north/northwest slopes, 4% on south/southeast slopes
Barn owl	24% on north/northwest slopes, 5% on west/southwest slopes
Mourning dove	15% on west/southwest slopes
Rock dove	7% on west/southwest slopes, 4% on flat terrain
All hawks	7% on northwest slopes, 3% on southern slopes
All raptors	5% on northwest slopes, 3% on southern slopes
All birds	7% on southeast to west-facing slopes
Elevation	
Red-tailed hawk	8% at mid elevation
American kestrel	12% at highest elevation, 5% at lowest elevation
Burrowing owl	44% at lowest elevation
Mallard	47% at lowest elevation
Western meadowlark	20% at lowest elevation
Mourning dove	46% at lowest elevation
Rock dove	19% at lowest elevation
European starling	14% at lowest elevation
All raptors	6% at lower elevations
All birds	12% at lower elevations
Slope grade	
Golden eagle	13% on steeper slopes
Red-tailed hawk	11% on steeper slopes
Barn owl	23% on steeper slopes
Western meadowlark	12% on steepest slopes
Rock dove	11% on shallower slopes
All hawks	9% on steeper slopes
All raptors	9% on steeper slopes
All birds	3% on steepest slopes
Edge index	
Golden eagle	27% at sites with greater vertical edge
Red-tailed hawk	13% at sites with greater vertical edge
Mourning dove	12% at sites with lots of vertical edge, 10% at sites with little or no edge
Rock dove	10% at sites with lateral but no vertical edge
All hawks	11% at sites with greater vertical edge
All raptors	11% at sites with greater vertical edge
All birds	5% at sites with greater vertical edge

Wind turbines with greater levels of vertical edge around its tower base killed disproportionately more golden eagles, red-tailed hawks, and mourning doves—as well as all hawks, all raptors, and all birds combined (Table 7-6).

Range Conditions

Had the rodent control program achieved the objective of reducing mortalities, then disproportionately more wind turbine-caused fatalities would have occurred where no rodent control was implemented during our study. In fact, wind turbines in areas of no rodent control killed disproportionately more golden eagles, mourning doves, rock doves and European starlings (Table 7-6).

Wind turbines in areas with rodent control killed disproportionately more red-tailed hawks, burrowing owls, mallards, and at the interspecific level of analysis, more hawks and raptors. The golden eagle association we obtained in this study differs from that of Smallwood and Thelander (in review), probably because the largest number of wind turbines in an area of no control occurs in the northwestern portion of the wind farm, and it corresponds with the intensive use of the wind farm by golden eagles. There is no evidence that the rodent control program, or lack thereof, had any influence on the spatial variation in the intensity of use of the wind farm by golden eagles (see Chapter 8).

Cattle pats were counted only at the original set of 1,526 wind turbines, so our analysis is limited to those. Wind turbines with more cattle pats nearby killed disproportionately more golden eagles, burrowing owls, and mallards (Table 7-6), although the association with mallard fatalities was likely spurious, because we can think of no ecological explanation for mallards to fly by wind turbines with greater levels of cattle visitation.

Table 7-6. The directions and magnitudes of the associations between wind turbine-caused fatalities and attributes of the range conditions surrounding the wind turbine, identified from the most reliable statistical test results

Species	Magnitude of increase in mortality
Rodent control	
Golden eagle	14% in areas with no control
Red-tailed hawk	8% in areas with moderate level of control
Burrowing owl	24% in areas with moderate level of control
Mallard	31% in areas with moderate level of control
European starling	8% in areas with no control
All hawks	7% in areas with moderate level of control
All raptors	7% in areas with moderate level of control
All birds	4% in areas with moderate level of control, 3% in areas with no control
Cattle pats at wind turbines	
Golden eagle	19% at turbines with more cattle pats
Burrowing owl	18% at turbines with more cattle pats
Mallard	22% at turbines with more cattle pats
Rock dove	13% at turbines with fewer or no cattle pats

Seasonality

For most species, summer and winter were most often associated with more than the expected number of fatalities; however, spring was associated with a disproportionate number of mallard fatalities, and fall was associated disproportionately with red-tailed hawk fatalities (Table 7-7). Significant associations between number of fatalities and season of the year are depicted in Figures 7-22 and 7-23.

Table 7-7. The directions and magnitudes of the associations between wind turbine-caused fatalities and season of the year, identified from the most reliable statistical test results

Species	Magnitude of increase in mortality with season of the year
Red-tailed hawk	10% in winter, 6% in fall, 5% in summer
American kestrel	18% in winter
Burrowing owl	21% in summer, 6% in winter
Mallard	20% in spring, 3% in summer
Western meadowlark	17% in winter
Horned lark	30% in summer
Rock dove	21% in summer
All hawks	10% in winter, 6% in fall, 4% in summer
All raptors	8% in summer, 8% in winter
All birds	8% in summer, 4% in winter

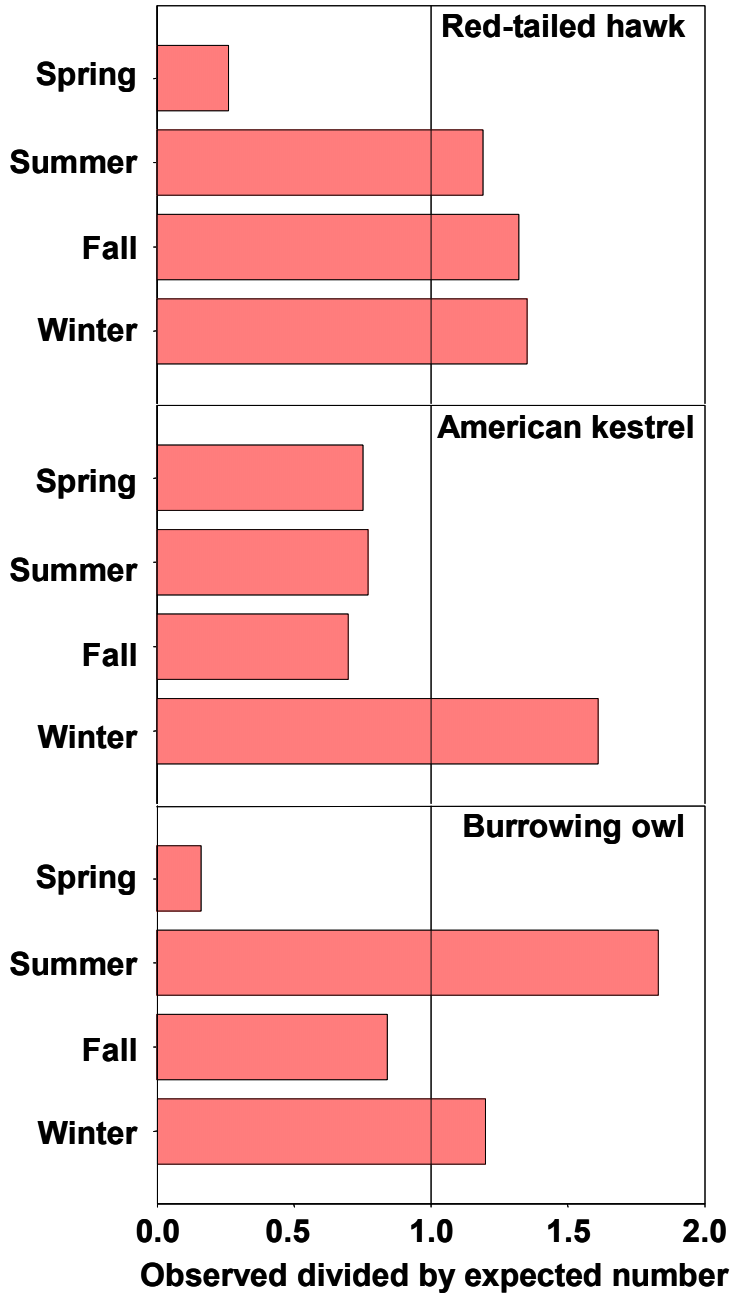


Figure 7-22. Observed-divided-by-expected number of fatalities of raptor species during each season of the year during our study in the APWRA. All associations shown were significant ($P < 0.05$).

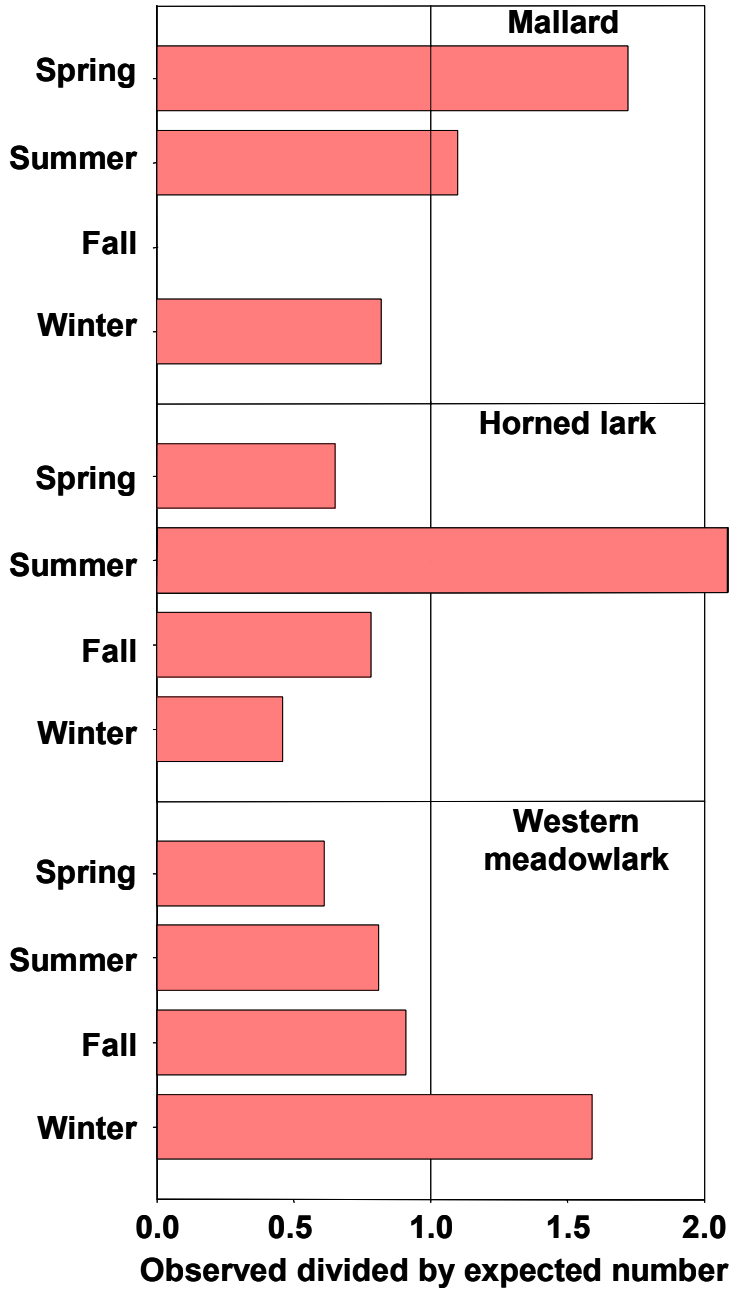


Figure 7-23. Observed–divided-by-expected number of fatalities of non-raptor species during each season of the year during our study in the APWRA. All associations shown were significant ($P < 0.05$).

7.3.3 Predictive Models of Mortality

Table 7-8 summarizes the associations between variables and species that were most reliable for use in model development. Some variables were not used for model development because doing so would be nonsensical from an ecological standpoint. For example, season of the year did not fit into models built around all of the data, including from all four seasons, considered together. Other variables not entered into the models included perch deterrent and blade color schemes. Turbine size (i.e., power output) was not used because it correlated strongly with other turbine attributes that were already used.

The empirical models developed were tested only against the database of the 4,074 wind turbines from which the data were obtained for model development. The remaining 1,326 wind turbines in the APWRA (which were not included in our study) cannot be subjected to model predictions, because we have not yet characterized those wind turbines based on the variables measured in our study.

The number of wind turbines that the model predicted to be more dangerous to each species was many more than the number where we actually found carcasses of each species. Assuming our predictive models are relatively precise, this discrepancy indicates that continued carcass searches would likely add many more wind turbines to the pool of wind turbines documented to have actually killed members of each species. Also, we note that our designation of "dangerous" is a relative one, meaning that these wind turbines are predicted to more likely kill members of the species in question. However, all wind turbines remain dangerous to some degree to every bird species.

Table 7-8. Chi-square test results that were significant, composed of expected cell values mostly > 5, and resulting in accountable mortality values that formed distinct gradients across categories or levels of the association variable. Numbers in the table are the largest accountable mortality values calculated from the chi-square tests between the association variable and the mortality of the species, where GOEA = golden eagle, RTHA = red-tailed hawk, AMKE = American kestrel, BUOW = burrowing owl, BAOW = barn owl, GHOW = great-horned owl, MALL = mallard, WEME = western meadowlark, HOLA = horned lark, MODO = mourning dove, RODO = rock dove, and EUST = European starling.

Predictor Variable	df	GOEA	RTHA	AMKE	BUOW	BAOW	GHOW	MALL	WEME	HOLA	MODO	RODO	EUST
Rotor diameter	5		10									15	
Tip speed	2										25		
Window	2				30	10		32	22				
Rotor-swept area/sec	3			10						25			17
Tower type	2		7		29			37	19		18		
Tower height	4				16								
Orientation to wind	2											15	
Derelict turbine	2									9			
Low reach of blades	4	25										24	
High reach of blades	3		9					23	13	27			14
Part of wind wall?	1	12			13			14	8		14	5	8
Position in string	3	19	12		25	9		32	14	21	25		
Position in farm	2	12	9			12					17	13	
Turbine congestion	3	21	8			23						17	
Elevation	6			17	44			47	20		46	25	14
Slope grade	3	20	11			23			12			11	
Physical relief	6	22		18			28	23			30	20	
Whether in canyon	1	13	15		6	26		36	15		11		
Slope aspect	4		11			29					15	11	
Edge index	5	27	13									10	
Rock piles	2												
Rodent control	3		10		24								12
Cattle pats, grass	3		7										
Cattle pats, turbines	3				18							13	
Cottontails, grass	2												
Cottontails, turbines	2								15				17
Vegetation height	3												

Golden Eagles

The only wind turbine attributes that reliably associated with fatalities of golden eagles was the height of the lowest reach of the turbine blades. This attribute accounted for 25% of the fatalities (Table 7-9). Other strong associations included wind turbines surrounded by greater levels of vertical edge (e.g., tower laydown areas cut into hill slopes), those on ridgelines, those that are more isolated from other wind turbines, and those with more cattle pats near the tower bases. Overall, it appears that wind turbines are most dangerous when they are isolated and located on ridgelines within canyons or deeper ravines where golden eagles forage by contour flying over areas that are relatively more exposed due to intense cattle grazing.

Table 7-9. The directions and magnitudes of the associations between wind turbine-caused golden eagle fatalities and levels within independent variables

Variable	Magnitude of increase in mortality
Height of lowest blade reach	25% at turbines with lower reaches of blades
Whether in wind wall	12% at turbines *not* in wind walls
Position in turbine string	17% at the string end, 2% next to gaps
Location in wind farm	12% at local cluster of turbines
Wind turbine congestion	21% at turbines more sparsely distributed
Physical relief	21% on ridgeline
Whether in canyon	13% in canyon
Slope grade	13% on steeper slopes
Edge index	27% at sites with greater vertical edge
Rodent control	14% in areas with no control
Cattle pats at wind turbines	19% at turbines with more cattle pats

The model correctly predicted wind turbines to be dangerous where 82% of the golden eagle fatalities actually occurred (Table 7-10). About 50% of the wind turbines were predicted to be dangerous to golden eagles. Model predictions are also depicted in Figure 7-24. The more dangerous wind turbines were distributed widely across the wind farm (Figure 7-25).

Table 7-10. The distribution of known golden eagle fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the nine variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	2007	2014	50% of turbines
1	10	42	81% of turbines
2	0	1	100% of turbines
Total fatalities	10	44	82% of fatalities

Red-tailed Hawks

No variable we measured could alone account for more than 15% of the red-tailed hawk fatalities (Table 7-11). Red-tailed hawk fatalities most strongly associated with wind turbines located on steep canyon slopes at the ends of turbine strings or edges of clusters of wind turbines, as well as those that are more isolated from other wind turbines and those with larger rotor diameters on tubular towers.

Table 7-11. The directions and magnitudes of the associations between wind turbine-caused red-tailed hawk fatalities and level within independent variables

Variable	Magnitude of increase in mortality
Rotor diameter	10% at turbines with larger rotor diameters
Tower type	7% at tubular towers
Height of highest blade reach	9% at turbines with *highest* reaches of blades
Position in turbine string	11% at the string end, 1% next to gaps
Location in wind farm	9% at local cluster of turbines
Wind turbine congestion	8% at turbines more sparsely distributed
Whether in canyon	15% in canyon
Slope aspect	5% on north/northwest slopes, 4% on south/southeast slopes
Elevation	8% at mid elevation
Slope grade	11% on steeper slopes
Edge index	13% at sites with greater vertical edge
Rodent control	8% in areas with moderate level of control

The model correctly predicted wind turbines to be dangerous where 37% of the red-tailed hawk fatalities actually occurred (Table 7-12), which indicates poor predictive power. Only 16% of the wind turbines were predicted to be dangerous to red-tailed hawks. Model predictions are also depicted in Figure 7-26. The more dangerous wind turbines were distributed in three main clusters within the wind farm (Figure 7-27).

Table 7-12. The distribution of known red-tailed hawk fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the eleven variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	3267	613	16% of turbines
1	125	51	29% of turbines
2	5	12	71% of turbines
3	0	1	100% of turbines
Total fatalities	135	78	37% of fatalities

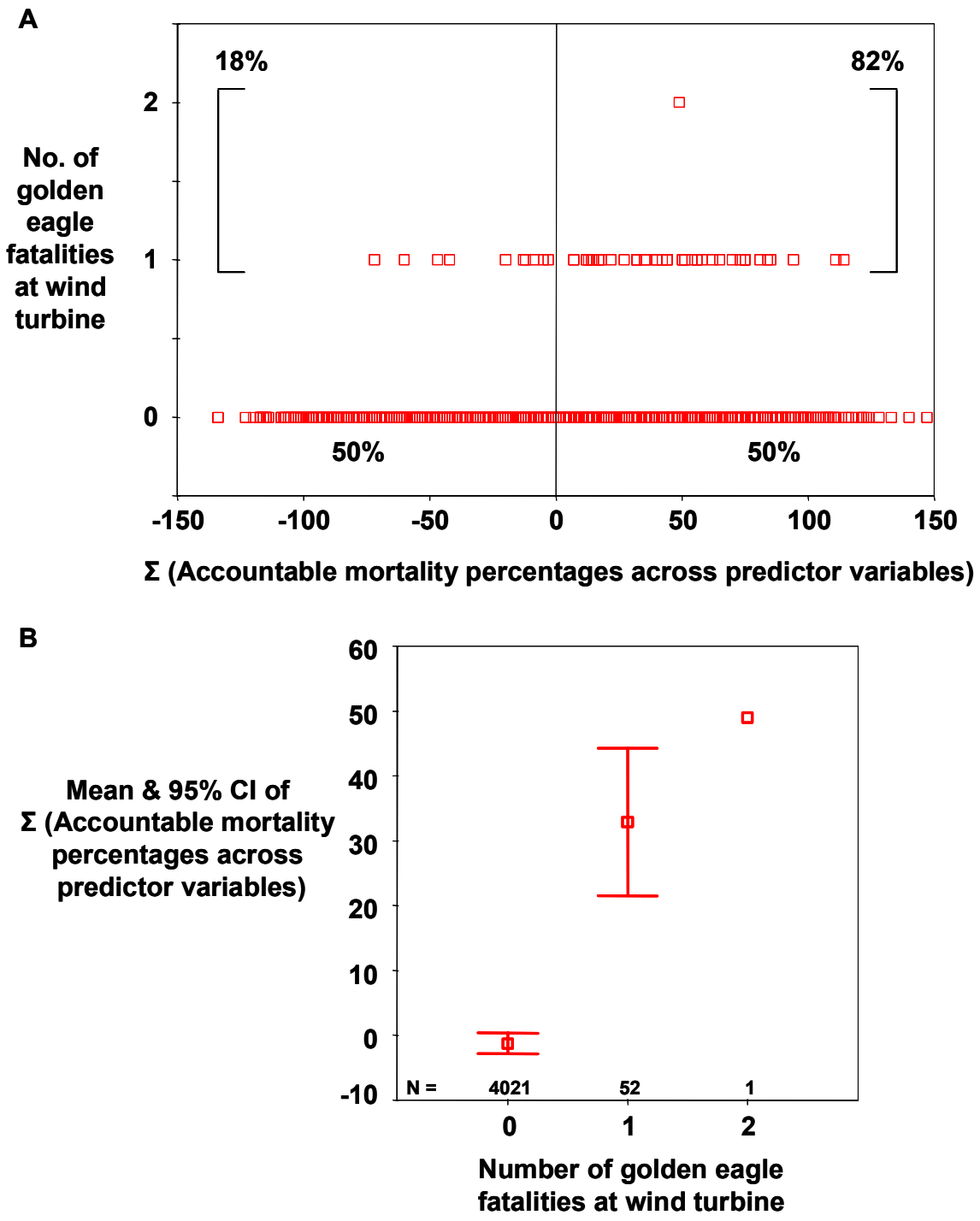


Figure 7-24. Most of the wind turbines documented to have killed golden eagles were correctly classified as more dangerous to golden eagles by the empirical model we developed (A), the mean values of which increased with the actual number of golden eagles killed by the wind turbine (B).

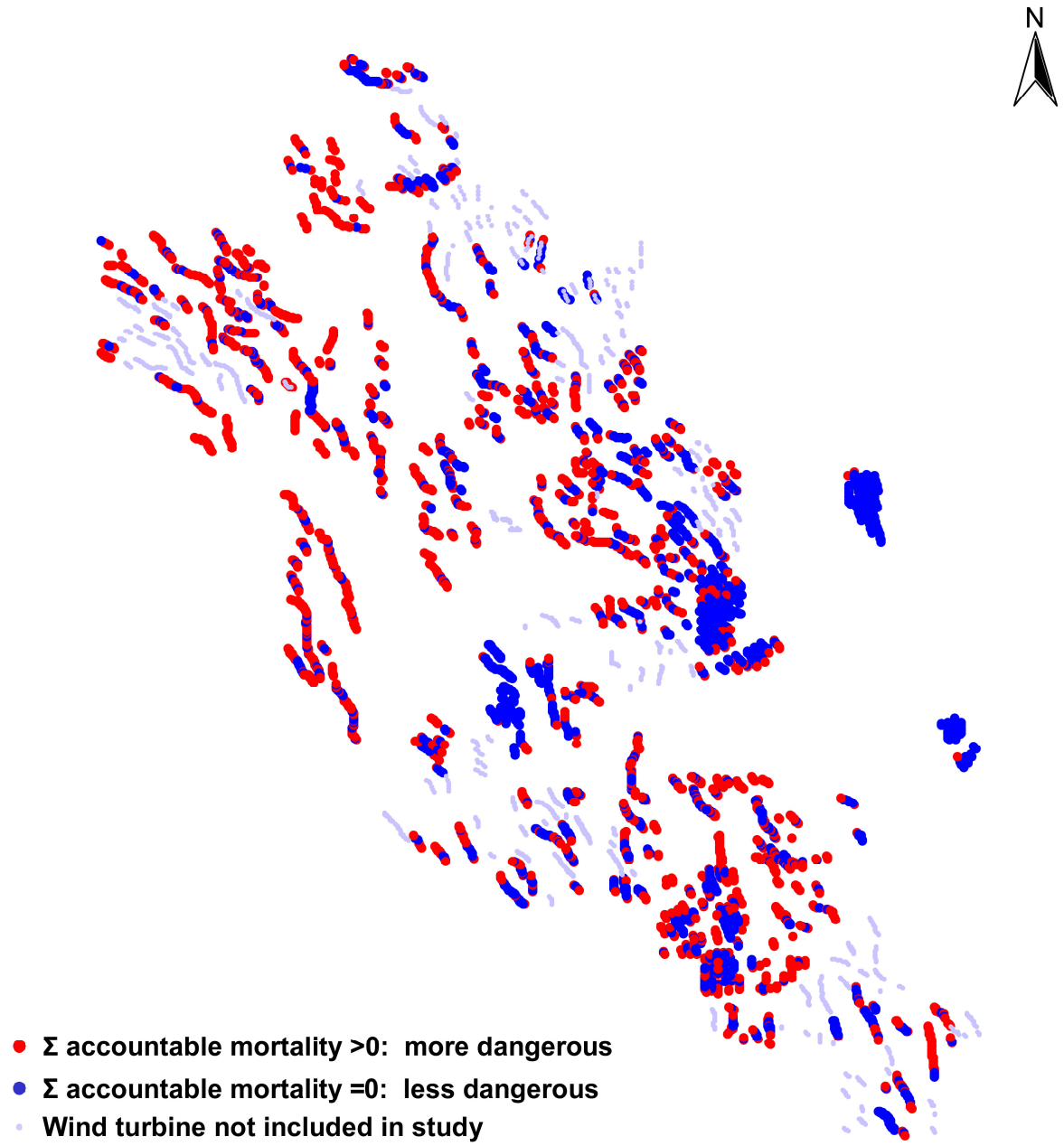


Figure 7-25. Wind turbines predicted by our model to be more dangerous to golden eagles are widely distributed across the APWRA.

American Kestrels

KVS-33 turbines were more dangerous to American kestrels than were other turbine types (because they had the larger rotor-swept area/second), and so were wind turbines on ridge lines and ridge crests at the highest and lowest elevations. Wind turbines on steeper slopes with more vertical edge around the tower laydown area also were dangerous (Table 7-13).

Table 7-13. The directions and magnitudes of the associations between wind turbine-caused American kestrel fatalities and levels within independent variables

Variable	Magnitude of increase in mortality
Rotor-swept area/second	10% at turbines with larger area swept/second
Physical relief	10% on ridgeline, 5% on ridge crest
Elevation	12% at highest elevation, 5% at lowest elevation
Slope grade	11% on steeper slopes
Edge index	13% at sites with greater vertical edge
Rodent control	8% in areas with moderate level of control

The model correctly predicted wind turbines to be dangerous where 75% of the American kestrel fatalities actually occurred (Table 7-14), which indicates solid predictive power. However, 66% of the wind turbines were predicted to be dangerous to American kestrels, meaning that continued carcass searches would continue to turn up American kestrel fatalities at wind turbines not previously documented to have killed this species. Model predictions are summarized in Figure 7-28. The more dangerous wind turbines were distributed widely across the wind farm (Figure 7-29).

Table 7-14. The distribution of known American kestrel fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the three variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	1353	2661	66% of turbines
1	15	42	74% of turbines
2	0	1	100% of turbines
Total fatalities	15	44	75% of fatalities

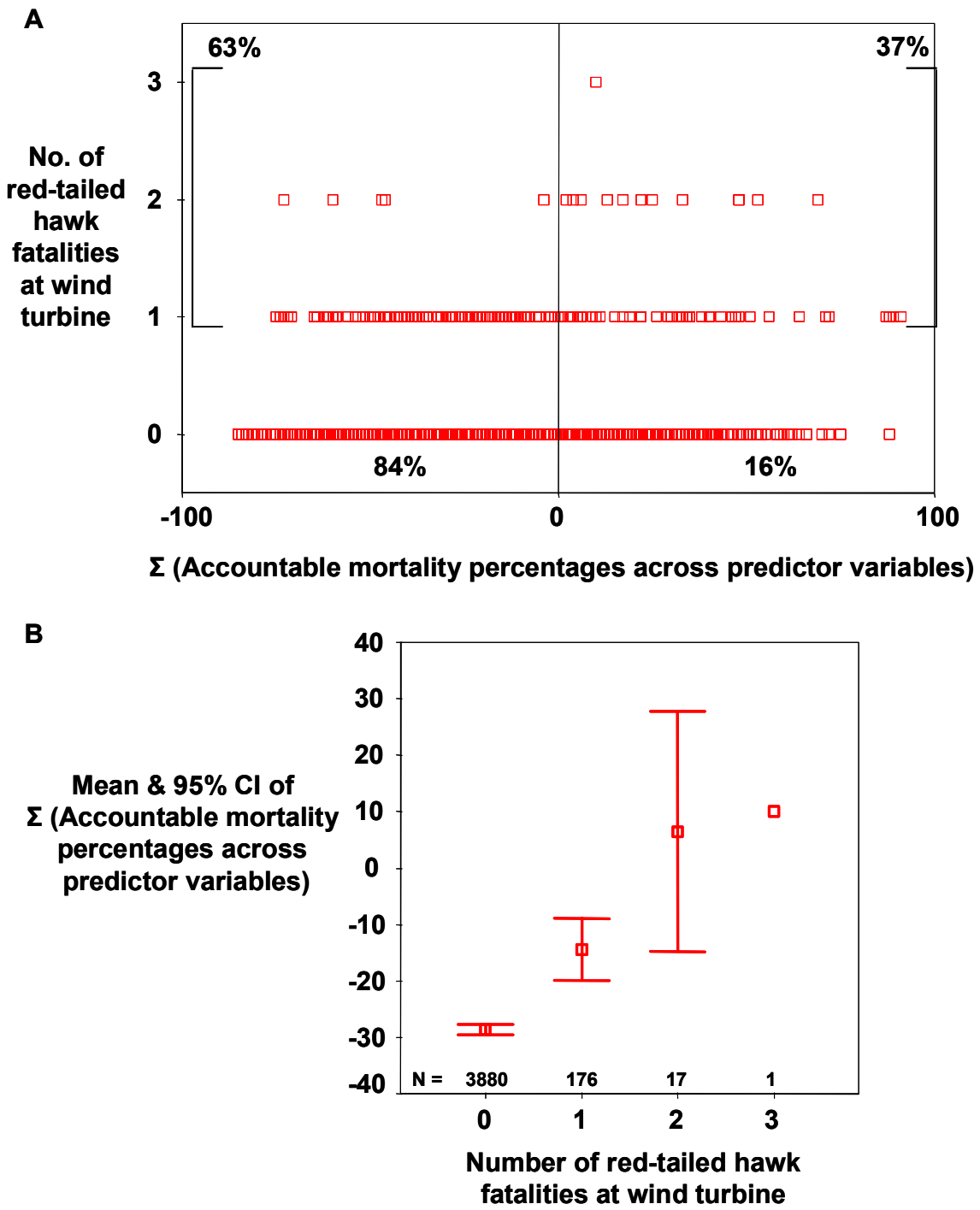


Figure 7-26. Most of the wind turbines documented to have killed red-tailed hawks were incorrectly classified as more dangerous to red-tailed hawks by the empirical model we developed (A), the mean values of which increased with the actual number of red-tailed hawks killed by the wind turbine (B).

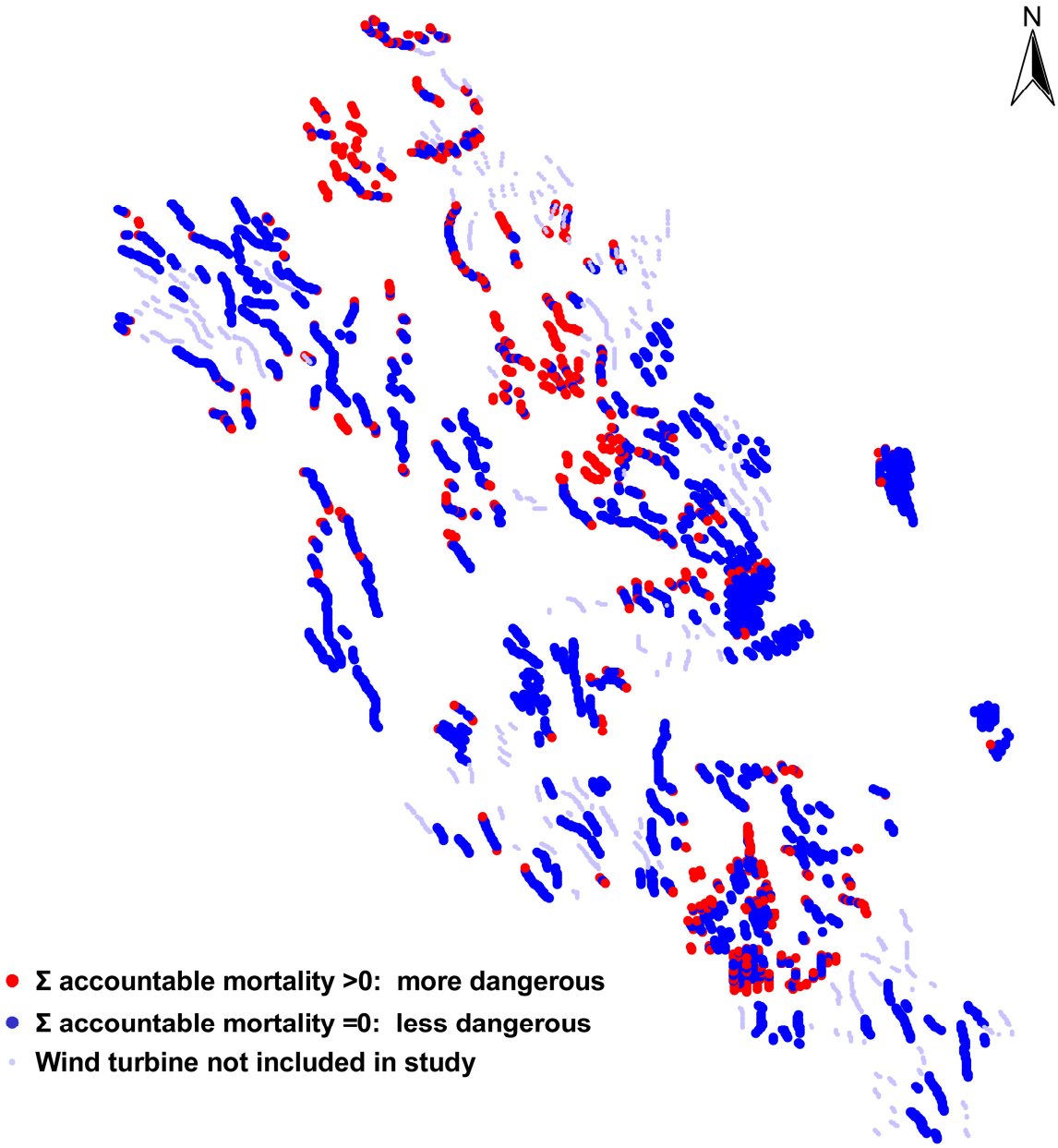


Figure 7-27. Wind turbines predicted by our model to be more dangerous to red-tailed hawks are distributed less widely across the APWRA than we actually documented.

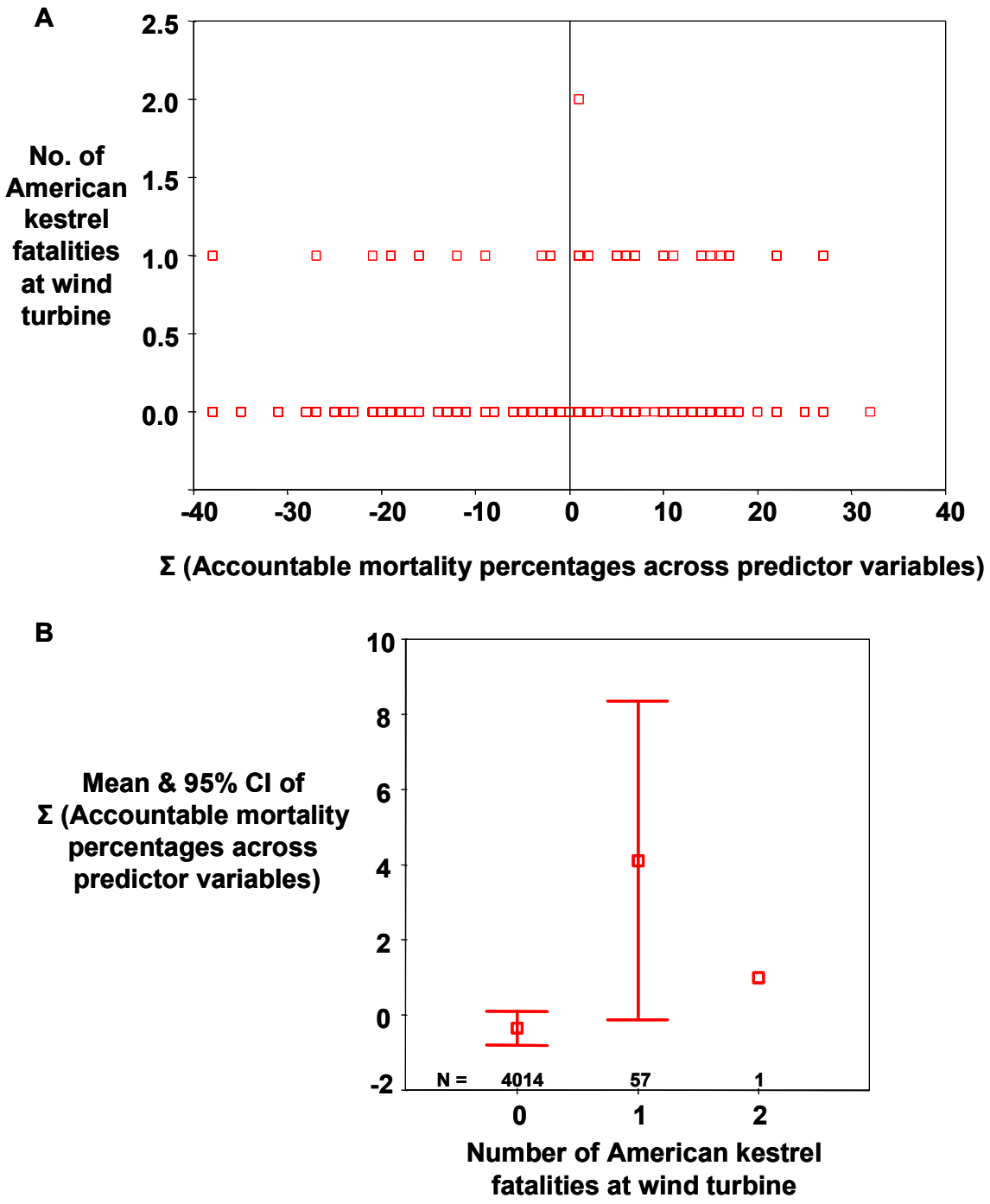


Figure 7-28. Most of the wind turbines documented to have killed American kestrels were incorrectly classified as more dangerous to American kestrels by the empirical model we developed (A), the mean values of which generally increased with the actual number of American kestrels killed by the wind turbine (B).

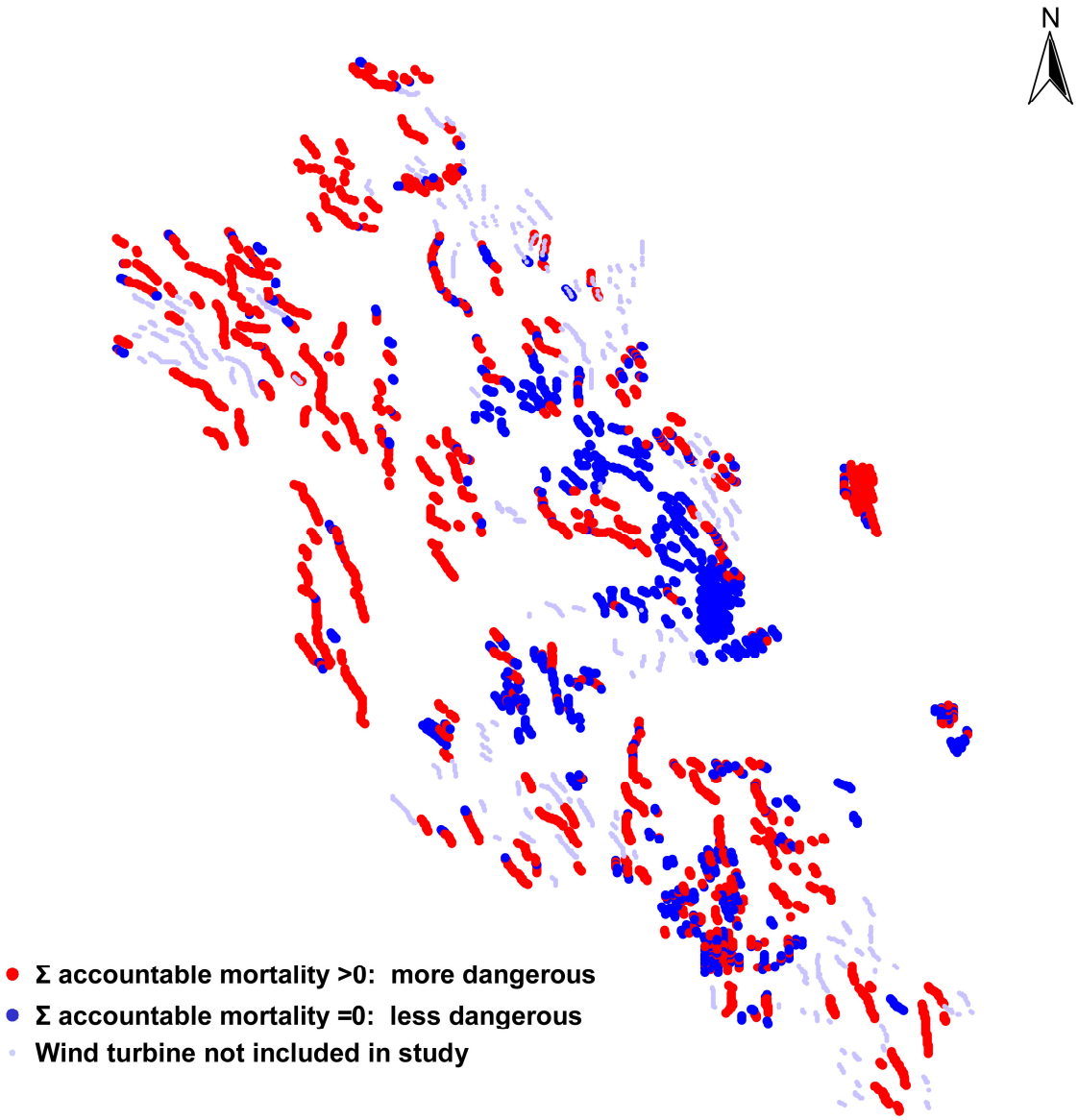


Figure 7-29. Wind turbines predicted by our model to be more dangerous to American kestrels are widely distributed across the APWRA.

Burrowing Owls

Wind turbines with longer intervals between rotor sweeps at the blade tip made burrowing owls most vulnerable, as did wind turbines located at the lowest elevations of the wind farm, turbines on tubular towers, at the ends of strings, and where rodent control was being implemented (Table 7-15). Also, wind turbines with more cattle pats nearby were more dangerous to burrowing owls, as were turbines outside of wind walls and those in canyons.

Table 7-15. The directions and magnitudes of the associations between wind turbine-caused burrowing owl fatalities and levels within independent variables

Variable	Magnitude of increase in mortality
Sec/rotor sweep at blade tip	30% at turbines with longer time per rotor sweep at blade tip
Tower type	19% at tubular towers, 10% at vertical axis towers
Tower height	16% at towers of medium height
Whether in wind wall	13% at turbines *not* in wind walls
Position in turbine string	24% at the string end
Whether in canyon	6% in canyon
Elevation	44% at lowest elevation
Rodent control	24% in areas with moderate level of control
Cattle pats at wind turbines	18% at turbines with more cattle pats

The model correctly predicted wind turbines to be dangerous where 71% of the burrowing owl fatalities actually occurred (Table 7-16), which indicates solid predictive power. Only 29% of the wind turbines were predicted to be dangerous to burrowing owls (Figure 7-30). The more dangerous wind turbines were distributed mostly along a low-elevation band across the wind farm, but also between the Patterson Pass and the Highway 205 corridor (Figure 7-31). This region of the APWRA possibly supports the greatest number of burrowing owls.

Table 7-16. The distribution of known burrowing owl fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the eight variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	2,838	1,172	29% of turbines
1	16	38	70% of turbines
2	2	4	67% of turbines
3	0	1	100% of turbines
Total fatalities	20	49	71% of fatalities

Key Raptors

The model correctly predicted wind turbines to be dangerous where 47% of the golden eagle, red-tailed hawk, American kestrel, and burrowing owl fatalities actually occurred (Table 7-17). Only 23% of the wind turbines were predicted to be dangerous to these species collectively. The more dangerous wind turbines were distributed mostly along a north-south oriented low-elevation band across the wind farm, but also at the ends of some turbine strings and at the edges of local clusters of wind turbines (Figure 7-32).

Table 7-17. The distribution of known golden eagle, red-tailed hawk, American kestrel, and burrowing owl fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	2,884	850	23% of turbines
1	179	112	38% of turbines
2	12	23	66% of turbines
3	2	7	78% of turbines
6	0	1	100% of turbines
Total fatalities	209	185	47% of fatalities

Barn Owls

The model correctly predicted wind turbines to be dangerous where 57% of the barn owl fatalities actually occurred (Table 7-18). Only 20% of the wind turbines were predicted to be dangerous to barn owls.

Table 7-18. The distribution of known barn owl fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the six variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	3,194	823	20% of turbines
1	18	25	58% of turbines
2	2	1	33% of turbines
Total fatalities	20	27	57% of fatalities

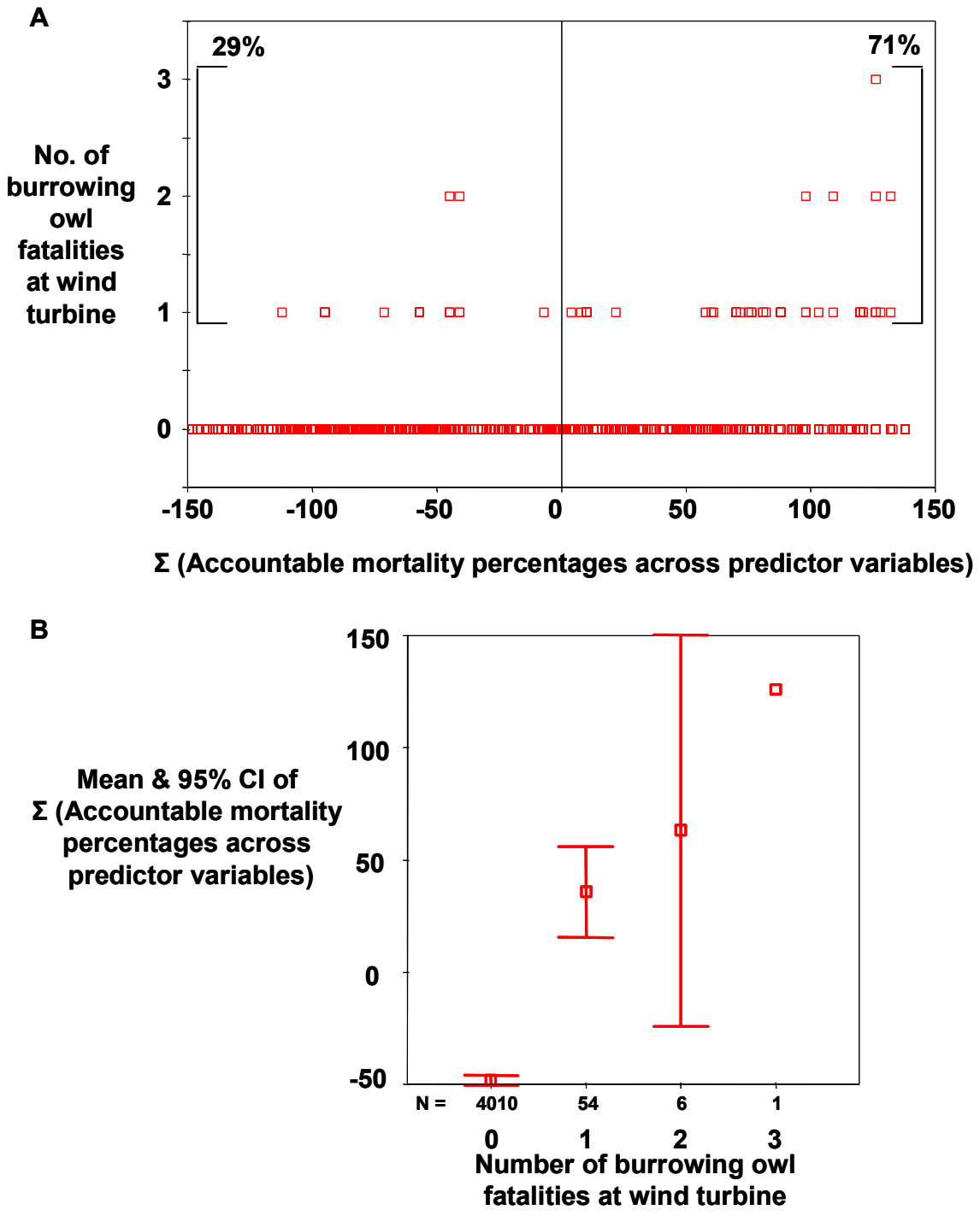


Figure 7-30. Most of the wind turbines documented to have killed burrowing owls were correctly classified as more dangerous to burrowing owls by the empirical model we developed (A), the mean values of which increased with the actual number of burrowing owls killed by the wind turbine (B).

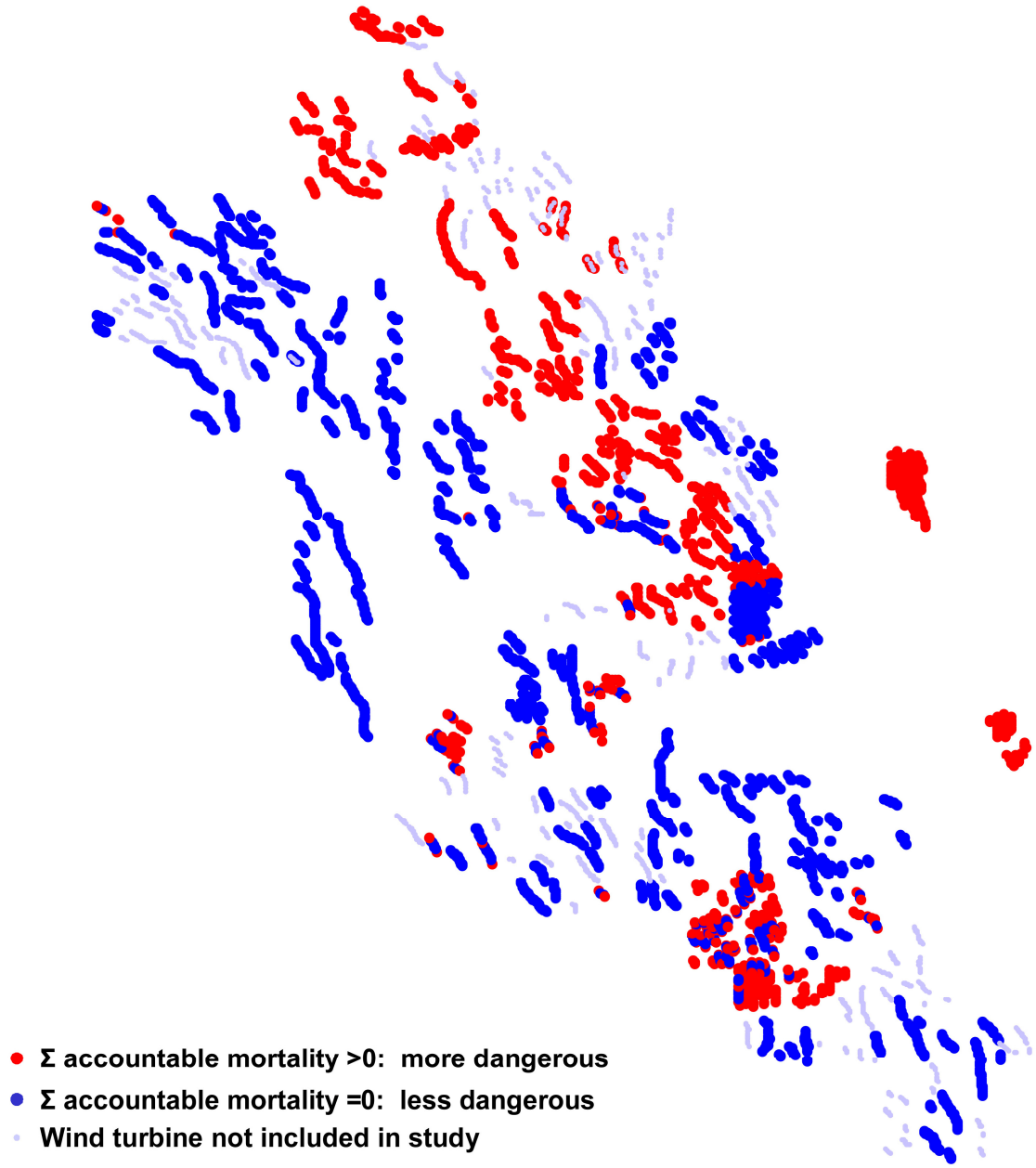


Figure 7-31. Wind turbines predicted by our model to be more dangerous to burrowing owls are distributed rather narrowly across the APWRA.

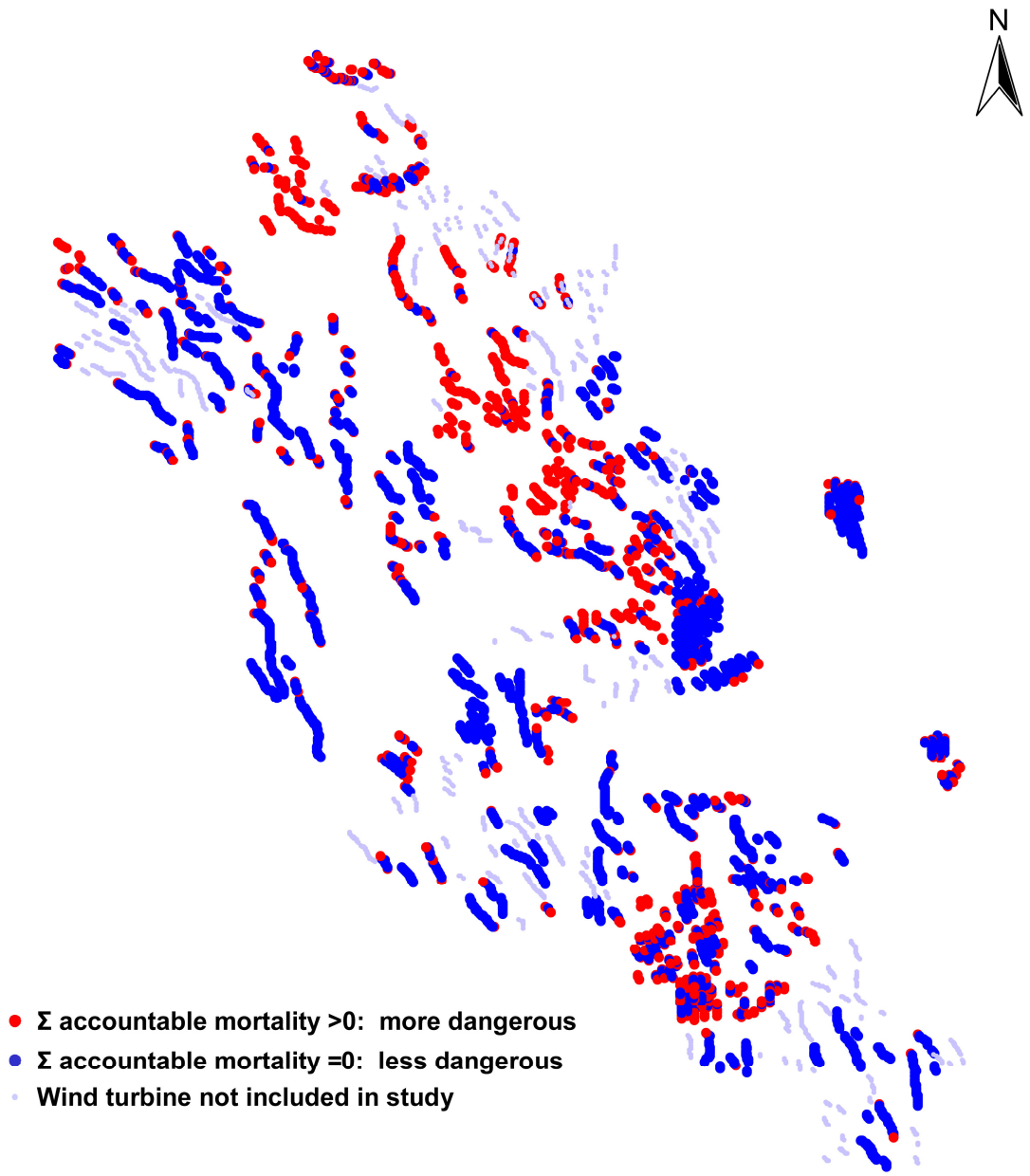


Figure 7-32. Wind turbines predicted by our model to be more dangerous in combination to golden eagles, red-tailed hawks, American kestrels, and burrowing owls are distributed relatively narrowly across the APWRA.

Great Horned Owls

The model, which was based on only a single independent variable, correctly predicted wind turbines to be dangerous where 56% of the great horned owl fatalities actually occurred (Table 7-19). Half of the wind turbines were predicted to be dangerous to great horned owls.

Table 7-19. The distribution of known great horned owl fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the one variable chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	2,028	2028	50% of turbines
1	8	8	50% of turbines
2	0	1	100% of turbines
Total fatalities	8	10	56% of fatalities

Mallards

The model correctly predicted wind turbines to be dangerous where 79% of the mallard fatalities actually occurred (Table 7-20). Only 25% of the wind turbines were predicted to be dangerous to mallards.

Table 7-20. The distribution of known mallard fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the eight variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	3,036	1,005	25% of turbines
1	7	20	74% of turbines
2	0	3	100% of turbines
Total fatalities	7	26	79% of fatalities

California Horned Lark

The model correctly predicted wind turbines to be dangerous where 48% of the California horned lark fatalities actually occurred (Table 7-21). Only 6% of the wind turbines were predicted to be dangerous to California horned larks.

Table 7-21. The distribution of known California horned lark fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the four variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	3,787	263	6% of turbines
1	12	11	48% of turbines
Total fatalities	12	11	48% of fatalities

Western Meadowlarks

The model correctly predicted wind turbines to be dangerous where 56% of the western meadowlark fatalities actually occurred (Table 7-22). Only 23% of the wind turbines were predicted to be dangerous to western meadowlarks.

Table 7-22. The distribution of known western meadowlark fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the eight variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	3,050	927	23% of turbines
1	42	48	53% of turbines
2	0	3	100% of turbines
Total fatalities	42	54	56% of fatalities

Mourning Doves

The model correctly predicted wind turbines to be dangerous where 82% of the mourning dove fatalities actually occurred (Table 7-23). Only 29% of the wind turbines were predicted to be dangerous to mourning dove.

Table 7-23. The distribution of known mourning dove fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the ten variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	2,867	1,164	29% of turbines
1	6	26	81% of turbines
2	0	1	100% of turbines
Total fatalities	6	28	82% of fatalities

Rock Doves

The model correctly predicted wind turbines to be dangerous where 53% of the rock dove fatalities actually occurred (Table 7-24). Only 20% of the wind turbines were predicted to be dangerous to rock dove.

Table 7-24. The distribution of known rock dove fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the ten variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	3,112	788	20% of turbines
1	78	57	42% of turbines
2	5	11	69% of turbines
3	1	4	80% of turbines
4	0	3	100% of turbines
Total fatalities	91	103	53% of fatalities

European Starlings

The model correctly predicted wind turbines to be dangerous where 74% of the European starling fatalities actually occurred (Table 7-25). Two-thirds of the wind turbines were predicted to be dangerous to European starling.

Table 7-25. The distribution of known European starling fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the five variables chosen for inclusion in the model.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	1,337	2,673	67% of turbines
1	15	43	74% of turbines
2	1	3	75% of turbines
Total fatalities	17	49	74% of fatalities

All Birds

The model correctly predicted wind turbines to be dangerous where 39% of the bird fatalities actually occurred (Table 7-26). Only 20% of the wind turbines were predicted to be more dangerous to birds.

Table 7-26. The distribution of known bird fatalities between wind turbines classified according to their relative likelihoods of causing the fatalities. These likelihoods are represented by the sum of the percent accountable fatalities from the variables chosen for inclusion in the combined model for all birds.

No. of fatalities at wind turbine	No. of wind turbines less likely to cause fatalities (scored ≤ 0)	No. of wind turbines more likely to cause fatalities (scored > 0)	Percent correctly classified as > 0
0	2,557	711	20% of turbines
1	395	176	31% of turbines
2	96	62	39% of turbines
3	15	29	66% of turbines
4	8	10	56% of turbines
5	2	2	50% of turbines
6	3	3	50% of turbines
7	1	0	0% of turbines
Total fatalities	699	455	39% of fatalities

7.4 DISCUSSION

7.4.1 Model Predictions

Our model predictions are somewhat simplistic, because we were unable to account for interaction effects between independent variables. The number of fatalities in our sample and the differential sampling effort precluded a reliable analysis of interaction effects or the use of multivariate statistics. Even had we attempted such analyses, we found that our sampling was incomplete for characterizing the distribution of fatalities of each and all species among wind turbines. Continued carcass searches would undoubtedly have expanded the number and variety of wind turbines that caused fatalities, although it is also possible that the representation of the associations identified in this study would have remained largely unchanged.

We can explain only a fraction of the variation in bird fatalities caused by wind turbines in the APWRA. All birds lumped together (and assuming additive effects from the factors entered into the model), the elimination of 20% of the wind turbines might reduce mortality on the order of 40%. We can do better for certain species—including burrowing owl, mallard, California horned lark, and mourning dove—for which elimination of a portion of the wind turbines in the APWRA would likely reduce most of the mortality. Nevertheless, for other species, such as golden eagle, red-tailed hawk, and American kestrel, if shutting down turbines was the only management treatment considered (but we recommend multiple treatments, see Chapter 9), it would be necessary to remove most or all of the currently operating wind turbines for mortality to substantially lessen.

Future plans to repower much of the APWRA (i.e., replace older turbines with newer ones at a ratio of 7:1) will require new siting criteria to be applied (Alameda County 1998). It may be that such a program is needed sooner than later, so that the most dangerous sites for turbine installations can be decommissioned and the new turbines can be installed in areas less likely to be dangerous, based on the results presented here. Regardless, extensive monitoring would be needed after turbine installation, to determine if the program, in fact, resulted in reduced bird mortality.

It is also possible that the percentage of accountable mortality of certain factors is misleading, and that mitigation measures taken to reduce the impact of particular factors might be more effective than suggested by the model predictions. For example, it is conceivable that translocating the existing wind turbines out of canyons and off of steep slopes, then clustering them into wind walls (or other aggregations) would reduce mortality to a much greater extent than suggested by the percentages resulting from our statistical tests. In fact, it is our opinion that a combination of such measures would indeed reduce mortality to levels that are lower than suggested by the models.

For certain species, our analysis suggests that we either did not characterize the key factors that are most important to predicting wind turbine-caused fatalities, or that there is a relatively equal threat posed by each and every wind turbine in the APWRA. For example, red-tailed hawk mortality appeared almost random in occurrence; no single variable that we measured could explain more than 15% of the variation. Red-tailed hawks appear to be highly susceptible to collisions with wind turbines.

However, red-tailed hawk mortality might be influenced more significantly by some variables we measured in a limited capacity but that we could not use in the predictive models. For example, early tests for association between red-tailed hawk mortality and the degree of pocket gopher clustering around wind turbines appeared promising, but we were able to measure this clustering only around 70 turbine strings, not around the 472 strings that were used for developing the model. Complicating matters further was the rodent control program, which was undoubtedly changing the numerical and spatial distributions of small mammals in the APWRA while we were attempting to explain the variation in raptor mortality. We also did not include in the predictive model the steps taken by the wind industry to reduce mortality, namely, rodent control, painting turbine blades, installing perch guards, and installing tubular towers in place of lattice towers during a later addition to the APWRA. Notably, each of these steps associated with greater levels of mortality, not lesser.

7.4.2 Wind Turbine/Tower Attributes

Bonus, Micon, and KVS-33 turbines were the most dangerous wind turbines to birds within our study area at the APWRA. Generally speaking, the taller towers supporting wind turbines with a larger rotor diameter and slower to intermediate blade tip speeds were the most dangerous wind turbines to birds. Also, tubular towers associated with more avian fatalities than did lattice or vertical axis towers. The test for association between fatalities and tower type indicated that perching on towers might be less of an issue than previously believed. Also, taller towers, or at least turbines with higher blade reaches, are more dangerous to a larger suite of bird species than previously claimed. This set of results supports the need to monitor any future repowering program in order to observe how wind turbines with larger diameter blades mounted on taller towers affect bird mortality.

Also, our results contradict the claims made in the repowering Draft Environmental Impact Report (DEIR) (Alameda County 1998) that slower-moving blades on taller, tubular towers will be safer for birds in the APWRA. We found that the vulnerability of birds in the APWRA is increased by taller towers, the slower-moving blades, and the longer time spans with which birds have to fly through the rotor plane. Of course, our results are interpreted only within the context of the APWRA and the range of conditions represented by our sample of wind turbines and fatalities.

The strong association between burrowing owl mortality and Flowind (vertical axis) turbines was most likely the result of an artifact of the higher densities of burrowing owl occurring where these wind turbines operated. Similarly, it was likely an artifact of flyways that mallards were disproportionately killed by Windmatic turbines. Despite these likely artifacts of location, burrowing owls and mallards were also killed more often than expected by chance by Bonus turbines on tubular towers.

Rotors facing the wind associated with a significantly greater mortality of birds, either because this rotor orientation is also associated with other wind turbine attributes that cause more fatalities or because there is a mechanism specific to the rotor orientation that causes more fatalities to occur. We were unable to determine which of these scenarios is more likely.

Mitigation measures implemented by the wind industry in an attempt to reduce fatalities, including painting turbine blades, installing perch deterrents, and shifting to tubular towers, associated with increased mortality. This increased mortality might be caused by the mitigation measures in some cases, such as birds flying up into moving turbine blades while averting landings on lattice towers just discovered to be blocked by chicken wire, or American kestrels for some reason being attracted to the green and red tips moving at the outer edge of the rotor plane. However, it is also possible that these particular wind turbines were located where vulnerability was greater for other reasons.

In summary, wind turbines were generally more dangerous when they swept larger portions of the sky, moved slower, reached higher into the sky, and were supported on tubular towers. But there were species-specific exceptions, such as wind turbines with lower reaches of the blade sweep killing disproportionately more golden eagles.

7.4.3 Physiography

Generally wind turbines at the lowest elevations and on canyon slopes were more dangerous to birds in our study area, especially on steeper slopes. The effect of wind turbines installed in canyons was one of the most consistently significant factors tested in our study. Ridge crests and peaks appeared to kill no more birds than one would expect of a random distribution of wind turbine strikes, but turbines on ridgelines and slopes did kill disproportionately more of certain key species.

Another factor that related strongly to bird fatalities was the presence of rock piles created by the wind industry when it cleared rocks from wind turbine laydown areas. This factor was only significant, however, for the original set of 1,526 wind turbines sampled in our study. Wind turbines with these rock piles nearby killed more raptors, and disproportionately more western meadowlarks and horned larks.

Rock piles likely attract raptors because they harbor ground squirrels and cottontails, the latter of which use these rock piles as principal den sites. Horned larks and western meadowlarks likely approach and use the rock piles for their elevated displays and calls, which are typical behaviors of these species in grasslands. Rock dove fatalities also associated with the presence of rock piles, but this relationship is likely spurious, given the behavior of rock doves in the APWRA.

The addition of 2,548 wind turbines in 2002/2003 to our sample changed the association test results involving rock piles. We noted during our data collection that the areas where we added wind turbines to our study included many natural rock piles and rock outcrops, which likely provided many opportunities for raptor prey species to find refuge and for bird species to perch and display upon.

The presence of rock piles was only significant for the original set of 1,526 wind turbines we sampled. Wind turbines with these rock piles nearby killed more raptors, and disproportionately more western meadowlarks and horned larks. The addition of 2,548 wind turbines in 2002-03 to our sample changed the association test results involving rock piles. We noted during field studies that the areas where we added wind turbines included many natural rock piles and rocky outcrops,

which likely provided many opportunities for raptor prey species to find refuge and for bird species to perch upon.

7.4.4 Wind Farm Configuration

The most dangerous wind turbines in our study were located at the ends of rows, next to gaps in rows, and at the edge of a local cluster of wind turbines within the wind farm. Overall, wind walls are safer for birds, as are the wind turbines situated in the interiors of clusters of wind turbines. Also, wind turbines that are more isolated from other wind turbines kill disproportionately more birds. These results suggest that birds recognize wind turbines and towers as obstacles and attempt to avoid them while flying, which is consistent with our behavioral observations, but fatalities occur where birds are surprised by wind turbines situated at the edges of local wind turbine clusters or alone.

An excellent example of a threatening wind turbine is the Micon 65-kW turbine sited alone at the northwest corner of the wind field we refer to as ”Mountain House” (String 179; ID = 1307 in our database). It is situated on a steep, northwest-facing slope. We estimated the mortality of this one wind turbine to be between 4 and 11 birds per year, adjusted for search detection biases and scavenger removal rates (see Chapter 3).

7.4.5 Rodent Control and Burrowing Animals

Rodent control did not associate with lesser bird mortality, except for golden eagles. Chapter 6 addressed the effects of the rodent control program in detail. Also, we provide measures of association between mortality and the abundance and distribution of small mammal burrow systems in the Appendices, but we did not build any predictive models based on these associations. Too few of the wind turbines were included in the burrow mapping efforts to contribute substantially to the development of predictive models for application across the entire APWRA.

CHAPTER 8

BIRD BEHAVIORS IN THE ALTAMONT PASS WIND RESOURCE AREA

8.1 INTRODUCTION

Specific behaviors have been thought to predispose certain bird species to being more likely to collide with operating wind turbines (Estep 1989; Howell and DiDonato 1991; Howell and Noone 1992; Orloff and Flannery 1992; Colson 1995; Tucker 1996a; Erickson et al. 1999; Hoover 2001; Strickland et al. 2001a). Thelander et al. (2003) and Smallwood and Thelander (in review) termed this predisposition "susceptibility." The intensity of use of wind farms, measured as number of birds per unit area or unit time, also has been proposed as a contributing factor to the susceptibility of birds to collide with wind turbines (Cade 1995; Morrison 1998; Anderson et al. 2001; Strickland et al. 2001b; Hunt 2002). Orloff and Flannery (1996) took a different view, arguing that intensity of use of the area in a wind farm is unrelated to turbine-caused bird mortality.

Since the APWRA had been operating for 15+ years when we initiated our study to assess susceptibility, we cannot characterize susceptibility in the pure sense of the term. Thelander et al. (2003) and Smallwood and Thelander (in review) reported that our measure of susceptibility of some species was confounded by evidence that the existence and operation of wind turbines may have already changed bird behaviors and perhaps their intensity of use. For example, we reported that red-tailed hawks flew within 50 m of wind turbines more often and for longer periods than expected by a uniform distribution of flight time observed across our study area. It is possible that prior to the development of the APWRA, red-tailed hawks already spent more time flying where the wind turbines were placed, perhaps because the declivity winds were favored by the hawks as well as by the wind turbine owners, or perhaps because the prey species of red-tailed hawk prefer ridge crests and ridgelines where many of the wind turbines were placed. There is no way to know with certainty why red-tailed hawks favor flying near wind turbines.

In this study we supplemented the analyses of behavior patterns in the APWRA that were presented in Thelander et al. (2003), and we modified our methods following Smallwood and Thelander (in review). Our goal was to better understand how bird behaviors and intensity of use related to variables we measured in the APWRA, as well as to bird fatalities.

8.2 METHODS

Two biologists collected bird behavior data within 61 observation plots (hereinafter referred to as OPs) during 15 October 2002 through 14 May 2003. The study plot boundaries encompassed wind turbines easily visible to the observers from a fixed observation point, resulting in a mosaic of irregular shaped, non-overlapping plots (Table 8-1). These 61 plots covered all of the area studied during the behavior research performed under funding from the National Renewable Energy Laboratory (Smallwood and Thelander, in review).

The plots contained 1,500 wind turbines, with 6 to 52 wind turbines per plot. Each observer carried maps of the plots in order to identify each turbine by its number designation and to link it to recorded bird activities. These maps included stitched ortho-photos so that the viewer could see the distribution of wind turbines and the underlying physical relief, roads, and other features observable in the field. A 300 m-buffer around the target wind turbines was also added to the map to aid the observers in plotting field observations and in deciding when birds arrived or left the sampling area.

At each plot, two observers performed circular visual scans (360°), also called *variable distance circular point observations* (Reynolds et al. 1980), using 8×40 binoculars out to 300 m. At the close of the 30-min observation session, the observers moved to the next sampling plot in order to begin another 30-min observation session.

We sampled the plots four times each through the study period, once every three to four weeks. We observed behaviors in various weather conditions, except when rain or fog reduced observer visibility to < 60%, which was too poor to track bird activity accurately.

Variables measured during observation sessions applied to three levels of analysis: the plot level, turbine string level, and individual turbine level. The dependent variables changed according to the level of analysis, and the suite of variables we tested for association with the dependent variables also was unique to each level of analysis.

During the 30-minute observation session, raptor observations were recorded at the turn of each minute during the session. Any raptor appearing within 300 m of a wind turbine was assigned a letter in sequence of entry, and then a number in sequence of observation during subsequent by-minute observations, so that the first bird observed was assigned the designator A1, and the second bird observed, B1. The next observations of these two birds at the turn of the next minute interval resulted in record designations of A2 and B2. A bird that left the 300-m buffer around wind turbines but stayed within sight retained its original identification letter. Birds that disappeared from sight for more than 30 seconds were considered different individuals, and assigned the next available letter designation if and when it reappeared. All of these designations were written onto the appropriate map of the plot and used to identify attribute data when entering them into a digital voice recorder. Audio recordings were transcribed to a spreadsheet within 48 hours.

In addition to the data collected each minute, we also recorded particular behavioral events whenever they occurred during the session. For example, we recorded observations of birds flying through the string of wind turbines, and when birds landed or interacted with others. We also made records whenever birds entered or exited the sampling area.

For each record we reported the species, number of birds in a flock, the times when the bird was detected and when last seen, predominant flight behavior (Table 8-2), flight direction, distance to the nearest turbine, type of turbine, number of passes by a turbine, and flight height relative to the rotor zone (Figure 8-1), which is the height above ground from the lowest to the highest reaches of the turbine blades.

Figure 8-1. The rotor plane of a Bonus turbine and the upper and lower reaches of the rotor zone of a string of four turbines

We divided bird activities into two major categories: flying and perching. In addition, we classified 20 different flying behaviors and 26 different perch structures within our study site (Table 8-2). Our focus was to determine how close to a turbine each bird species flew, and what types of behaviors it exhibited near the "rotor zone," which is where we considered the birds most vulnerable to turbine strikes. The rotor zone in this study represents a 50-m lateral extension of the rotor plane along the length of the string of turbines (Figure 8-1).

Table 8-1. Plot number, types of wind turbine, and power output for 1,500 wind turbines included in behavioral observation sessions

Plot	No. turbines	MW	Turbine Model	Plot	No. turbines	MW	Turbine Model
1	14	1.86	Bonus, Flowind	**33**	31	3.10	KCS-56
2	35	4.92	Bonus, Flowind	**34**	20	2.00	KCS-56
3	25	4.43	Bonus, Flowind	**35**	42	4.20	KCS-56
4	39	4.68	Bonus	**36**	40	4.00	KCS-56
5	27	4.05	Bonus	**37**	28	2.80	KCS-56
6	17	2.31	Bonus, Flowind	**38**	16	1.60	KCS-56
9	6	0.72	Bonus	**39**	45	4.50	KCS-56
10	27	4.05	Bonus	**40**	21	4.20	KCS-56, KVS-33
11	45	6.06	Bonus	**41**	18	4.50	KCS-56
12	32	4.05	Bonus, Flowind	**42**	52	5.20	KVS-33
13	29	3.48	Bonus	**43**	45	4.50	KCS-56
14	12	1.80	Bonus	**44**	52	5.20	KCS-56
15	15	2.13	Bonus	**45**	31	1.24	Enertech
16	15	3.10	Bonus, Flowind	**46**	21	1.17	Micon, Enertech
17	18	2.64	Bonus, Flowind	**47**	20	0.80	Enertech
18	8	0.96	Bonus	**48**	27	1.13	Micon, Enertech
19	11	1.65	Flowind	**49**	21	0.84	Enertech
20	27	4.05	Flowind	**50**	24	0.96	Enertech
21	15	1.74	Bonus, Danwin	**51**	38	2.10	Enertech, Micon
22	14	1.68	Bonus	**52**	41	2.67	Micon
23	32	3.26	Bonus, KCS-56	**53**	27	1.76	Micon
24	13	1.30	KCS-56	**54**	24	1.56	Micon
25	31	3.28	Bonus, Danwin, KCS-56	**55**	39	2.54	Micon
26	32	3.20	KCS-56	**56**	18	1.17	Micon
27	25	2.50	KCS-56	**57**	34	2.21	Micon
28	18	1.80	KCS-56	**58**	9	0.36	Enertech
29	27	2.70	KCS-56	**59**	11	0.44	Enertech
30	40	4.00	KCS-56	**60**	24	1.56	Windmatic
32	18	1.80	KCS-56	**61**	14	0.91	Windmatic

Table 8-2. Flight behaviors and perching structures recorded during 30-min observation sessions in the study plots

Flight Behavior	Perching Structures
1. Fly through	1. Tree
2. Gliding	2. Fence Post
3. Soaring	3. Ground
4. High soaring	4. Rock/vegetation
5. Contouring	5. Power pole top
6. Circling	6. Power pole wire
7. Kiting/hovering	7. Power pole cross-arm
8. Diving	8. Anemometer tower
9. Mobbing/chase	9. Electrical tower
10. Mobbed	10. Vertical axis top
11. Soaring column	11. V. axis inner support
12. Surfing	12. V. axis guide wire
13. Ground hopping	13. Motor top
14. Fly-catching	14. Inside motor
15. Fleeing	15. Turbine blade
16. Interacting	16. Rotor cone
17. Flocking	17. Catwalk
18. Flushed	18. Ladder
19. Land	19. Diagonal lattice, top
20. Mating	20. Diagonal lattice, middle
	21. Diagonal lattice, lower
	22. Horizontal axis, top
	23. Horizontal axis, middle
	24. Horizontal axis, bottom
	25. Other tower (not lattice or tubular)
	26. Derelict tower

8.2.1 Plot Level of Analysis

At the plot level of analysis, we calculated the total number of minutes of flying and perching behaviors among the 30-min observation sessions for each bird species, assuming that the number of on-the-minute observations represented the same number of continuous minutes of the same activity. Minutes of flying and perching were tested for relationships with session start time, temperature during the session, month of the year, wind speed, wind direction, and proximity of the bird(s) to wind turbines.

At the beginning of each 30-min observation session we recorded temperature, wind speed, the specific wind turbines operating, and weather. We measured temperature at the start of each session with a hand-held thermometer, and for analysis we combined these temperatures into categories most of which spanned 10˚ intervals. We recorded wind force measured on the Beaufort scale, where 0 was < 0.3 m/s, 1 was 0.3 to 1.5 m/s, 2 was 1.6 to 3.3 m/s, 3 was 3.4 to 5.4 m/s, 4 was 5.5 to 7.9 m/s, 5 was 8 to 10.7 m/s, 6 was 10.8 to 13.8 m/s, and 7 was > 13.8 m/s. When the wind speed reached > 15 m/s (near gale winds), the wind farm managers advised us to leave the premises for safety reasons. We recorded wind direction (its origin) during the sessions, and the time the session started. For the purpose of this analysis, we combined actual start times into representative times of the day, so 08:00 represented 07:00 to 08:30 hours, 10:00 was for 09:00 to 10:30 hours, 12:00 for 11:00 to 12:30 hours, 14:00 for 13:00 to 14:30 hours, 16:00 for 15:00 to 16:30 hours, and 18:00 for 17:00 to 20:30 hours.

A proximity value was assigned to each behavior in terms of how close that behavior was performed in relation to the wind turbine blades (Figure 8-2). Proximity Level 1 involved behaviors performed within 0–50 m of the wind turbines. Proximity Level 2 involved behaviors seen within 51–100 m. Proximity Level 3 behaviors were performed farther from the turbine at 101–300 m. The geographic areas composing these proximity levels were estimated using ArcView GIS and publicly available aerial imagery. Ground surface modeling was performed using 30 m DEM data that were compiled into a GRID mosaic. This single GRID was then converted into a triangulated irregular network (TIN), and the resulting TIN was used in data creation efforts that included contouring, profiling, and hillside mapping. Buffers at 50, 100, and 300 m were generated around the turbine strings and then intersected with the TIN in order to modify the existing TIN-based surface. The output TIN represented 3-D geometry by draping the buffer polygons and creating only that intersected subset of the TIN for Surface Modeling. The buffer TIN surfaces were exported to GRIDs, which were then converted to 3-D Shapefiles from which geographic areas that are resolved to the 3-D landscape could be calculated.

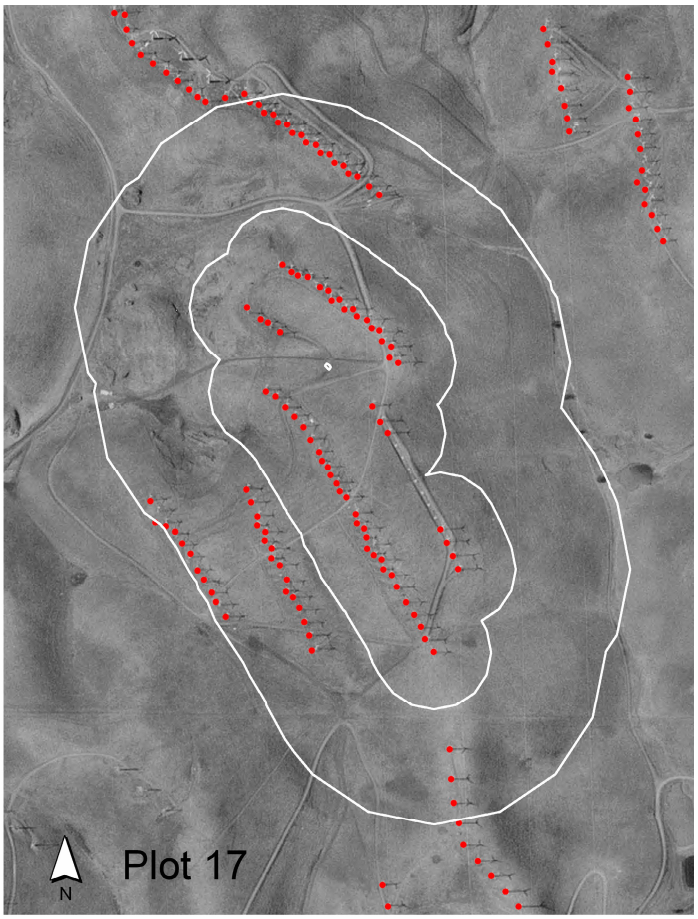


Figure 8-2. An example of a buffer created in GIS and corrected to fit the 3-D landscape in order to test for patterns of behavior in relation to proximity to wind turbines. The inner white line encompasses the wind turbines composing the sample that is the subject of the study plot, and it is 100 m from the wind turbines. The outer white line is the 300-m buffer around the focal wind turbines that also forms the boundary of the study plot.

8.2.2 Wind Turbine Level of Analysis

We identified the wind turbine nearest the observed bird and recorded its designation number to later relate behaviors to attributes of the wind turbines and their local environments, which we characterized in another data set. We related behavioral observations to wind turbine model as well as to the turbine's orientation to the oncoming wind, where blades positioned between the rotor and the wind are "toward" the wind, and blades positioned behind the rotor relative to the wind are "away" from the wind. We recorded the operational status of the wind turbine during the observation session(s), the tower type, tower height, and its position in the turbine string, such as at the end of the string, second to the end, interior to the string, or separated from other turbines by a gap created by a gully or the removal of one or two turbines and their towers. Wind turbines recorded as not operating or broken typically were missing blades, the motor, or both, but at least the tower remained, and we noted whether operating turbines were adjacent to non-operating turbines.

We also recorded whether the wind turbine was part of a wind wall, which is composed of wind turbines at different heights situated next to each other so that winds at a greater height and lateral extent are captured for energy generation. We used ArcView GIS to count the number of other wind turbines occurring within a 300-m radius. Also, we recorded the edge index of its laydown area, and whether rocks were piled nearby as San Joaquin kit fox mitigation. The edge index was measured from the string transect while viewing the 40-m radius from the turbine: 0 = no vertical or lateral edge within 40 m of turbine; 1 = some lateral edge such as the presence of a dirt road other than just the service road found at all of the turbines, or cleared area adjacent to vegetated area, or area tilled for pipeline, etc.; 2 = lots of lateral edge; 3 = some vertical edge such as road cut, road embankment, or cut into the hillside for creating a flat laydown area; and 4 = lots of vertical edge, covering half or more of the area within 40 m of the turbine.

We classified each wind turbine by the slope aspect where it was situated, and we estimated slope grade and recorded elevation. Slope aspect was classified as facing north, northeast, east, southeast, south, southwest, west, northwest, or located in a valley. For analysis we aggregated slope aspect into five categories: northeast and east, southeast and south, southwest and west, northwest and north, and no aspect (flat terrain). Slope grade was estimated at the base of the wind turbine and recorded along with elevation as attributes when mapping the wind turbines using a Trimble Pathfinder Pro-XR GPS. For analysis, slope grade and elevation were lumped into ranges of values with fairly even distributions of wind turbine frequencies.

We also recorded the physical relief on which each wind turbine was situated, such as on ridge crests, ridgelines, slopes, saddles, peaks, or plateaus. Wind turbines were classified by whether they were in or out of three major canyons in the APWRA, although our "canyons" were really deeper, larger drainage basins as compared to the many ravines in the APWRA, and were not canyons in the usual sense of the term. Due to the complex topography of the APWRA, wind turbines could be classified as being on a ridge crest while also being inside a canyon, because peaks and ridge crests exist within the influence of canyons but of course at lower elevations than the canyon borders.

Our study area included three levels of rodent control intensity, which were attributed to the wind turbines. These were derived by interviews with the County staff person (Jim Smith) who conducted the rodent control program, for information on where and how chlorophacinone-treated oats were deployed across the APWRA. The levels of rodent control were none, intermittent, and intense. The intermittent control was applied to the land leased by EnXco, and consisted of the rancher applying poison bait on and around ground squirrel colonies on a less systematic and less frequent basis than applied elsewhere by Alameda County and some other ranchers.

8.2.3 Statistical Tests

Variables measured were tested for associations with the bird behaviors in chi-square analysis (Smallwood 1993). Statistical tests were performed only for the most commonly observed raptor species, because the results of tests involving small sample sizes are unreliable and we had enough bird species with larger sample sizes to recognize general inter-specific patterns. The species included in our more rigorous analyses reported herein include turkey vulture, red-tailed hawk, American kestrel, and golden eagle.

Chi-square tests were performed at two levels: across plots and across individual turbines. Observed values were either the number of minutes of activity of a particular behavior (m_i) or the number of behavioral events (n_i), and were related to expressed values for both statistical hypothesis testing and for deriving a measure of effect.

Expected values were based on sampling effort because sampling effort varied slightly among plots, strings, and wind turbines. Sampling effort was calculated as the following:

$e_{i,p}$ = number of sessions performed under the *i*th condition of the association variable;

$e_{i,s}$ = windswept area in turbine string (m^2) × number of sessions at corresponding plot under the *i*th condition of the association variable;

$e_{i,t}$ = rotor swept area of turbine (m^2) × number of sessions at corresponding plot under the *i*th condition of the association variable;

where e represents sampling effort, p represents the plot level of analysis, s represents the string level, and t represents the turbine level.

The expected values were calculated as a product of the total sample size of the dependent variable and the incidence (P), or relative frequency of occurrence, of the *i*th condition of the association variable:

$$P_{i,p} = e_{i,p} \div S;$$

$$P_{i,s} = e_{i,s} \div \Sigma\, e_{i,s};$$

$$P_{i,t} = e_{i,t} \div \Sigma\, e_{i,t};$$

where S is the total number of behavioral observation sessions, or 241 in this case.

The expected (E) number of minutes (M) of activity was then calculated as:

$$E_p = M \times P_{i,p};$$

$$E_s = M \times P_{i,s};$$

$$E_t = M \times P_{i,t}.$$

And the expected number of events (N) of a specific type of behavior was calculated as:

$$E_p = N \times P_{i,p};$$

$$E_s = N \times P_{i,s};$$

$$E_t = N \times P_{i,t}.$$

In many of our results we will state that a species "prefers" or "favors" a particular condition. We use this term in the statistical sense only, because we cannot know what an animal really prefers unless it communicates that sentiment to us directly. What we mean by preference is that a species occurred or performed some behavior more often or for longer than expected, which we assessed using either of two measures of effect.

8.2.4 Measures of Effect

In-depth examination of test results was based on two measures of effect. The first was the observed-divided–by-expected frequency of a particular behavior at the level or category of a measured variable, where the expected frequency of the behavior at that level or category was the frequency that would have resulted from a uniform or random distribution of that behavior throughout the measured set.

The second measure of effect was the percentage of total observations of a particular behavior that can be attributed to the independent variable's attribute, level, or category in question, and is measured as the following:

$$\text{Accountable Behavior} = (\text{Observed}_i - \text{Expected}_i) \div \text{Total observations of behavior} \times 100\%.$$

This measure is similar to the one used in Smallwood and Erickson (1995). Accountable behavior ranged from -100 to 100% of the total observations of the behavior attributable to a particular level or category of an association variable.

In this chapter we mostly report accountable behavior, because we are most interested in coming to a solution to the bird collision problem in the APWRA. Accountable behavior informs of the association variable's relative contribution to the total frequency of a particular behavior, and it does so by emphasizing the portion of the total observations of the behavior associated with an independent variable. Observed-divided-by-expected values, on the other hand, express the deviation of the observed from the expected value relative to the magnitude of the expected value, and neglects the association variable's relative contribution to the total frequency of the observed behavior. Both measures of effect are useful in this study, but accountable behavior, like accountable mortality in Chapter 3, puts the measure of effect in the context of the magnitude of the problem experienced in the APWRA.

8.3 RESULTS

8.3.1 Characteristics of the Observation Sessions

Most of the 30-minute sessions started between 0900 hours and 1700 hours, and the most common start time was mid-morning (Figure 8-3). The sessions peaked in frequency during January and

were few during February due to wet, muddy roads in the APWRA (Figure 8-4). Most occurred during cool temperatures, from 55 to 65 ˚F (Figure 8-5).

The most frequent wind direction during the sessions was from the southwest, and northwest and north winds were also common (Figure 8-6). Most of the sessions were conducted during slow to modest wind speeds, mostly ranging from 5 to 20 kph (Figure 8-7). The average wind speed during these sessions was greatest when the winds blew from the southwest, followed by the west and northwest (Figure 8-8).

Special behaviors were noticed more quickly than other behaviors (Figure 8-9), with special behaviors reaching an asymptote in frequency of occurrence by about nine minutes and other behaviors doing so by about 20–27 minutes into the behavior observation sessions. Special behaviors included entry into and exit from study plots, as well as landings, diving, mating, flying through the wind turbine string, and a few others. That all behavior observations required 20 to 27 minutes before reaching an asymptote in frequency of occurrence suggests that 30 minutes was the minimum session time necessary for making behavior observations using the 360˚ visual scan approach.

We recorded observations of 10 raptor species during the 241 behavioral observation sessions, or 120.6 hours. Sightings averaged 2.48 raptors per observation session, or 4.96 raptors per hour, and we recorded 598 raptor sightings. We observed no raptors in 48 of the observation sessions.

8.3.2 Overall Raptor Use

We recorded 3,884 minutes of raptor activity, including 855 minutes spent flying (22%) and 3,029 minutes spent perching (78%). Half of the raptor observations were of raptors within 88 m of the wind turbines (Figure 8-10A). Nearly a third of the raptor perching observations were on wind turbines or their towers (Figure 8-10B).

Of 1,405 total flight observations recorded, 368 passed within 50 m of a wind turbine at the height domain of the rotor or below, and 153 passed through the rotor zone. The frequency of flights through the rotor zone of the wind turbine string was related more closely to the total number of minutes of flights recorded during the observation session (Figure 8-11A) than to the total number of minutes of perching (Figure 8-11B).

The average time raptors were observed flying was greatest during intermediate winds (Figure 8-12A), and the average time raptors were observed perching was greatest during slow winds (Figure 8-12B).

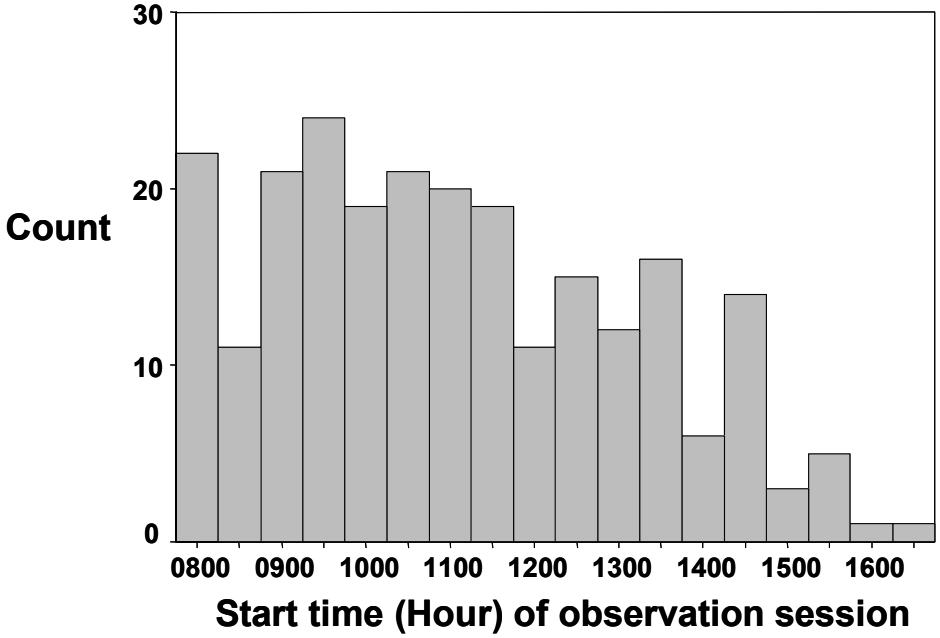


Figure 8-3. Frequency distribution of start times for the 241 behavioral observation sessions

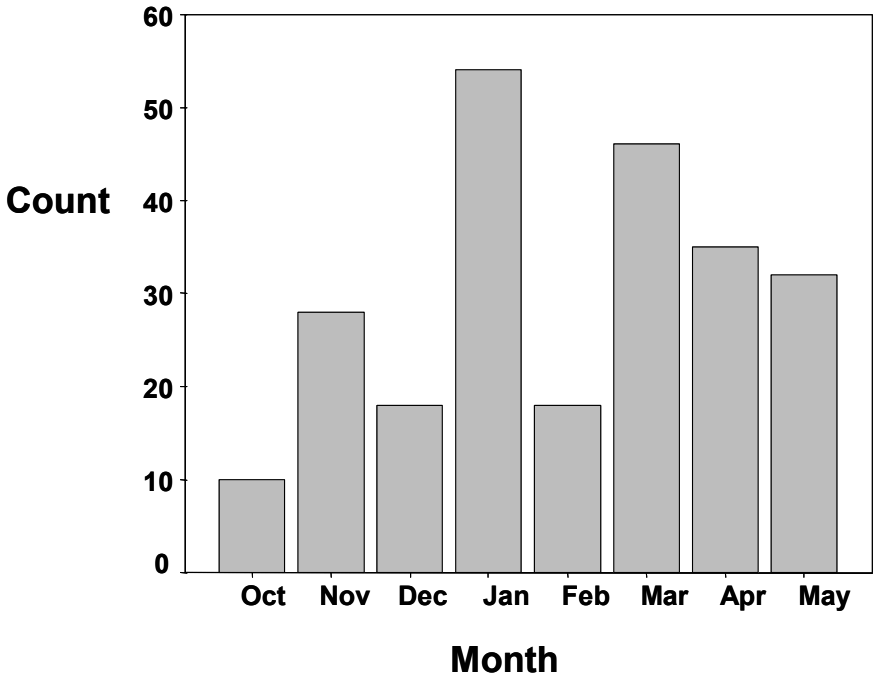


Figure 8-4. Frequency distribution of behavioral observation sessions among months of the year

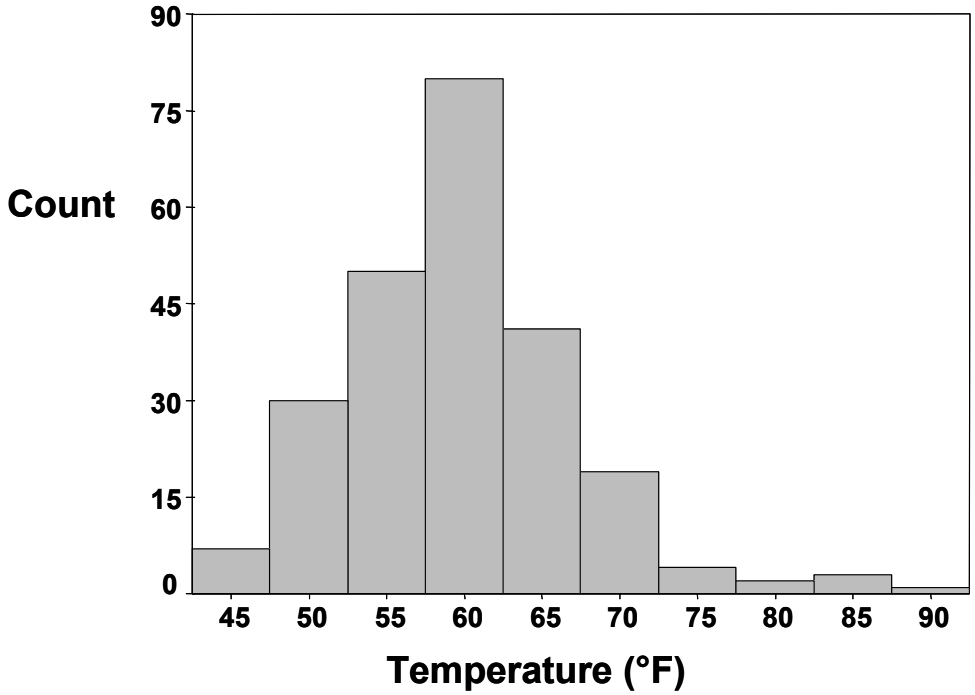


Figure 8-5. Frequency distribution of temperature at the start of 241 behavioral observation sessions

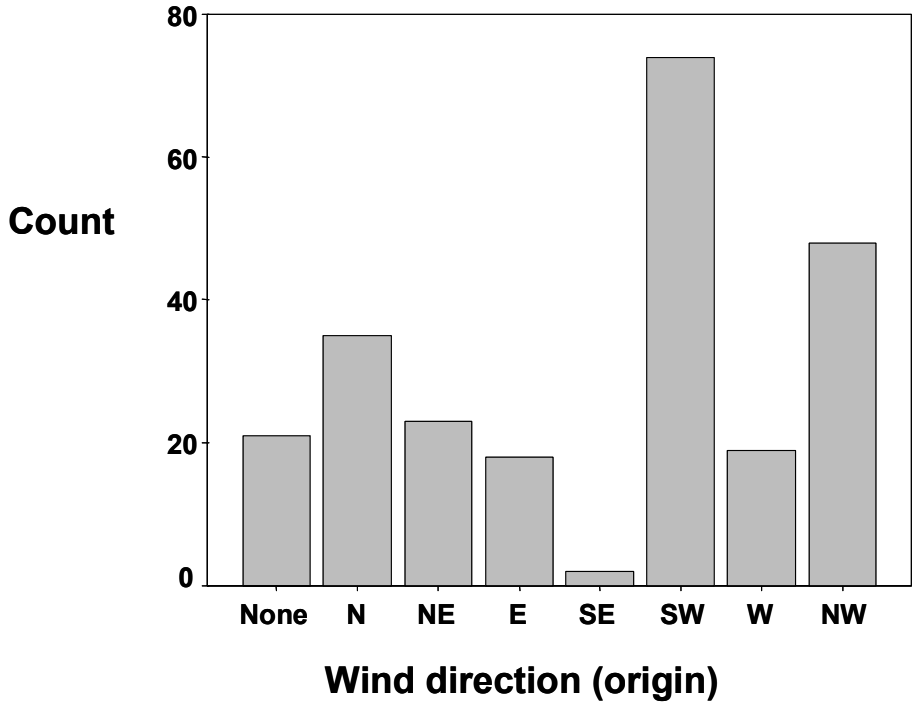


Figure 8-6. Frequency distribution of wind directions (origin) during behavioral observation sessions

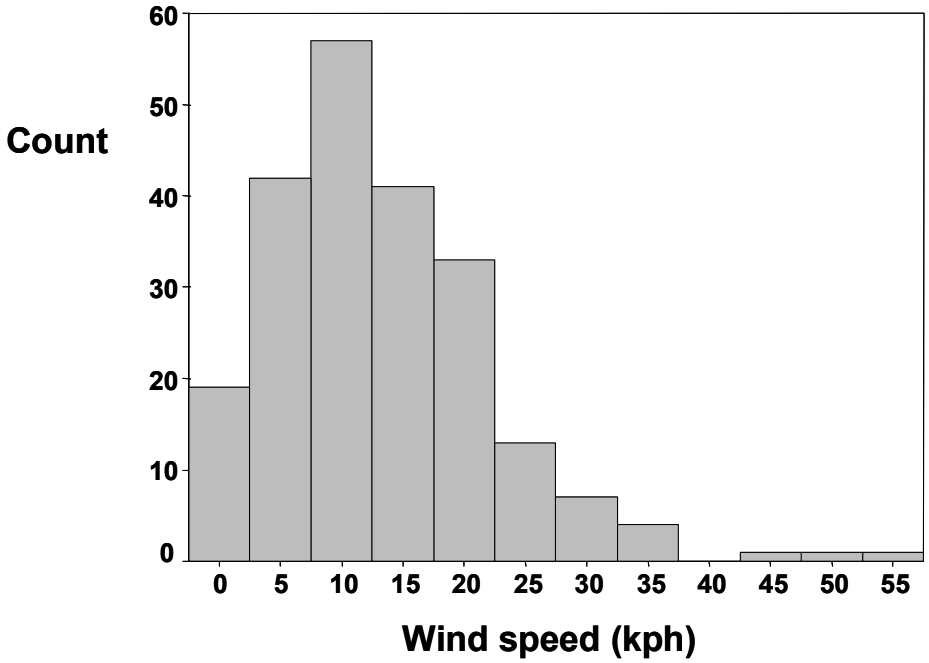


Figure 8-7. Frequency distribution of wind speeds among behavioral observation sessions

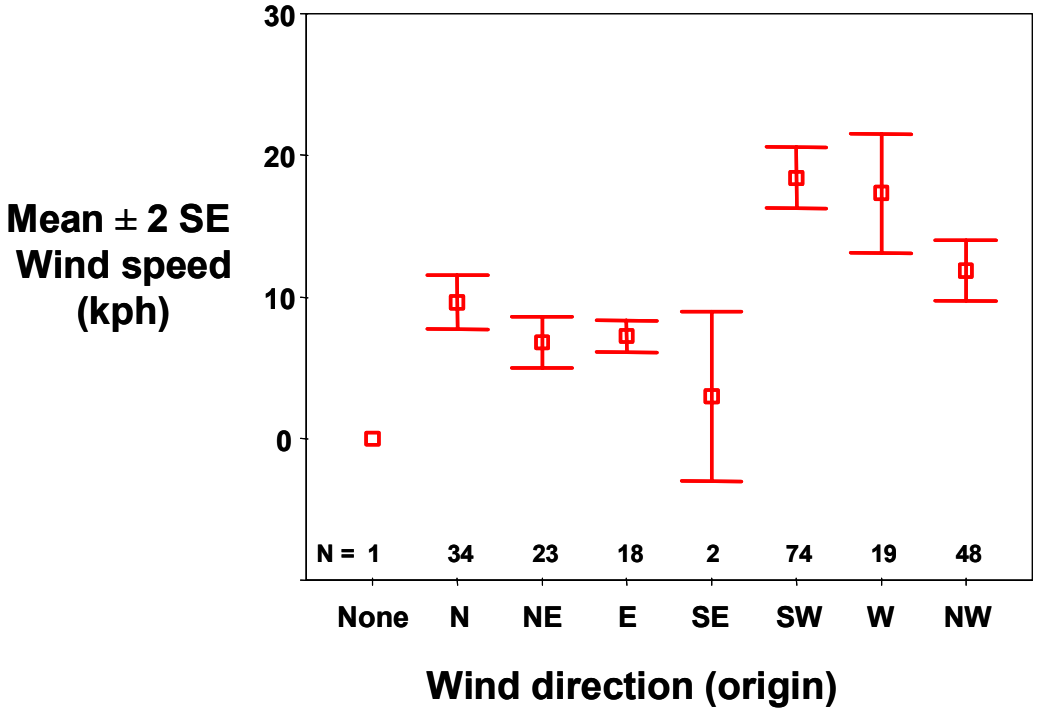


Figure 8-8. Wind speed during behavioral observation sessions as functions of direction of origin

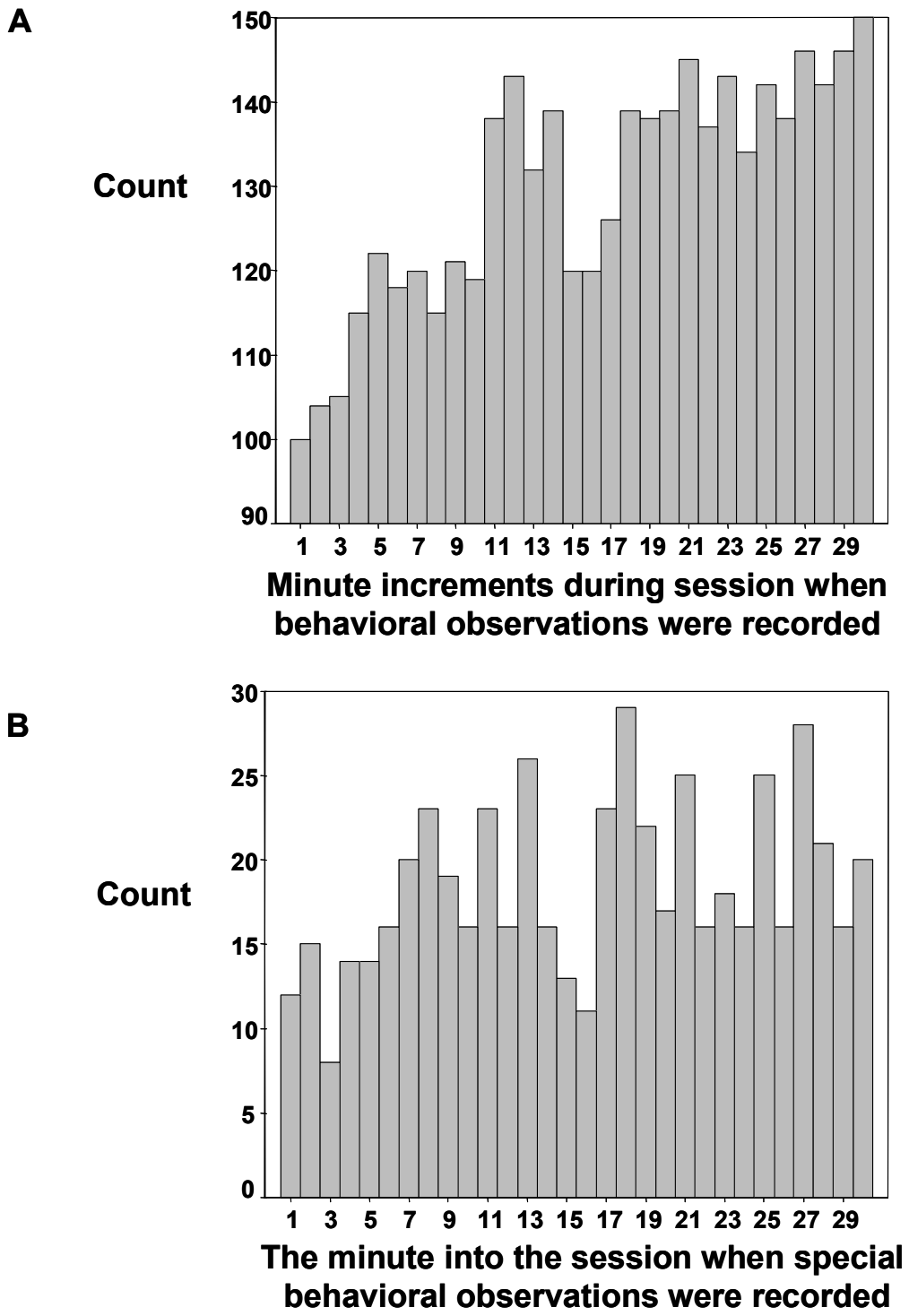


Figure 8-9. The by-the-minute frequency of behavioral observations increased with the number of minutes into the behavioral observation session and appeared to reach an asymptote by 25 minutes (A), whereas the frequency of special behavioral events (e.g., crossing the turbine string, entering or exiting the plot) appeared to increase only during the first 8 minutes of the session (B).

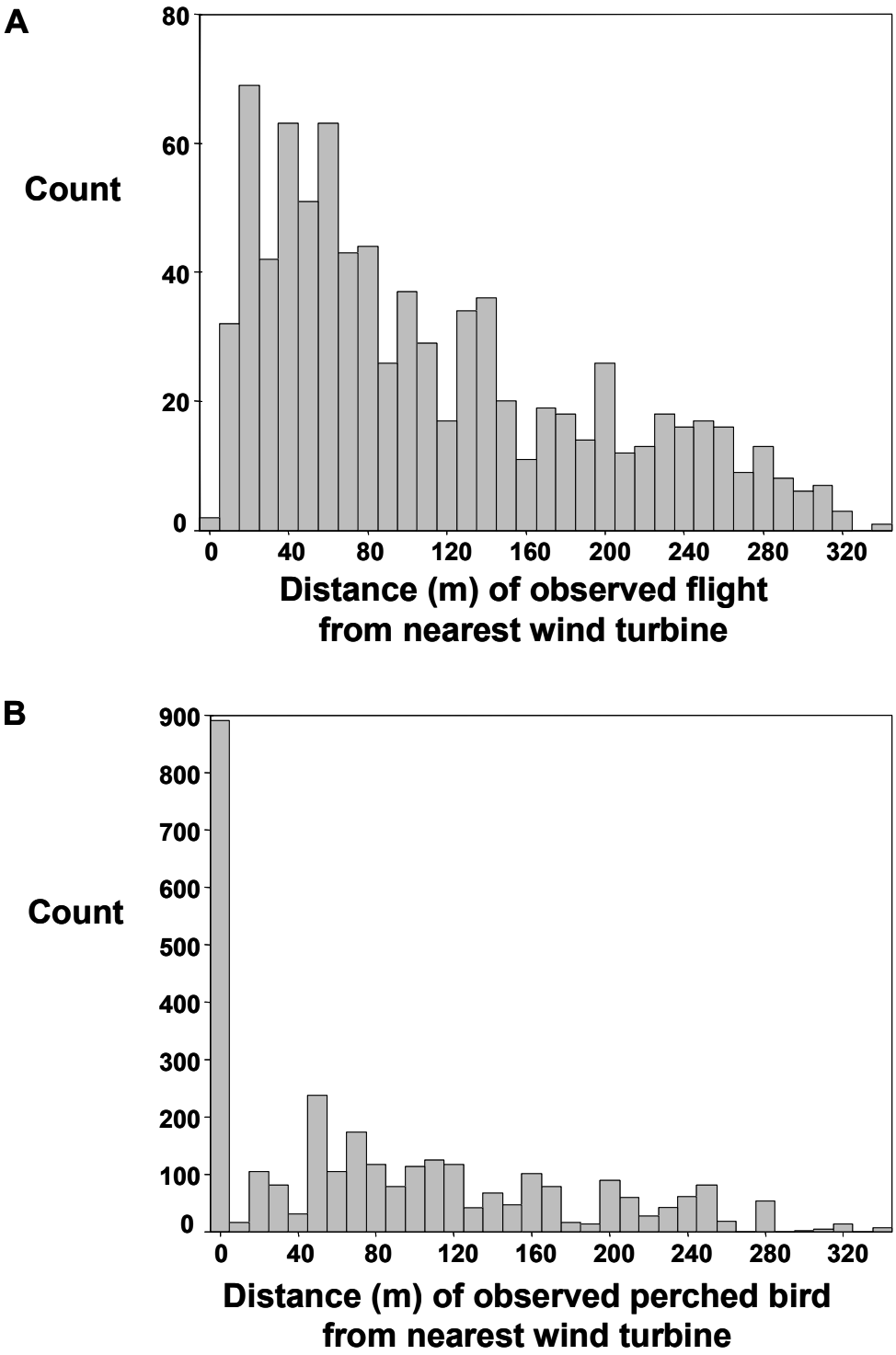


Figure 8-10. Frequency distribution of the distance to the nearest turbine recorded for raptors flying (A) and perching (B) during the behavioral observation sessions

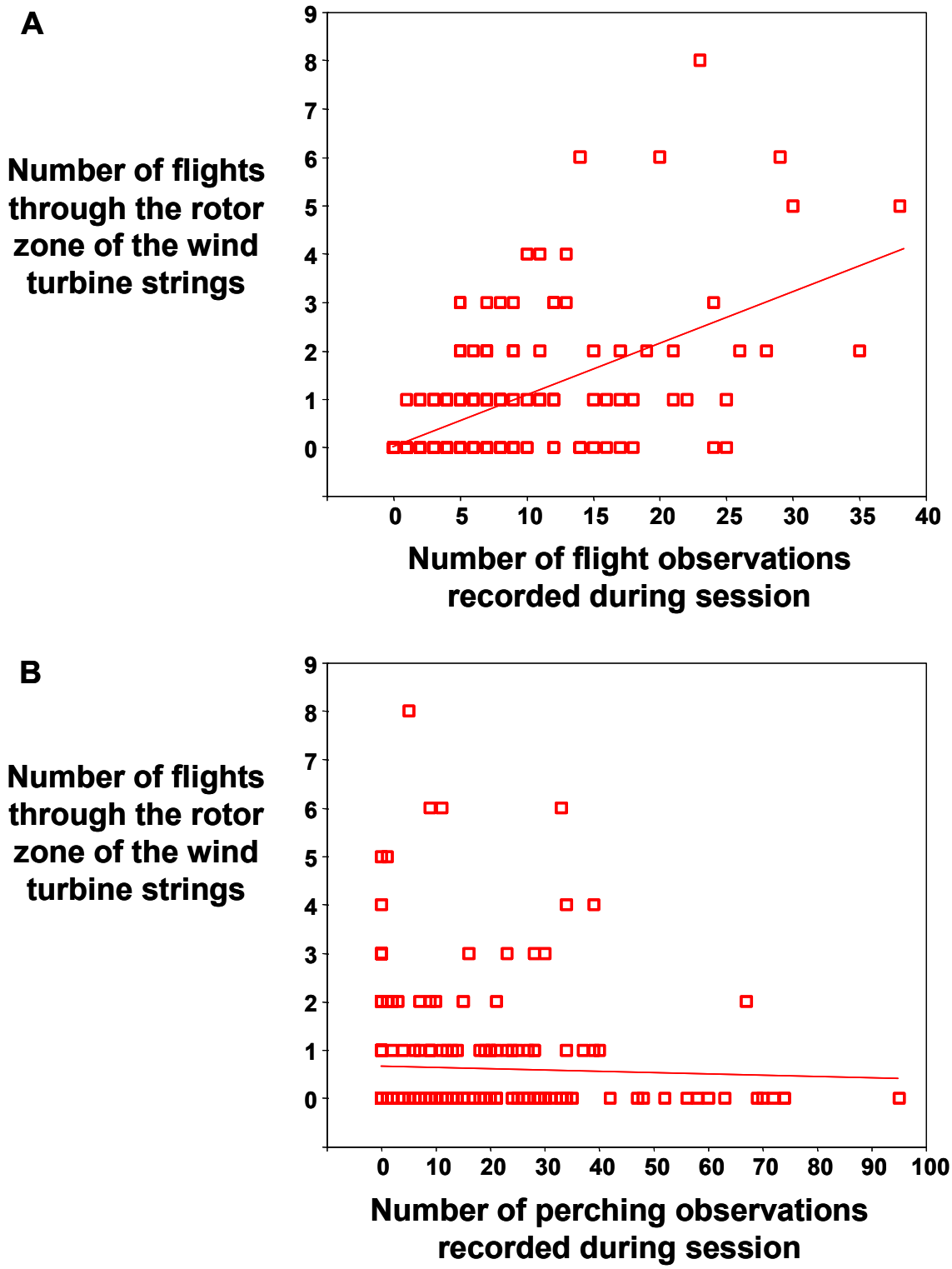
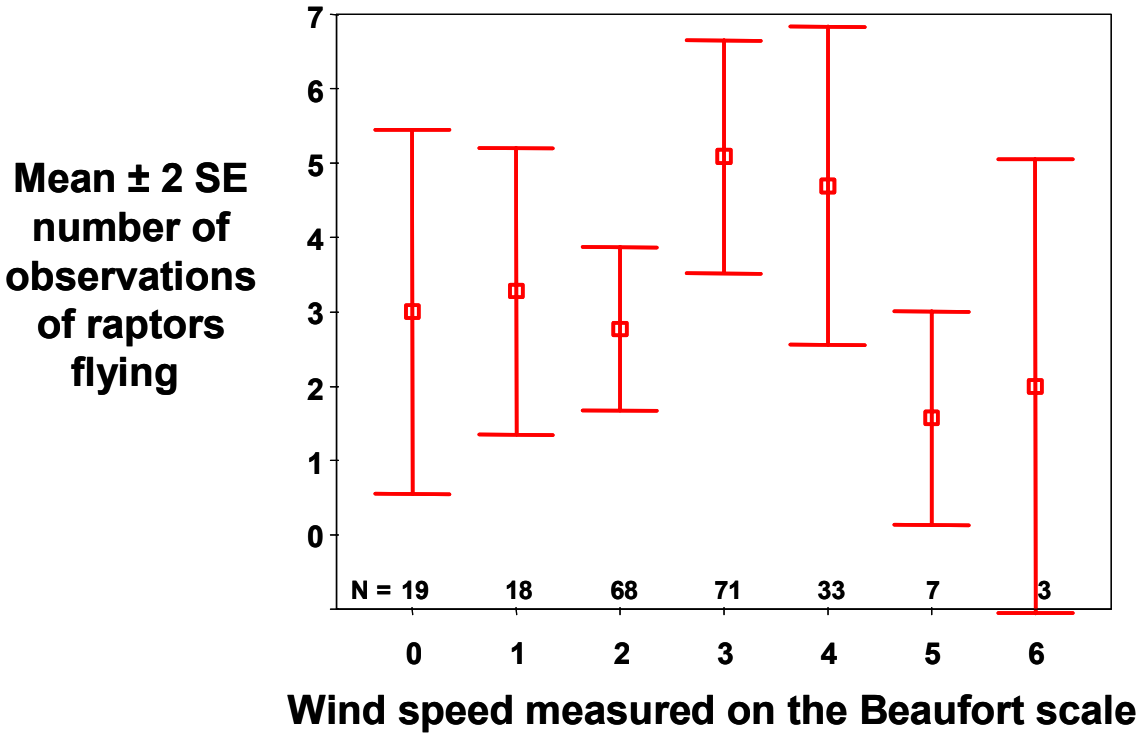


Figure 8-11. The number of passes of birds through the rotor zone increased with the number of observations of flights during the session (A), but not with the number of observations of perching (B)



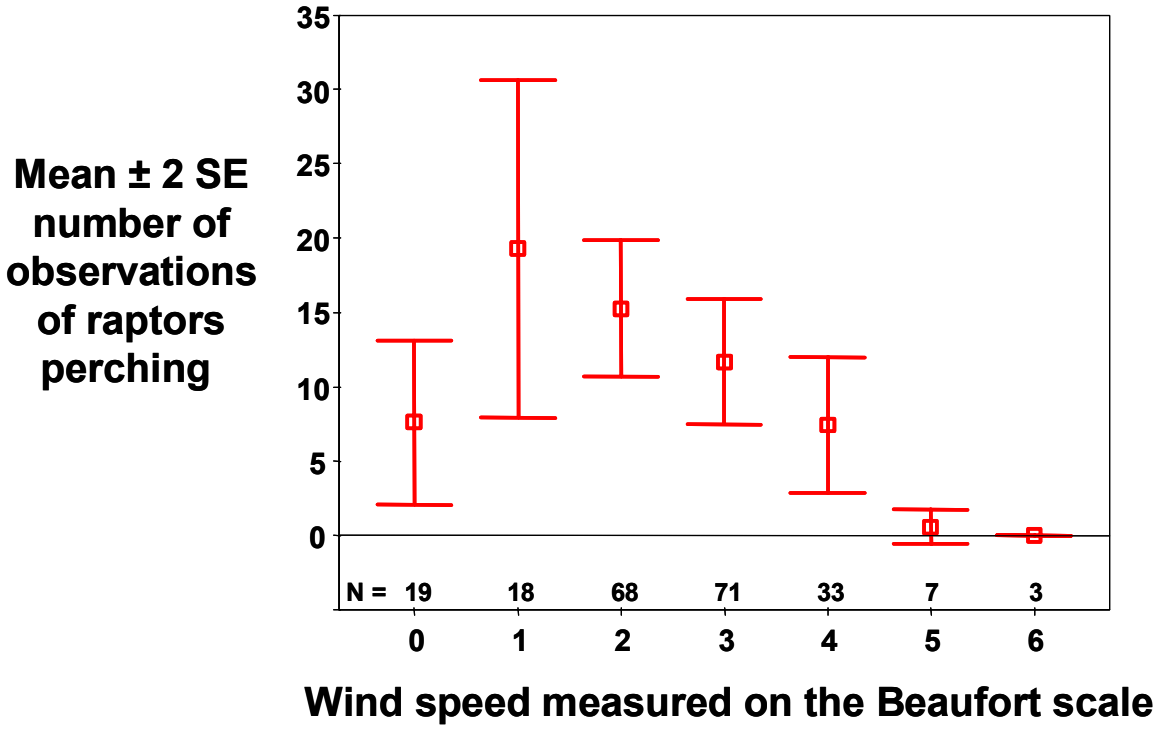


Figure 8-12. The average time raptors spent flying was greatest during intermediate winds (A), and the average time spent perching was greatest during slow winds (B)

Red-tailed hawk was one of the species most often observed in the APWRA and the species most often performing what we assumed to be more dangerous behaviors (Table 8-3). Other commonly observed raptors besides red-tailed hawks included turkey vulture, American kestrel, and golden eagle. Had our study extended into later spring and summer we likely would have seen more burrowing owls than we did.

We assumed that dangerous behaviors included flights through the turbine strings within the height domain of the blades, and we referred to these flights as *through the rotor zone* (rather than the rotor plane, which is specifically through the area swept by the blades). We also considered greater proximity to the turbines to be more dangerous, as well as the number of flights made within 50 m of the turbines. The species performing more of these dangerous behaviors included turkey vulture, red-tailed hawk, and American kestrel (Table 8-3).

Specific flight behaviors observed were mostly soaring, flying through the plot, and gliding, followed by surfing and hovering (Table 8-4). Wind turbines and their towers were commonly perched upon and for lengthy durations (Table 8-5). Other common perch structures included the ground and on power wires.

Table 8-3. Summary of behavioral activities by species

Species	Scientific name	Sum of minutes		Mean distance (m) to closest turbine	Mean flight height (m) above ground	Number of flights	
		Flying	Perching			Through rotor zone	< 50 m to turbine
Turkey vulture	*Cathartes aura*	229	1	126.4	66.4	73	83
Golden eagle	*Aquila chrysaetos*	35	115	162.7	84.4	4	9
Red-tailed hawk	*Buteo jamaicensis*	397	1,391	87.0	69.3	42	185
Rough-legged hawk	*Buteo lagopus*	0	30	0	---	0	0
Ferruginous hawk	*Buteo regalis*	29	83	134.1	204.6	1	4
Northern harrier	*Circus cyaneus*	16	1	94.3	24.1	0	7
Merlin	*Falco columbarius*	2	0	71.9	196.8	1	2
American kestrel	*Falco sparverius*	116	1,103	73.9	23.4	23	66
Prairie falcon	*Falco mexicanus*	4	5	42.2	112.3	3	3
Burrowing owl	*Athene cunicularia*	0	180	119.9	---	0	0
Raptors		**855**	**3,029**	**91.1**	**66.6**	**153**	**604**

Table 8-4. Flight behaviors recorded per bird observation during 241 sessions, where AMKE = American kestrel, BUOW = burrowing owl, FEHA = ferruginous hawk, GOEA = golden eagle, MERL = merlin, NOHA = northern harrier, PRFA = prairie falcon, RLHA = rough-legged hawk, RTHA = red-tailed hawk, and TUVU = turkey vulture

Flight behaviors observed within the 61 plots in the APWRA	**Minutes of Flight Activity**										
	Raptors	**TUVU**	**GOEA**	**RTHA**	**RLHA**	**FEHA**	**NOHA**	**PRFA**	**AMKE**	**MERL**	**BUOW**
Soaring	121	27	3	78	0	8	1	0	2	0	0
Column soaring	140	16	5	105	0	11	4	0	0	1	0
Flying through	117	9	7	38	0	1	3	2	49	1	0
Gliding	267	164	17	57	0	9	6	0	0	4	0
Surfing	105	4	0	66	0	0	0	0	28	0	0
Contouring	18	7	1	4	0	0	4	0	1	0	0
Circling/Searching	0	0	0	0	0	0	0	0	0	0	0
Kiting/Hovering	52	0	0	27	0	0	0	0	25	0	0
Fly-catching	0	0	0	0	0	0	0	0	0	0	0
Diving	1	0	0	1	0	0	0	0	0	0	0
Ground hopping	0	0	0	0	0	0	0	0	0	0	0
Display (interact)	0	0	0	10	0	0	0	0	2	0	0
Flocking	0	0	0	0	0	0	0	0	0	0	0
Chase	7	0	0	3	0	0	0	0	4	0	0
Mobbed/fleeing	14	2	2	8	0	0	0	2	0	0	0
Flushed	0	0	0	0	0	0	0	0	0	0	0

Table 8-5. Perching behaviors recorded per bird observation during 241 sessions, where AMKE = American kestrel, BUOW = burrowing owl, FEHA = ferruginous hawk, GOEA = golden eagle, MERL = merlin, NOHA = northern harrier, PRFA = prairie falcon, RLHA = rough-legged hawk, RTHA = red-tailed hawk, and TUVU = turkey vulture

Perch structures used within the 61 plots in the APWRA	Minutes of Perching										
	Raptors	TUVU	GOEA	RTHA	RLHA	FEHA	NOHA	PRFA	AMKE	MERL	BUOW
Ground, rock, shrub, fence	596	1	56	243	0	28	0	0	73	0	180
Electrical distribution pole	384	0	0	294	0	0	0	2	59	0	0
Transmission tower	297	0	59	120	0	50	0	0	0	0	0
Electric distribution line	531	0	0	55	0	0	0	0	471	0	0
Ancillary equipment	170	0	0	80	0	0	0	0	90	0	0
Wind turbine	897	0	0	510	30	5	0	3	322	0	0
Derelict wind turbine	154	0	0	89	0	0	1	0	50	0	0

8.3.3 Association Analysis

Tables 8-6 through 8-10 summarize the chi-square tests of association between dependent variables and independent variables that express weather, time of day, and seasonal factors. These factors were measured and analyzed at the level of the observation plot. Table 8-11 summarizes the chi-square tests of association between dependent variables and proximity levels, which were analyzed at the wind turbine level. Tables 8-12 through 8-16 summarize the chi-square tests of association between dependent variables and independent variables that express attributes of the wind turbines and of the physiography and range conditions in the area where the turbines occur.

Wind speed

Raptors perched more often than expected by chance during slower wind speeds, which could account for 20% and 39% of red-tailed hawk and golden eagle perching time, respectively, although American kestrel did so during moderate wind speeds (Table 8-6). Raptors flew disproportionately more often during moderate wind speeds, which could account for 16%–26% of the flights observed for our focal species (Table 8-7).

Raptors tended to fly disproportionately lower to the ground during slow winds, and flew higher during moderate to high winds (Table 8-8). Though significant, the distance of raptors species from wind turbines did not display a clear pattern or gradient with wind speed (Table 8-9). However, dangerous flights, or those made within 50 m of the rotor zone, were observed disproportionately more often during moderate-fast wind speeds (Table 8-10).

Wind Direction (origin)

Golden eagles perched disproportionately longer during periods of no wind or when the winds blew from the north, whereas red-tailed hawks did so when winds blew from the east (Table 8-6). American kestrels also perched more often than expected by chance when no winds were blowing. Red-tailed hawks flew disproportionately more often during north and northwest winds, while turkey vultures did so during northwest winds and American kestrels did so during northwest and southwest winds (Table 8-7).

Turkey vultures flew disproportionately closer to the ground when no winds were blowing, and golden eagles did so during northeast winds, and red-tailed hawks and American kestrels did so during southwest winds (Table 8-8). Turkey vultures also flew disproportionately closer to wind turbines during periods of no winds, and golden eagles did so during northeast winds, and red-tailed hawks did so during southwest winds (Table 8-9). Turkey vultures performed disproportionately more of their dangerous flights during northwest winds, as did red-tailed hawks, but red-tailed hawks and American kestrels also did so during southwest winds (Table 8-10).

Session Start Time

Golden eagles perched disproportionately more often during the morning hours, but red-tailed hawks did so during the afternoon (Table 8-6). Most raptor species flew disproportionately more often during the noon period, although American kestrels did so during the late afternoon (Table

8-7). Raptors flew disproportionately closer to the ground and closer to wind turbines during the morning hours, and higher and farther from wind turbines after noon (Tables 8-8 and 8-9). The dangerous flights were observed disproportionately more often after noon for turkey vultures and red-tailed hawks, and after 16:00 hours for American kestrels (Table 8-10).

Month

Raptors perched disproportionately more often during January (Table 8-6), and red-tailed hawks and American kestrels flew more often during November and spring, whereas turkey vultures flew more often than expected by chance during March (Table 8-7).

Golden eagles and American kestrels flew disproportionately closer to the ground and closer to wind turbines during mid to late spring (Tables 8-8 and 8-9), which is also when they made disproportionately more of their dangerous flights (Table 8-10). Red-tailed hawks made more of their dangerous flights during November and March, and turkey vultures did so during March and May.

Temperature

Golden eagles and American kestrels perched more often than expected by chance during cooler temperatures, which was also more or less when they flew more often (Tables 8-6 and 8-7). Turkey vultures, golden eagles, and red-tailed hawks favored relatively cool temperatures for flying closer to the ground as well as closer to the wind turbines and when they made their dangerous flights (Tables 8-8 to 8-10).

Proximity Zone

All raptors except turkey vulture perched more often than expected by chance within 50 m of wind turbines (Table 8-11). A turkey vulture was seen perching during only one minute sampling event, and so was not included in the species-specific analysis. Raptors also flew disproportionately more often within 50 m of wind turbines, as opposed to 100–300 m away, and they performed disproportionately more of their more dangerous flights within the height domain of the rotor zone within 50 m compared to 100–300 m away. As we found during the 1998–2000 behavior study, raptors favor flying and perching within close proximity to wind turbines compared to farther away.

Smallwood and Thelander (in review) reported that raptor species flew in the 50-m proximity zone 8–10 times more often than expected by chance, but that a potentially inherent error in data interpretation might have inflated these estimates of the magnitude of the effect by two-fold. This current behavior study removed the inherent error in data interpretation of the first study, and indeed we found that the magnitude of the measure of effect reduced by half. Regardless, as predicted in Smallwood and Thelander (in review), the apparent preference for the closest proximity zone to wind turbines remained.

Table 8-6. Chi-square tests of association between minutes of perching and independent variables expressing weather, time of day and seasonal factors; t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less time perching than expected of a uniform distribution, and positive values express longer time spent perching. *No test* indicates the sample size was insufficient for reliable statistical testing.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Wind speed (Beaufort scale)	342.47**	No test	72.98**	239.94**	213.07**
0 (< 0.3 m/s)	-3		-9	-2	-8
1 (0.3 to 1.5 m/s)	5		-8	6	5
2 (1.6 to 3.3 m/s)	9		39	14	-4
3 (3.4 to 5.4 m/s)	-1		-4	-10	15
4 (5.5 to 7.9 m/s)	-6		-14	-4	-3
5 (8 to 10.7 m/s)	-3		-3	-3	-3
6 (>10.8 m/s)	-1		-1	-1	-1
Wind direction (origin)	619.02**	No test	182.96**	494.05**	145.54**
None	5		16	4	7
North	2		36	4	0
Northeast	-2		-10	-2	-5
East	8		-7	10	2
South	1		-1	3	-1
Southwest	-14		-8	-16	-7
West	-3		-8	-2	-2
Northwest	3		-17	-1	6
Time of day (hour started)	36.64**	No test	54.40**	47.65**	40.18**
0800	-3		12	-3	-3
1000	-1		14	-6	2
1200	3		-27	5	3
1400	0		5	4	-4
1600	1		-4	0	2
Month	1043.30**	No test	164.31**	462.58**	648.77**
October 2002	-4		-4	-4	-3
November 2002	-1		-12	3	-6
December 2002	3		17	0	4
January 2003	18		-20	17	25
February 2003	5		17	0	6
March 2003	-10		-18	-14	-4
April 2003	-1		7	6	-10
May 2003	-10		13	-8	-12
Temperature (˚F)	100.30**	No test	134.08**	56.05**	117.21**
40–49	-2		-5	-2	0
50–59	8		7	1	13
60–69	-3		-20	2	-7
70–79	-2		21	-3	-4
80–89	0		-3	2	-2

Table 8-7. Chi-square tests of association between minutes of flight and independent variables expressing weather, time of day and seasonal factors, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less flight time than expected of a uniform distribution, and positive values express longer flight time.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Wind speed (Beaufort scale)	72.75**	35.48**	4.66	66.22**	55.72**
0 (< 0.3 m/s)	-2	-5	-3	-5	2
1 (0.3 to 1.5 m/s)	-1	-3	-8	-1	-1
2 (1.6 to 3.3 m/s)	-9	-7	-1	-6	-24
3 (3.4 to 5.4 m/s)	11	4	10	18	5
4 (5.5 to 7.9 m/s)	3	12	0	-4	21
5 (8 to 10.7 m/s)	-2	0	0	-3	-2
6 (> 10.8 m/s)	-1	-1	2	0	-1
Wind direction (origin)	126.58**	46.02**	11.94	73.27**	25.89**
None	-6	-9	-3	-7	-1
North	5	0	-9	9	-7
Northeast	-3	-2	-10	-2	-8
East	-4	-5	-5	-3	-5
South	-1	-1	-1	-1	-1
Southwest	0	4	9	-2	12
West	0	3	6	-2	1
Northwest	9	11	11	8	8
Time of day (hour started)	201.64**	93.25**	9.16	102.03**	36.19**
0800	-11	-12	-11	-13	-8
1000	-8	-10	1	-5	-10
1200	18	26	19	17	4
1400	3	-2	-8	4	5
1600	-1	-3	-1	-3	10
Month	101.94**	87.37**	3.88	81.63**	36.28**
October 2002	-2	-2	-1	-2	-3
November 2002	5	-8	3	9	8
December 2002	-5	-5	-2	-4	-6
January 2003	-8	-11	-11	-10	-2
February 2003	1	1	4	2	-6
March 2003	8	19	1	4	8
April 2003	1	-2	5	5	-8
May 2003	0	8	1	-5	8
Temperature (˚F)	9.78 [t]	29.60**	5.55	10.98 [t]	11.36*
40–49	-2	0	-6	-2	-5
50–59	-2	-17	8	4	4
60–69	4	14	0	-2	6
70–79	0	0	-5	1	-4
80–89	0	2	3	-2	-2

Table 8-8. Chi-square tests of association between mean flight height and independent variables expressing weather, time of day and seasonal factors, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express lower heights above the ground than expected of a uniform distribution, and positive values express higher flights.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Wind speed (Beaufort scale)	147.07**	1066.30**	550.75**	438.22**	123.51**
0 (< 0.3 m/s)	0	2	0	-4	1
1 (0.3 to 1.5 m/s)	-2	0	-8	-1	-2
2 (1.6 to 3.3 m/s)	1	-8	23	10	-6
3 (3.4 to 5.4 m/s)	1	5	-13	2	2
4 (5.5 to 7.9 m/s)	-3	-5	-5	-5	8
5 (8 to 10.7 m/s)	2	7	2	-3	-1
6 (> 10.8 m/s)	0	-1	2	1	-1
Wind direction (origin)	237.20**	639.58**	578.10**	659.58**	330.28**
None	-2	-9	-2	-1	4
North	3	1	-3	5	2
Northeast	-2	4	-10	-2	-4
East	2	-1	0	3	-3
South	-1	-1	-1	0	-1
Southwest	-3	-1	-4	-12	-12
West	-1	2	-2	-3	0
Northwest	3	5	21	11	15
Time of day (hour started)	451.54**	529.85**	598.95**	1221.50**	294.80**
0800	-7	-4	-6	-13	-7
1000	-1	-8	-21	-6	-3
1200	6	11	21	19	-7
1400	4	5	9	2	15
1600	-2	-3	-3	-2	3
Month	966.32**	779.53**	651.47**	520.99**	1235.90**
October 2002	6	6	0	5	-1
November 2002	3	-5	12	3	28
December 2002	-4	-5	-6	-4	1
January 2003	-7	0	6	-2	-1
February 2003	1	3	0	4	-4
March 2003	0	1	-12	-4	-6
April 2003	1	-2	-10	2	-7
May 2003	0	2	8	-4	-9
Temperature (˚F)	544.71**	473.30**	960.95**	694.60**	46.93**
40–49	-2	1	-3	-2	-2
50–59	-8	-13	3	3	0
60–69	3	11	-8	-10	6
70–79	4	-2	-4	7	-2
80–89	3	2	12	2	-1

Table 8-9. Chi-square tests of association between mean distance from nearest wind turbine and independent variables expressing weather, time of day and seasonal factors, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express closer distances than expected of a uniform distribution, and positive values express farther distances.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Wind speed (Beaufort scale)	298.67**	807.90**	1153.40**	666.59**	226.97**
0 (< 0.3 m/s)	-2	-5	0	-2	-2
1 (0.3 to 1.5 m/s)	-1	5	-8	-3	2
2 (1.6 to 3.3 m/s)	2	-2	22	7	-2
3 (3.4 to 5.4 m/s)	3	-2	-11	4	3
4 (5.5 to 7.9 m/s)	0	5	-4	-4	2
5 (8 to 10.7 m/s)	-1	0	-1	-3	-2
6 (> 10.8 m/s)	0	-1	3	0	-1
Wind direction (origin)	375.89**	1112.20**	541.89**	481.32**	391.98**
None	-1	-9	-1	0	2
North	2	1	6	4	1
Northeast	2	1	-10	2	-4
East	1	0	1	0	1
South	0	-1	-1	0	-1
Southwest	-3	-1	0	-7	-4
West	-2	5	-1	-2	-2
Northwest	1	3	5	4	7
Time of day (hour started)	528.31**	1482.80**	326.84**	605.46**	211.23**
0800	-3	-11	-8	-4	-1
1000	2	-6	-5	1	-7
1200	6	10	6	8	4
1400	-3	9	7	-5	2
1600	-1	-2	0	0	2
Month	453.22**	1605.40**	773.57**	763.10**	1097.00**
October 2002	0	1	-2	-1	-2
November 2002	2	-5	3	7	0
December 2002	-1	-3	-5	1	1
January 2003	-5	-11	5	-3	11
February 2003	0	-3	2	0	-2
March 2003	2	8	-8	-4	6
April 2003	3	7	-6	3	-5
May 2003	-1	5	11	-3	-9
Temperature (˚F)	251.73**	925.17**	565.08**	321.56**	229.18**
40–49	-2	-3	-3	-2	0
50–59	-1	-13	2	7	3
60–69	1	10	-7	-7	1
70–79	2	3	2	1	-2
80–89	0	3	5	0	-2

Table 8-10. Chi-square tests of association between flight time within 50 m of rotor zone and independent variables expressing weather, time of day and seasonal factors, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less close-by flight time than expected, and positive values express longer close-by flight time.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Wind speed (Beaufort scale)	57.18**	22.17**	4.31	53.18**	22.47**
0 (< 0.3 m/s)	-3	-1	4	-5	2
1 (0.3 to 1.5 m/s)	-1	-3	-8	-1	-2
2 (1.6 to 3.3 m/s)	-12	-7	-19	-10	-23
3 (3.4 to 5.4 m/s)	15	-6	30	24	16
4 (5.5 to 7.9 m/s)	3	17	-3	-3	10
5 (8 to 10.7 m/s)	-2	2	-3	-3	-2
6 (> 10.8 m/s)	-1	-1	-1	-1	-1
Wind direction (origin)	72.16**	28.92**	10.37	39.44**	18.15*
None	-6	-9	2	-7	-3
North	-1	-6	-15	2	-7
Northeast	-5	-1	-10	-6	-7
East	-5	-7	-7	-4	-7
South	-1	-1	-1	-1	-1
Southwest	8	5	3	10	15
West	-1	3	25	-4	3
Northwest	11	16	2	10	7
Time of day (hour started)	68.87**	24.52**	5.30	51.26**	44.90**
0800	-11	-10	-14	-14	-8
1000	-8	-11	8	-6	-10
1200	11	18	18	11	-4
1400	8	7	-20	11	6
1600	1	-4	7	-3	16
Month	62.19**	27.66**	7.36	72.93**	16.64*
October 2002	-3	-4	-4	-3	-3
November 2002	5	-8	-1	12	7
December 2002	-6	-4	15	-7	-7
January 2003	-3	-1	-11	-8	2
February 2003	-3	-4	4	-4	-6
March 2003	10	12	-8	13	7
April 2003	1	-4	19	5	-5
May 2003	-1	12	-13	-7	6
Temperature (˚F)	24.63**	4.38	2.44	18.68**	4.70
40–49	-5	-5	-6	-6	-4
50–59	4	-3	23	6	8
60–69	4	8	-10	4	1
70–79	-2	0	-5	-2	-3
80–89	-1	0	-3	-2	-1

Table 8-11. Chi-square tests of association between dependent variables and proximity level to the wind turbines, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Dependent Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Minutes of perching	6033.40**	No test	54.19**	3789.70**	2132.20**
0–50 m from turbines	36		17	44	33
51–100 m from turbines	7		-11	3	18
101–300 m from turbines	-44		-5	-46	-50
Minutes of flying	781.57**	148.64**	9.99*	431.14**	212.51**
0–50 m from turbines	22	17	9	25	32
51–100 m from turbines	13	13	12	13	16
101–300 m from turbines	-35	-30	-21	-38	-48
Low flights (≤rotor zone)	630.45**	69.36**	11.50*	375.57**	188.49**
0–50 m from turbines	25	15	12	30	32
51–100 m from turbines	15	12	22	13	16
101–300 m from turbines	-39	-27	-34	-43	-48

Wind Turbine Model

Golden eagles spent disproportionately more time perching amongst wind turbines at lower elevations, and these happened to be Micon, Windmatic, and Enertech wind turbines (Table 8-12). Red-tailed hawks perched more often than expected by chance near or on Flowind turbines. Raptors also spent disproportionately more time flying nearer to Flowind turbines than to most other turbine models, whereas American kestrels flew more often near KVS-33 turbines, golden eagle nearer Windmatic and Enertech turbines, and turkey vultures nearer Windmatic turbines (Table 8-13). Notably, golden eagles, red-tailed hawks, and American kestrels flew disproportionately less often nearer KCS-56 turbines.

Raptors flew disproportionately lower to the ground and closer to Bonus and KCS-56 turbines (Tables 8-14 and 8-15). However, the number of dangerous flights (i.e., those within 50 m of the rotor zone) made by raptors was disproportionately less in relation to these very same wind turbines (Table 8-16). Dangerous flights were disproportionately more common at Flowind turbines (note that many of these no longer operate).

Rotor Diameter

Golden eagles perched and flew disproportionately more often near wind turbines with a smaller rotor diameter (Tables 8-12 and 8-13), likely because the Enertech turbines were located at the lower elevations where golden eagles preferred to perch. Turkey vultures and red-tailed hawks flew lower to the ground than expected by chance near wind turbines with larger rotor diameters (Table 8-14), and golden eagles and American kestrels also flew closer to these wind turbines (Table 8-15). However, golden eagles made disproportionately more dangerous flights near wind turbines with

smaller rotor diameters (Table 8-16). Otherwise, clear patterns between dangerous flights and rotor diameter were few among raptor species.

Tip Speed

Golden eagles and red-tailed hawks perched more often than expected by chance nearest wind turbines with slower tip speeds, and red-tailed hawks also flew disproportionately more often nearest these wind turbines (Tables 8-12 and 8-13). Turkey vultures, golden eagles, and American kestrels flew lower to the ground by wind turbines with faster tip speeds (Table 8-14), and all the focal raptors in our study flew disproportionately closer to wind turbines with faster tip speeds (Table 8-15). However, the dangerous behaviors were performed disproportionately nearer wind turbines with intermediate tip speeds (Table 8-16).

Rotor Plane Swept Per Second

Golden eagles and red-tailed hawks perched and flew more often than expected by chance by wind turbines that swept less of the sky per second (Tables 8-12 and 8-13), but all our focal raptors flew closer to the ground near wind turbines that swept more of the sky per second (Table 8-14), and most flew disproportionately closer to turbines that swept the sky at intermediate rates (Table 8-15). All the raptors species in our study performed disproportionately more of their dangerous flights at wind turbines that swept the sky at the lowest rates (Table 8-16).

Tower Type

Golden eagles preferred to perch near tubular towers, whereas red-tailed hawks did so near vertical axis towers (these tower types are very similar with regards to perching availability) (Table 8-12). All our focal raptor species spent disproportionately more time flying near vertical axis towers, perhaps because these do not operate as often in the APWRA (Table 8-13). Raptors also flew disproportionately lower to the ground near tubular towers, and they also flew closer to these towers (Tables 8-14 and 8-15). Disproportionately more of the dangerous flights were made near vertical axis towers (Table 8-16).

Tower Height

Though chi-square tests were often significant, clear patterns between dependent variables and tower height were few, and the patterns we did recognize appeared to be highly correlated with tower type.

Height of Low Blade Reach

The relationships observed for this variable also appeared to correlate strongly with tower type.

Height of High Blade Reach

The relationships observed for this variable also appeared to correlate strongly with tower type.

Derelict Turbines

Red-tailed hawks and American kestrels perched disproportionately more often on or near derelict wind turbines (Table 8-12). Red-tailed hawks performed disproportionately more of their dangerous flights by derelict wind turbines; and red-tailed hawks, golden eagles, and American kestrels did so by wind turbines next to derelict turbines (Table 8-16).

Wind Walls

Golden eagles and red-tailed hawks perched disproportionately more often by wind turbines that were not part of wind walls; and golden eagles and American kestrels also flew more often by these turbines (Tables 8-12 and 8-13). Raptors flew disproportionately closer to the ground and closer to the wind turbines in wind walls (Tables 8-14 and 8-15), but most raptors performed disproportionately more of their dangerous flights near wind turbines that were not part of wind walls (Table 8-16).

Position in String

All the focal raptors in our study perched and flew disproportionately more often nearer wind turbines at the ends of strings (Tables 8-12 and 8-13). However, at these turbines raptors also flew disproportionately higher and farther away than they did at wind turbines forming the interior of the turbine string (Tables 8-14 and 8-15). But despite these relationships connoting safer flights around end turbines, all the raptors in our study performed disproportionately more of their dangerous flights nearer wind turbines at the ends of the strings (Table 8-16).

Location in Wind Farm

Raptors generally perched and flew disproportionately more often by wind turbines bordering the APWRA and local clusters of turbines within the APWRA (Tables 8-12 and 8-13). At these locations, most raptors flew disproportionately higher above the ground and farther from the wind turbines, while raptors in the interior of the APWRA flew lower to the ground and closer to the wind turbines (Tables 8-14 and 8-15). For most species, disproportionately more of their dangerous flights were made by wind turbines bordering local clusters of wind turbines or the edge of the APWRA (Table 8-16).

Turbine Congestion

Raptor species perched and flew disproportionately more often by wind turbines that were more isolated from other wind turbines, or where the density of wind turbines was less (Tables 8-12 and 8-13). Golden eagles flew disproportionately lower to the ground where wind turbines were most densely distributed, and also where they were sparse (Table 8-14). Raptors also flew closer to wind turbines that were more densely distributed, but most likely this pattern was forced by the fact that any bird flying through a dense turbine field will necessarily be closer to wind turbines there (Table 8-15). Most raptor species performed disproportionately more of their dangerous flights in sparsely distributed turbine fields, the exception being golden eagle, which did so in relatively dense turbine fields (Table 8-16).

Elevation

Golden eagles and red-tailed hawks preferred to perch at lower elevations in the APWRA, and American kestrels preferred to perch in the higher elevations (Table 8-12). Golden eagles flew disproportionately more often at lower elevations, red-tailed hawks at middle elevations, and American kestrels at highest elevations (Table 8-13). All the focal raptors except American kestrel flew disproportionately lower to the ground at higher elevations, and American kestrels did so at the lowest elevations (Table 8-14). Dangerous flights were made disproportionately more often by golden eagles at lowest elevations, red-tailed hawks at middle elevations, and American kestrels at highest elevations (Table 8-16).

Physical Relief

Golden eagles and red-tailed hawks preferred to perch on slopes (Table 8-12). Red-tailed hawks flew preferentially over slopes and ridgelines, and American kestrels flew preferentially over ridge crests (Table 8-13). Raptors flew disproportionately lower to the ground when flying over ridge crests (Table 8-14), which is where most of them also flew disproportionately closer to wind turbines (Table 8-15). However, raptors generally made disproportionately more of their dangerous flights on slopes and ridgelines, and golden eagles also did so over peaks (Table 8-16).

Canyons

Golden eagles, red-tailed hawks and American kestrels perched preferentially in canyons (Table 8-12), but they flew preferentially outside of canyons (Table 8-13). Nevertheless, flights inside canyons were disproportionately lower to the ground and for golden eagles they were closer to wind turbines (Tables 8-14 and 8-15). All the focal raptor species in our study made disproportionately more of their dangerous flights by wind turbines while within canyons (Table 8-16).

Edge Index

Red-tailed hawks perched preferentially where wind turbines were surrounded by more vertical edge, or where the tower laydown area and access road cut deeply into the hillside (Table 8-12). All the focal raptors in our study flew disproportionately more often near wind turbines with lots of vertical edge (Table 8-13), and most flew lower to the ground but farther away from the wind turbines with these greater edge conditions (Tables 8-14 and 8-15). Nevertheless, all of the focal raptor species made disproportionately more of their dangerous flights near wind turbines with either some or lots of vertical edge around their bases (Table 8-16).

Rock Piles

Golden eagles and red-tailed hawks preferred to perch where there were no rocks piled within 50 m of wind turbines (Table 8-12) and red-tailed hawks also preferred to fly where no such rocks were piled (Table 8-13). American kestrels, on the other hand, preferred to perch and fly where rocks had been piled near wind turbines. Red-tailed hawks flew disproportionately lower to the ground near wind turbines within 50 m of rock piles, and most focal raptors flew closer to these wind

turbines (Tables 8-14 and 8-15). American kestrels made disproportionately more of their dangerous flights near wind turbines with rock piles nearby (Table 8-16).

Rodent Control

Golden eagles and American kestrels perched more often than expected by chance in areas of intense rodent control, and red-tailed hawks did so in areas of intermittent control (Table 8-12). Turkey vultures flew disproportionately longer over areas where no control was implemented, but golden eagles did so where control was applied intermittently and American kestrels did so where rodent control was applied intensively (Table 8-13). Red-tailed hawks showed no discernable response to the rodent control program in terms of time spent flying.

Turkey vultures, golden eagles, and American kestrels flew disproportionately closer to the ground in areas of intense control, and red-tailed hawks did so in areas of intermittent rodent control (Table 8-14). All the focal raptor species in our study flew disproportionately closer to wind turbines in areas of intermittent rodent control, and golden eagles did so in areas of intense rodent control (Table 8-15). All the focal raptors also made disproportionately more of their dangerous flights in areas of intense rodent control (Table 8-16).

Years of Past Rodent Control

Golden eagles perched longer than expected by chance in areas treated with rodent poisons for only one year, and avoided perching in areas treated for at least five years (Table 8-12). Time spent perching did not appear to relate to the duration of rodent control for the other focal raptor species. Time spent flying, however, was disproportionately greater in areas where no control had yet been applied for all species except American kestrel, which spent more time flying over areas treated for at least the past five years (Table 8-13).

Turkey vultures and golden eagles flew disproportionately lower to the ground in areas treated with rodent poisons for at least five years, and golden eagles and American kestrels did so in areas treated for only one year (Table 8-14). All focal raptor species flew disproportionately closer to wind turbines in areas that have undergone either one year or at least five years of rodent control (Table 8-15). American kestrels made disproportionately more of their dangerous flights near wind turbines in areas treated with rodent poison for at least five years (Table 8-16).

Cattle Pats

Red-tailed hawks and American kestrels perched preferentially in areas where more cattle pats occurred near wind turbines, but golden eagles did so where cattle pats were sparse in the vicinity of wind turbines (Table 8-12). Turkey vultures flew disproportionately more often over areas where wind turbines had fewer cattle pats nearby, but golden eagles, red-tailed hawks, and American kestrels did so where there were many cattle pats nearby (Table 8-13).

Golden eagles flew disproportionately lower to the ground near wind turbines with many cattle pats nearby (Table 8-14), and turkey vultures, golden eagles, and American kestrels flew disproportionately closer to wind turbines with many cattle pats within 20 m of wind turbines (Table

8-15). Golden eagles, red-tailed hawks and American kestrels performed disproportionately more of their dangerous behaviors at wind turbines with many cattle pats nearby (Table 8-16).

Cottontail Pellet Abundance

Golden eagles perched preferentially in areas where more cottontail pellets were counted at and near wind turbines (Table 8-12). Turkey vultures preferentially flew over areas where more cottontail pellets were counted at and near wind turbines, and golden eagles did so in areas where cottontail pellets occurred but were not numerous (Table 8-13).

Turkey vultures and golden eagles flew disproportionately lower to the ground where no cottontail pellets were counted at or near wind turbines (Table 8-14), and turkey vultures, golden eagles and red-tailed hawks flew closer to wind turbines in areas where no cottontail pellets were counted at or near wind turbines (Table 8-15). Only turkey vultures related to the abundance of cottontail pellets in terms of the number of dangerous flights made (Table 8-16). Turkey vultures made disproportionately more of their dangerous flights near wind turbines with abundant sign of cottontails, which probably means little ecologically.

Vegetation Height

Golden eagles and red-tailed hawks perched preferentially in areas where the vegetation grew tallest around the wind turbines (Table 8-12), but red-tailed hawks flew disproportionately more often where the vegetation was shorter (Table 8-13). All the focal raptor species in our study flew disproportionately closer to the ground where the vegetation near wind turbines was taller (Table 8-14), and turkey vultures and golden eagles flew disproportionately closer to the wind turbines (Table 8-15). Turkey vultures and red-tailed hawks, however, made disproportionately more of their dangerous flights near wind turbines where the vegetation was the shortest, and golden eagles and American kestrels showed tendency to also make more of their dangerous flights in these conditions, but the statistical test results were non-significant (Table 8-16).

Degree of Pocket Gopher Clustering at Wind Turbines

Though statistically significant, there was no clear pattern between the degree of pocket gopher clustering at wind turbines and the frequencies of red-tailed hawk and American kestrel perching (Table 8-12). Turkey vultures and red-tailed hawks flew disproportionately more often over areas where pocket gophers either did not occur near wind turbines or where they did not cluster at wind turbines (Table 8-13). Turkey vultures, golden eagles, and red-tailed hawks flew disproportionately lower to the ground where pocket gophers were most clustered at wind turbines, and American kestrels did so where no pocket gophers occurred (Table 8-14).

Where pocket gophers were more clustered at wind turbines, turkey vultures, golden eagles, red-tailed hawks, and American kestrels flew disproportionately closer to those same wind turbines (Table 8-15). However, turkey vultures and red-tailed hawks made disproportionately more of their dangerous flights near wind turbines with no clustering of gophers (Table 8-16).

Degree of Ground Squirrel Clustering at Wind Turbines

Golden eagles and red-tailed hawks perched preferentially where ground squirrels were uniformly distributed within the 90-m sampling areas surrounding wind turbines (Table 8-12), and red-tailed hawks flew preferentially over areas lacking ground squirrels (Table 8-13). Golden eagles flew disproportionately lower to the ground where wind turbines either lacked ground squirrels nearby or where ground squirrel burrow systems were distributed uniformly out to 90 m (Table 8-14). Red-tailed hawks flew disproportionately lower to the ground where ground squirrels were clustered around wind turbines (Table 8-14).

Turkey vultures and golden eagles flew disproportionately closer to wind turbines that were in the midst of uniform ground squirrel burrow system distributions, red-tailed hawks did so where ground squirrels were clustered at wind turbines, and American kestrels did so where there were no ground squirrel burrows within 90 m of the turbines (Table 8-15). Where ground squirrels were most clustered around wind turbines, turkey vultures and American kestrels made disproportionately more of their dangerous flights by wind turbines, and red-tailed hawks did so where no ground squirrel burrow systems occurred within 90 m of wind turbines (Table 8-16).

Degree of Clustering of All Burrow Systems at Wind Turbines

Golden eagles and red-tailed hawks perched preferentially where wind turbines lacked any burrow systems of the mammal species we searched for out to 90 m (Table 8-12), but turkey vultures flew disproportionately over areas with greatest clustering of all burrow systems at wind turbines (Table 8-13). American kestrels flew more often than expected by chance over areas where wind turbines lacked burrow systems of all the species we studied (Table 8-14).

Golden eagles flew disproportionately closer to the ground while near wind turbines with the greatest degree of clustering of burrow systems of all species, whereas turkey vultures, red-tailed hawks, and American kestrels did so near wind turbines with more modest levels of clustering (Table 8-14). Red-tailed hawks made disproportionately more of their dangerous flights near wind turbines with modest degrees of clustering of burrow systems of all species (Table 8-16).

Density of Pocket Gopher Burrow Systems ≤ 90 m from Wind Turbines

Red-tailed hawks perched preferentially at or near wind turbines with highest densities of pocket gophers out to 90 m, and golden eagles and American kestrels did so where intermediate densities of gophers occurred (Table 8-12). Golden eagles flew more often than expected by chance near wind turbines with the highest densities of pocket gophers, and turkey vultures did so near wind turbines with the lowest gopher densities (Table 8-13). Red-tailed hawks and turkey vultures flew disproportionately lower to the ground where pocket gopher densities were highest, whereas golden eagles did so where gopher densities were lowest and American kestrels did so where gopher densities were intermediate (Table 8-14).

Turkey vultures flew disproportionately closer to wind turbines where pocket gopher densities were greater, and golden eagles did so where gopher densities were lowest (Table 8-15). Turkey vultures made disproportionately more of their dangerous flights near wind turbines with lowest densities of

pocket gophers, and the frequencies of dangerous flights made by other focal species did not relate significantly with gopher density (Table 8-16).

Density of Ground Squirrel Burrow Systems ≤ 90 m from Wind Turbines

Golden eagles and red-tailed hawks perched preferentially near wind turbines with highest densities of ground squirrel burrow systems (Table 8-12). However, red-tailed hawks flew preferentially near wind turbines that lacked ground squirrel burrow systems out to 90 m, and golden eagle flight time did not relate significantly to ground squirrel density (Table 8-13). Golden eagles and red-tailed hawks flew disproportionately closer to the ground near wind turbines with low to intermediate densities of ground squirrel burrow systems, and golden eagles flew disproportionately higher near wind turbines with the highest ground squirrel densities (Table 8-14).

Golden eagles, red-tailed hawks, and turkey vultures flew disproportionately closer to wind turbines with low to intermediate ground squirrel burrow system densities (Table 8-15). Red-tailed hawks and all raptor species combined made disproportionately more of their dangerous flights near wind turbines with no ground squirrel burrow systems out to 90 m (Table 8-16).

Density of All Burrow Systems ≤ 90 m from Wind Turbines

Golden eagles, red-tailed hawks, American kestrels, and all raptor species combined perched more often than expected by chance on or near wind turbines with the highest densities of all fossorial mammal burrow systems combined (Table 8-12). American kestrels also flew disproportionately more often over these areas of higher burrow system density, but turkey vultures did so over areas lacking all burrow systems (Table 8-13).

At wind turbines with highest densities of burrow systems of all fossorial mammal species combined, golden eagles flew disproportionately higher and farther away, but red-tailed hawks and turkey vultures flew lower and closer to the wind turbines (Tables 8-14 and 8-15). Red-tailed hawks made disproportionately more of their dangerous flights near wind turbines with intermediate densities of burrow systems of all fossorial mammal species combined, and turkey vultures did so at lowest densities (Table 8-16).

Table 8-12. Chi-square tests of association between time spent perching and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less perching than expected by chance, and positive values express more perching.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Turbine model	269.70**	No test	533.83**	279.84**	20.01*
Micon	-1		15	-2	-1
Bonus	-2		-3	1	1
Danwin	0		-1	-1	1
Flowind	6		-8	8	1
Windmatic	2		24	0	0
Enertech	2		16	6	0
KCS-56	-5		-39	-10	-3
KVS-33	-2		-4	-3	0
Rotor Diameter	220.51**	No test	329.82**	255.12**	24.05**
13.5–14.8	4		40	6	0
16.0	-1		15	-2	-1
17.2–17.8	-1		-45	-6	0
19.1–19.5	5		5	12	4
23.4–25.2	-6		-11	-7	-4
31.4–33.2	-2		-4	-3	0
Blade tip speed (kph)	59.25**	No test	200.35**	96.75**	7.88*
137.77–149.64	7		63	12	4
173.77–194.69	-1		-24	-2	-2
212.39–246.18	-5		-39	-10	-3
Rotor plane (m^2) swept/s	195.98**	No test	161.90**	251.07**	19.99**
1499–1859	8		47	13	0
2141	4		9	8	5
2780–3287	-10		-52	-18	-5
4014–5646	-2		-4	-3	0
Tower type	136.90**	No test	12.28**	142.23**	2.01
Vertical axis	6		-8	8	1
Tubular	-3		11	-2	1
Lattice	-3		-3	-7	-2
Tower height	258.81**	No test	23.91**	177.31**	20.55**
14.0	-2		-2	-2	-1
18.5	5		16	0	5
24.0–25.2	-10		-4	-8	-5
29.5–32.3	6		-8	8	1
36.9–43.1	1		-2	1	0

Table 8-12. (cont'd)

Variable	χ^2 and percent deviation from expected value				
Height (m), low blade reach	126.51**	No test	85.50**	125.37**	41.93**
4.0–5.1	4		-10	6	0
8.0–9.6	-1		-27	-8	5
11.1–14.85	3		36	6	3
15.7–17.2	-7		3	-5	-8
25.2–34.2	1		-2	1	0
Height (m), high blade reach	113.45**	No test	31.59**	118.01**	39.60**
22.9–27.4	4		14	-2	4
29.5–33.6	-1		-6	2	-6
34.4	4		9	8	5
36.9–52.0	-7		-17	-9	-3
Derelict turbines	85.90**	No test	7.73*	78.34**	28.48**
Away from derelict	-3		6	-5	-2
Derelict	3		-3	4	3
Next to derelict	0		-3	1	0
Wind wall	11.52**	No test	15.70**	92.68**	0.26
Not in wind wall	2		12	8	1
In wind wall	-2		-12	-8	-1
Position in string	2388.38**	No test	168.08**	1021.79**	581.73**
End	37		51	36	31
Edge of gap	-2		-9	0	-2
Interior	-35		-41	-35	-28
Non-operational	0		-1	0	0
Location in wind farm	90.61**	No test	160.90**	41.79**	74.08**
Edge of farm	3		33	-4	7
Edge of local cluster	4		17	4	4
Interior of wind farm	-6		-50	1	-11
Turbine congestion	120.30**	No test	25.18**	53.31**	56.02**
0–12 within 300 m	2		12	4	-4
13–24 within 300 m	6		-19	3	6
25–36 within 300 m	-1		0	-1	4
37–72 within 300 m	-7		6	-7	-7
Elevation (m)	154.19**	No test	95.46**	210.09**	125.27**
110–85	-1		7	-1	0
160–135	3		25	7	-5
210–185	3		11	10	-3
260–235	1		-3	-1	4
310–285	-6		-13	-5	-4
360–335	3		-9	-4	5
460–385	-2		-19	-4	3

Table 8-12. (cont'd)

Variable	χ^2 and percent deviation from expected value				
Slope grade (degrees)	74.45**	No test	44.27**	103.65**	71.84**
0	-1		2	-2	-2
2–5	2		-3	5	2
6–14	-4		-20	-3	-8
15–58	2		22	0	8
Physical relief	168.92**	No test	131.10**	257.57**	76.03**
Peak	1		-2	1	0
Plateau	-4		14	-7	-2
Ridge crest	0		-36	-7	4
Ridgeline	-3		-9	-1	-6
Slope	7		38	16	0
Saddle	-1		-4	-4	3
Ravine	1		-1	1	1
Canyon	0.46	No test	13.62**	4.67*	2.80 [t]
Not in canyon	0		-12	-2	-2
In canyon	0		12	2	2
Slope aspect	170.29**	No test	18.98**	125.17**	57.75**
None (flat)	-1		-8	-11	8
East-Northeast	3		10	8	-2
South-Southeast	4		7	2	3
West-Southwest	-3		-4	-1	-2
North-Northwest	-3		-5	3	-7
Edge index at tower base	177.45**	No test	43.58**	202.81**	12.69*
No edge	-3		-4	-4	0
Some lateral edge	3		15	1	2
Lots lateral edge	-5		-12	-10	1
Some vertical edge	-2		-8	1	-4
Lots vertical edge	6		9	12	2
Rock piles ≤ 50 m away	27.09**	No test	16.26**	35.02**	6.17*
None	4		13	6	-3
One or more	-4		-13	-6	3
Rodent control through 2002	23.72**	No test	43.74**	8.17*	12.36*
None	0		9	-1	1
Intermittent	-4		-28	4	-5
Intense	4		19	-3	4
Years of past rodent control	23.91**	No test	288.13**	0.78	1.58
0	0		9	-1	1
1	2		40	0	-1
5	-2		-49	1	0

Table 8-12. (cont'd)

Variable	χ^2 and percent deviation from expected value				
Cattle pats 40 m from turbines	76.90**	No test	129.45**	45.95**	33.54**
0	-3		-8	-2	-4
1–9	-4		53	-5	-2
10–25	4		-33	3	4
> 25	3		-12	5	2
Cattle pats at turbines	34.72**	No test	164.87**	79.57**	42.89**
0–2	-4		37	-7	-5
3–9	2		-32	6	5
10–25	1		-8	-2	4
> 25	1		3	3	-5
Cottontails 40 m from turbines	2.50	No test	105.43**	13.89**	21.13**
No pellets	0		-25	-3	5
Some pellets	-1		4	4	-5
Abundant pellets	1		21	0	0
Cottontails at turbines	35.75**	No test	61.27**	9.91*	55.23**
No pellets	-1		-23	-3	-2
Some pellets	3		4	3	7
Abundant pellets	-2		19	0	-4
Vegetation height (cm)	12.42*	No test	207.87**	25.00**	56.77**
0–10	-1		-17	1	1
11–20	0		-5	-6	-2
21–35	2		-30	4	8
> 35	-2		52	2	-7
Pocket gopher clustering	81.03**	No test	263.89**	51.61**	111.58**
Obs/Exp in 15 m = 0	0		87	1	-9
Obs/Exp in 15 m < 1.5	9		-16	6	16
Obs/Exp in 15 m = 1.5–3.0	-10		-37	-15	-5
Obs/Exp in 15 m > 3	1		-34	7	-1
Ground squirrel clustering	131.29**	No test	43.65**	147.37**	23.68**
Obs/Exp in 15 m = 0	-6		-28	-3	-11
Obs/Exp in 15 m ≤ 1.14	17		58	23	7
Obs/Exp in 15 m > 1.14	-11		-29	-21	4
Pocket gopher density ≤ 90 m	148.88**	No test	70.25**	16.66**	46.51**
0–1.4/ha	-16		-42	-1	-13
1.41–3.5/ha	15		70	-7	13
> 3.5/ha	1		-28	8	0
Ground squirrel density ≤ 90 m	54.59**	No test	80.02**	42.22**	1.56
0/ha	-1		-17	-6	0
0.01–5.99/ha	-8		-55	-6	-3
≥ 6/ha	10		71	12	2

Table 8-12. (cont'd)

Variable	χ^2 and percent deviation from expected value				
Clustering of all burrows	18.67**	No test	81.47**	15.50**	2.79
Obs/Exp in 15 m = 0–1.2	6		71	7	-3
Obs/Exp in 15 m = 1.2–3.0	-5		-50	-7	4
Obs/Exp in 15 m > 3	-1		-21	1	-1
Density of all burrow systems	105.27**	No test	65.99**	127.12**	16.81**
< 5/ha	-10		-33	-10	-9
5–9/ha	-3		-34	-13	7
> 9/ha	14		67	23	2

Table 8-13. Chi-square tests of association between time spent flying and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less time flying than expected by chance, and positive values express more time flying.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Turbine model	284.41**	142.43**	28.64**	168.60**	141.64**
Micon	1	4	-3	-1	-5
Bonus	-9	-16	-3	-4	-12
Danwin	2	-1	-1	5	1
Flowind	11	11	9	12	13
Windmatic	4	8	10	2	-1
Enertech	-2	0	5	-4	-4
KCS-56	-7	-2	-17	-8	-10
KVS-33	0	-3	-1	-3	18
Rotor Diameter	48.83**	41.51**	12.21*	48.50**	111.75**
13.5–14.8	2	7	15	-2	-5
16.0	1	4	-3	-1	-5
17.2–17.8	0	1	-5	1	5
19.1–19.5	4	0	-8	11	-6
23.4–25.2	-7	-9	2	-7	-7
31.4–33.2	0	-3	-1	-3	18
Blade tip speed (kph)	23.35**	2.41	4.21	13.16**	40.78**
137.77–149.64	1	5	7	1	-15
173.77–194.69	6	-3	10	7	26
212.39–246.18	-7	-2	-17	-8	-10
Rotor plane (m^2) swept/s	82.00**	59.65**	8.30*	27.98**	106.00
1499–1859	14	22	22	9	3
2141	-1	-6	-5	3	-5
2780–3287	-12	-13	-16	-10	-16
4014–5646	0	-3	-1	-3	18
Tower type	136.04**	43.14**	4.45	77.07**	33.42**
Vertical axis	11	11	9	12	13
Tubular	-5	-13	-7	0	-16
Lattice	-5	2	-2	-12	2
Tower height	144.17**	42.18**	10.03*	76.36**	31.02**
14.0	-1	0	-2	-1	-2
18.5	-4	-6	14	-7	-3
24.0–25.2	-4	-3	-19	-3	-7
29.5–32.3	11	11	9	12	13
36.9–43.1	-2	-2	-2	-1	-1

Table 8-13. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Height (m), low blade reach	115.99**	90.10**	6.81	57.93**	48.21**
4.0–5.1	10	11	7	11	11
8.0–9.6	-6	-17	-2	-8	20
11.1–14.85	-5	-9	11	0	-16
15.7–17.2	2	17	-14	-2	-14
25.2–34.2	-2	-2	-2	-1	-1
Height (m), high blade reach	101.05**	85.72**	2.52	60.05**	8.86*
22.9–27.4	-5	-6	12	-7	-5
29.5–33.6	15	27	-6	15	1
34.4	-1	-6	-5	3	-5
36.9–52.0	-9	-15	-1	-11	10
Derelict turbines	5.22 [t]	3.32	0.03	26.57**	1.99
Away from derelict	-2	2	1	-5	1
Derelict	1	-2	0	4	-2
Next to derelict	1	0	-1	1	1
Wind wall	9.81**	0.03	4.78*	4.59	7.68*
Not in wind wall	4	0	12	4	8
In wind wall	-4	0	-12	-4	-8
Position in string	599.31**	188.69**	35.84**	468.00**	12.81*
End	33	38	43	33	11
Edge of gap	-3	-2	-3	-2	-7
Interior	-33	-35	-39	-37	-3
Non-operational	2	-1	-1	6	-1
Location in wind farm	162.64**	51.06**	7.67*	130.73**	0.83
Edge of farm	8	9	14	4	3
Edge of local cluster	10	10	6	15	-1
Interior of wind farm	-17	-19	-19	-19	-1
Turbine congestion	67.86**	5.50	2.53	75.66**	33.28**
0–12 within 300 m	8	3	-1	13	4
13–24 within 300 m	2	-7	9	1	22
25–36 within 300 m	-4	3	3	-6	-12
37–72 within 300 m	-7	1	-10	-8	-14
Elevation (m)	32.24**	40.81**	3.85	49.58**	68.93**
110–85	1	4	7	-3	-8
160–135	-6	0	8	-10	-10
210–185	0	-3	-3	5	-10
260–235	2	1	-1	4	4
310–285	2	11	-7	1	-8
360–335	2	-3	-3	3	7
460–385	-1	-10	-2	-1	25

Table 8-13. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Slope grade (degrees)	51.85**	5.52	2.91	53.18**	17.13**
0	-8	-5	-5	-10	-12
2–5	-1	-2	-1	-2	-3
6–14	-2	5	-7	-5	0
15–58	11	2	13	17	16
Physical relief	66.06**	33.88**	5.37	83.57**	8.89
Peak	-1	-1	4	-1	-2
Plateau	-3	4	-4	-6	-5
Ridge crest	-10	-15	-8	-15	6
Ridgeline	3	-3	3	8	4
Slope	11	13	3	15	-2
Saddle	0	2	4	-1	-1
Ravine	0	0	-1	0	-1
Canyon	16.25**	10.58**	0.16	4.23*	2.26
Not in canyon	5	8	2	4	5
In canyon	-5	-8	-2	-4	-5
Slope aspect	79.47**	10.99*	0.80	93.78**	15.96**
None (flat)	-10	-8	0	-18	11
East-Northeast	7	4	3	11	-6
South-Southeast	-1	6	-4	-5	-7
West-Southwest	2	1	-1	4	-4
North-Northwest	3	-2	2	8	6
Edge index at tower base	59.10**	22.89**	1.25	47.83**	6.37
No edge	0	2	-2	-1	0
Some lateral edge	-3	-6	-4	-3	0
Lots lateral edge	-9	-7	-3	-13	-7
Some vertical edge	4	3	5	8	-2
Lots vertical edge	8	8	3	9	9
Rock piles ≤ 50 m away	9.50**	1.98	0.00	13.38**	4.10*
None	4	3	0	7	-9
One or more	-4	-3	0	-7	9
Rodent control through 2002	32.49**	27.35**	2.62	4.91[t]	7.78*
None	6	11	3	3	-4
Intermittent	-7	-12	10	-4	-9
Intense	1	1	-13	1	13
Years of past rodent control	29.78**	19.80**	1.33	8.13*	9.15*
0	6	11	3	4	-4
1	-3	-2	4	-3	-7
5	-3	-9	-10	0	10

Table 8-13. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Cattle pats 40 m from turbines	38.83**	10.03*	5.51	30.77**	16.26**
0	0	4	-8	1	-5
1–9	-1	3	6	-6	-1
10–25	-6	-8	-6	-4	-5
> 25	7	2	9	9	11
Cattle pats at turbines	4.52	22.72**	2.28	35.54**	4.15
0–2	0	8	-1	-3	-3
3–9	-2	6	11	-7	-6
10–25	-1	-3	-10	-2	7
> 25	3	-10	-1	12	2
Cottontails 40 m from turbines	12.98**	9.86*	3.99	8.06*	7.17*
No pellets	-5	-7	-15	-5	10
Some pellets	4	3	11	6	-7
Abundant pellets	1	4	4	0	-3
Cottontails at turbines	16.51**	31.49**	6.96*	3.60	0.83
No pellets	-4	-11	-18	2	2
Some pellets	0	1	17	-3	0
Abundant pellets	4	10	1	1	-2
Vegetation height (cm)	39.14**	38.74**	2.40	15.93**	1.18
0–10	3	6	3	3	4
11–20	4	8	6	0	-1
21–35	2	2	-12	5	-2
> 35	-9	-16	3	-8	0
Pocket gopher clustering	30.85**	36.27**	0.04	30.74**	2.31
Obs/Exp in 15 m = 0	9	9	-1	14	-14
Obs/Exp in 15 m < 1.5	3	14	0	-5	4
Obs/Exp in 15 m = 1.5–3.0	3	-4	2	8	7
Obs/Exp in 15 m > 3	-15	-19	-1	-17	4
Ground squirrel clustering	43.63**	29.26**	0.18	59.01**	8.60*
Obs/Exp in 15 m = 0	16	8	5	29	-23
Obs/Exp in 15 m ≤ 1.14	-14	-24	1	-15	28
Obs/Exp in 15 m > 1.14	-2	16	-6	-13	-6
Pocket gopher density ≤ 90 m	9.18*	35.68**	4.81 [t]	0.47	0.96
0–1.4/ha	5	18	-25	0	-7
1.41–3.5/ha	3	8	4	-2	9
> 3.5/ha	-8	-26	21	2	-2
Ground squirrel density ≤ 90 m	61.25**	7.13*	2.62	72.98**	8.69*
0/ha	16	9	2	25	-8
0.01–5.99/ha	-12	-4	-22	-15	-19
≥ 6/ha	-5	-5	20	-11	27

Table 8-13. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Clustering of all burrows	1.10	6.19*	0.23	0.84	6.48*
Obs/Exp in 15 m = 0–1.2	-1	-10	2	1	23
Obs/Exp in 15 m = 1.2–3.0	-1	6	4	-3	-11
Obs/Exp in 15 m > 3	2	4	-6	3	-11
Density of all burrow systems	21.26**	45.70**	3.70	5.37*	7.93*
< 5/ha	12	31	-28	8	-28
5–9/ha	-6	-19	11	0	18
> 9/ha	-6	-12	16	-7	10

Table 8-14. Chi-square tests of association between flight height and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express lower heights above the ground than expected by chance, and positive values express higher flights.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Turbine model	3325.05**	6040.01**	20739.30**	1340.39**	1154.08**
Micon	5	6	-3	1	-1
Bonus	-6	-13	-6	-5	-4
Danwin	-1	-1	-1	-1	1
Flowind	6	15	-1	4	16
Windmatic	2	5	35	2	0
Enertech	1	1	-5	0	0
KCS-56	-4	-9	-16	2	-12
KVS-33	-3	-3	-3	-3	0
Rotor Diameter	2109.47**	1820.92**	3499.43**	792.18**	48.74**
13.5–14.8	3	6	30	2	0
16.0	5	6	-3	1	-1
17.2–17.8	0	-1	-15	5	6
19.1–19.5	2	3	-6	-1	-2
23.4–25.2	-6	-9	-3	-5	-3
31.4–33.2	-3	-3	-3	-3	0
Blade tip speed (kph)	673.49**	404.35**	680.93**	159.55**	360.60**
137.77–149.64	8	8	23	3	-2
173.77–194.69	-4	2	-7	-5	14
212.39–246.18	-4	-9	-16	2	-12
Rotor plane (m^2) swept/s	2760.68**	3918.69**	1018.93**	727.03**	368.56**
1499–1859	13	27	26	8	15
2141	1	-4	-3	0	-1
2780–3287	-11	-20	-20	-4	-14
4014–5646	-3	-3	-3	-3	0
Tower type	1234.21**	3431.77**	137.13**	377.19**	1098.08**
Vertical axis	6	15	-1	4	16
Tubular	-2	-8	-10	-5	-4
Lattice	-4	-7	11	0	-12
Tower height	1605.70**	3632.52**	1189.58**	675.64**	1169.01**
14.0	-1	-1	-2	-2	-2
18.5	-4	-6	29	0	-2
24.0–25.2	1	-6	-24	-1	-13
29.5–32.3	6	15	-1	4	16
36.9–43.1	-1	-2	-2	-1	1

Table 8-14. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Height (m), low blade reach	2666.27**	3969.48**	714.53**	744.81**	733.34**
4.0–5.1	5	14	-3	2	14
8.0–9.6	-10	-15	-3	-5	-2
11.1–14.85	-4	-8	22	-4	-3
15.7–17.2	10	12	-14	8	-10
25.2–34.2	-1	-2	-2	-1	1
Height (m), high blade reach	3404.32**	3660.70**	955.87**	1166.56**	72.37**
22.9–27.4	-6	-7	27	-2	-4
29.5–33.6	15	26	-16	11	7
34.4	1	-4	-3	0	-1
36.9–52.0	-10	-15	-7	-9	-2
Derelict turbines	12.24**	110.50**	48.40**	284.10**	114.50**
Away from derelict	0	-1	2	-2	-5
Derelict	0	-1	0	2	1
Next to derelict	0	2	-2	-1	3
Wind wall	186.27**	375.24**	389.42**	105.95**	119.15**
Not in wind wall	3	6	12	3	7
In wind wall	-3	-6	-12	-3	-7
Position in string	3959.48**	5200.43**	3842.47**	2546.80**	384.80**
End	17	30	49	18	13
Edge of gap	-1	-1	-6	-3	-4
Interior	-16	-28	-42	-16	-10
Non-operational	0	-1	-1	1	1
Location in wind farm	930.75**	252.44**	1621.63**	605.90**	1.36
Edge of farm	7	5	27	7	0
Edge of local cluster	-1	1	-2	2	-1
Interior of wind farm	-6	-6	-25	-8	0
Turbine congestion	206.37**	292.72**	845.27**	18.24**	142.38**
0–12 within 300 m	-3	-5	-7	-1	0
13–24 within 300 m	-1	3	19	0	9
25–36 within 300 m	1	0	6	0	-2
37–72 within 300 m	2	2	-17	1	-7
Elevation (m)	1508.96**	1924.68**	972.12**	1719.44**	601.60**
110–85	5	5	21	0	-1
160–135	0	1	1	-2	-9
210–185	2	2	-4	1	9
260–235	-1	5	0	-2	0
310–285	3	2	-11	3	-6
360–335	0	-5	-2	8	9
460–385	-9	-11	-4	-8	-1

Table 8-14. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Slope grade (degrees)	530.99**	585.84**	383.95**	188.63**	176.86**
0	2	-9	-12	5	-5
2–5	-2	-2	0	0	-2
6–14	4	7	-4	-1	-4
15–58	-4	4	17	-4	11
Physical relief	1294.96**	3050.64**	412.20**	511.15**	80.45**
Peak	-1	-1	-1	0	-1
Plateau	0	2	0	-1	0
Ridge crest	-9	-22	-14	-4	-6
Ridgeline	1	-1	3	1	1
Slope	8	22	8	0	7
Saddle	1	1	5	1	0
Ravine	1	0	-1	1	0
Canyon	997.50**	872.06**	131.09**	283.20**	2.64
Not in canyon	7	10	8	5	1
In canyon	-7	-10	-8	-5	-1
Slope aspect	2524.41**	1987.07**	156.08**	1843.60**	45.80**
None (flat)	-6	-12	-1	-1	0
East-Northeast	9	13	4	11	-3
South-Southeast	-2	6	5	-9	1
West-Southwest	1	-2	-3	3	2
North-Northwest	-3	-5	-5	-4	1
Edge index at tower base	900.35**	526.81**	592.42**	1982.56**	350.92**
No edge	2	0	-4	6	-1
Some lateral edge	-4	-4	-8	-1	-4
Lots lateral edge	-4	1	3	-13	-7
Some vertical edge	1	-4	-4	5	-1
Lots vertical edge	5	7	14	3	13
Rock piles ≤ 50 m away	0.10	84.28**	0.10	451.68**	392.68**
None	0	-3	0	7	-12
One or more	0	3	0	-7	12
Rodent control through 2002	561.23**	813.31**	1770.83**	97.80**	12.49**
None	6	10	28	1	1
Intermittent	0	-1	0	-4	2
Intense	-5	-9	-29	3	-3
Years of past rodent control	524.58**	785.26**	1786.22**	14.03**	29.59**
0	6	10	30	1	1
1	0	-1	-7	1	-3
5	-5	-10	-23	-1	1

Table 8-14. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Cattle pats 40 m from turbines	313.35**	277.27**	575.88**	550.65**	431.54**
0	3	3	-8	4	-4
1–9	-3	3	20	-5	-10
10–25	-2	-7	-11	-3	3
> 25	2	0	-1	4	11
Cattle pats at turbines	721.69**	1156.88**	838.38**	37.73**	24.99**
0–2	4	9	8	1	2
3–9	3	-7	19	2	-2
10–25	-4	6	-16	-1	-2
> 25	-4	-8	-11	-1	2
Cottontails 40 m from turbines	988.95**	1140.56**	1829.91**	125.07**	18.57**
No pellets	-6	-13	-29	-1	-2
Some pellets	8	13	13	2	3
Abundant pellets	-2	1	16	-2	-1
Cottontails at turbines	1024.39**	1142.89**	1815.06**	165.52**	71.03**
No pellets	-8	-14	-33	-3	-2
Some pellets	8	9	16	4	5
Abundant pellets	0	5	17	-1	-3
Vegetation height (cm)	2252.40**	2029.12**	669.19**	411.55**	366.57**
0–10	4	11	0	3	4
11–20	9	6	21	2	-1
21–35	-2	-1	-17	2	10
> 35	-11	-16	-5	-7	-13
Pocket gopher clustering	1571.17**	1512.80**	405.23**	3831.99**	605.81**
Obs/Exp in 15 m = 0	16	16	-21	39	-24
Obs/Exp in 15 m < 1.5	2	2	14	-2	21
Obs/Exp in 15 m = 1.5–3.0	-1	9	18	-9	5
Obs/Exp in 15 m > 3	-17	-27	-10	-28	-1
Ground squirrel clustering	602.44**	315.14**	72.27**	549.43**	62.17**
Obs/Exp in 15 m = 0	11	9	-9	14	8
Obs/Exp in 15 m ≤ 1.14	-6	-12	-6	-4	-12
Obs/Exp in 15 m > 1.14	-5	4	15	-10	4
Pocket gopher density ≤ 90 m	704.30**	1167.53**	670.59**	1074.16**	465.74**
0–1.4/ha	12	16	-42	17	12
1.41–3.5/ha	-3	7	4	2	-33
> 3.5/ha	-9	-22	37	-18	22
Ground squirrel density ≤ 90 m	355.50**	471.97**	644.72**	836.12**	34.24**
0/ha	7	10	-1	14	-6
0.01–5.99/ha	-5	1	-39	-13	8
≥ 6/ha	-2	-10	40	-1	-3

Table 8-14. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Clustering of all burrows	1671.82**	135.71**	120.46**	1247.48**	431.26**
Obs/Exp in 15 m = 0–1.2	10	6	10	3	28
Obs/Exp in 15 m = 1.2–3.0	-20	-8	7	-21	-20
Obs/Exp in 15 m > 3	9	1	-17	18	-8
Density of all burrow systems	300.43**	716.60**	585.03**	358.28**	515.62**
< 5/ha	8	12	-36	12	-18
5–9/ha	-5	6	0	-7	34
> 9/ha	-3	-17	36	-5	-15

Table 8-15. Chi-square tests of association between mean distance from nearest wind turbine and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express closer distances than expected by chance, and positive values express farther distances.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Turbine model	5604.98**	17017.40**	17506.87**	4782.72**	725.72**
Micon	3	10	4	0	0
Bonus	-8	-22	-6	-6	-4
Danwin	0	-1	-1	-1	0
Flowind	3	11	-1	4	2
Windmatic	4	9	23	5	1
Enertech	0	-2	-1	1	0
KCS-56	-1	-2	-18	-1	-3
KVS-33	0	-3	1	-2	4
Rotor Diameter	2583.52**	5143.68**	3863.90**	2228.46**	660.50**
13.5–14.8	4	7	21	6	0
16.0	3	10	4	0	0
17.2–17.8	1	3	-17	2	1
19.1–19.5	-2	-7	-6	0	-3
23.4–25.2	-6	-10	-4	-7	-3
31.4–33.2	0	-3	1	-2	4
Blade tip speed (kph)	568.63**	218.43**	1327.36**	475.34**	59.20**
137.77–149.64	5	5	23	6	0
173.77–194.69	-4	-3	-5	-5	3
212.39–246.18	-1	-2	-18	-1	-3
Rotor plane (m^2) swept/s	2172.99**	7625.30**	1843.71**	1323.86**	640.51**
1499–1859	10	28	25	10	3
2141	-2	-12	-2	0	-1
2780–3287	-7	-12	-23	-8	-6
4014–5646	0	-3	1	-2	4
Tower type	744.33**	3200.85**	42.43**	812.29**	116.14**
Vertical axis	3	11	-1	4	2
Tubular	-5	-12	-3	-7	-4
Lattice	2	2	4	3	2
Tower height	1312.66**	3081.42**	1038.07**	3020.85**	611.68**
14.0	-1	0	-2	-1	-2
18.5	2	-1	19	4	8
24.0–25.2	-5	-8	-14	-11	-8
29.5–32.3	3	11	-1	4	2
36.9–43.1	1	-2	-2	4	0

Table 8-15. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Height (m), low blade reach	1139.31**	7011.53**	576.27**	2012.12**	936.66**
4.0–5.1	2	11	-3	3	0
8.0–9.6	-2	-12	-1	-4	12
11.1–14.85	-5	-15	14	-1	-4
15.7–17.2	4	18	-7	-2	-8
25.2–34.2	1	-2	-2	4	0
Height (m), high blade reach	1279.79**	8132.89**	694.61**	341.09**	273.22**
22.9–27.4	1	-1	17	3	6
29.5–33.6	6	28	-10	1	-6
34.4	-2	-12	-2	0	-1
36.9–52.0	-5	-15	-5	-5	1
Derelict turbines	3.32	150.10**	27.24**	178.81**	358.92**
Away from derelict	0	2	2	-2	-2
Derelict	0	-2	0	1	-1
Next to derelict	0	0	-1	0	3
Wind wall	121.76**	139.65**	750.48**	0.74	450.14**
Not in wind wall	2	3	12	0	6
In wind wall	-2	-3	-12	0	-6
Position in string	18870.45**	13003.22**	8109.67**	15260.70**	5162.52**
End	27	36	51	34	28
Edge of gap	-1	-3	-4	-1	-3
Interior	-26	-32	-46	-34	-24
Non-operational	0	-1	-1	0	0
Location in wind farm	7676.48**	7376.10**	3043.06**	2773.15**	876.25**
Edge of farm	13	20	24	11	10
Edge of local cluster	3	7	6	3	1
Interior of wind farm	-16	-27	-30	-14	-10
Turbine congestion	1537.57**	595.51**	897.88**	1655.70**	914.86**
0–12 within 300 m	4	5	0	4	1
13–24 within 300 m	1	-6	13	3	13
25–36 within 300 m	1	4	3	2	-6
37–72 within 300 m	-6	-2	-15	-10	-7
Elevation (m)	1904.66**	4018.40**	1215.63**	671.21**	1456.34**
110–85	7	15	14	4	3
160–135	-5	-6	2	-6	-6
210–185	-1	-6	0	0	-1
260–235	-1	2	-1	0	-1
310–285	0	5	-11	0	-7
360–335	-1	-2	-4	-1	2
460–385	2	-8	1	3	11

Table 8-15. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Slope grade (degrees)	250.86**	178.10**	1679.04**	589.37**	240.57**
0	0	-4	-10	3	-5
2–5	-1	-1	-1	0	-1
6–14	0	1	-13	-6	1
15–58	1	4	25	4	5
Physical relief	1897.24**	4580.54**	1203.02**	2234.48**	209.71**
Peak	0	-1	0	1	0
Plateau	-1	5	-3	-5	-2
Ridge crest	-7	-19	-16	-7	0
Ridgeline	0	-4	5	-1	-2
Slope	8	15	9	13	3
Saddle	1	4	6	0	1
Ravine	0	1	-1	-1	-1
Canyon	758.54**	1669.81**	249.60**	447.73**	2.48
Not in canyon	5	11	-8	5	-1
In canyon	-5	-11	8	-5	1
Slope aspect	1355.36**	1660.65**	64.61**	1848.41**	852.81**
None (flat)	-2	-6	0	-7	9
East-Northeast	6	5	2	8	-6
South-Southeast	-1	10	0	-2	-1
West-Southwest	0	-2	-2	3	-3
North-Northwest	-3	-7	-1	-2	1
Edge index at tower base	310.92**	2061.97**	916.07**	627.41**	262.99**
No edge	-1	1	-3	-1	-1
Some lateral edge	-1	-8	-2	1	0
Lots lateral edge	-1	-4	-6	-6	0
Some vertical edge	-1	3	-5	-1	-5
Lots vertical edge	3	9	15	5	5
Rock piles ≤ 50 m away	221.53**	810.05**	52.03**	133.81**	107.33**
None	3	8	4	3	-4
One or more	-3	-8	-4	-3	4
Rodent control through 2002	2602.10**	5389.03**	1428.99**	990.12**	172.21**
None	8	18	19	7	2
Intermittent	-8	-18	-6	-7	-6
Intense	0	-1	-13	0	4
Years of past rodent control	2188.41**	4241.43**	1585.79**	909.84**	280.93**
0	8	18	20	7	2
1	-2	-2	1	-3	-4
5	-5	-16	-21	-4	2

Table 8-15. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Cattle pats 40 m from turbines	28.11**	557.23**	998.48**	25.33**	293.65**
0	0	2	-8	0	-4
1–9	1	3	19	-1	3
10–25	-1	-8	-10	1	0
> 25	0	3	-1	0	1
Cattle pats at turbines	323.59**	1518.42**	1374.00**	182.49**	619.28**
0–2	2	6	9	0	-1
3–9	2	5	15	-4	11
10–25	-2	-2	-20	1	-7
> 25	-2	-10	-3	3	-3
Cottontails 40 m from turbines	522.85**	367.86**	1667.53**	1648.93**	12.52**
No pellets	-4	-5	-19	-11	-1
Some pellets	3	2	8	7	1
Abundant pellets	1	3	11	4	0
Cottontails at turbines	798.50**	2412.45**	1420.80**	1768.27**	1.06
No pellets	-5	-7	-21	-10	0
Some pellets	2	-2	11	4	0
Abundant pellets	3	10	10	6	0
Vegetation height (cm)	476.33**	1892.25**	1010.46**	207.99**	171.32**
0–10	0	7	0	-3	-2
11–20	5	6	7	4	-3
21–35	-2	-2	-18	0	3
> 35	-2	-11	11	-1	3
Pocket gopher clustering	3222.63**	6973.71**	615.76**	1494.09**	1458.25**
Obs/Exp in 15 m = 0	11	27	18	-3	-1
Obs/Exp in 15 m < 1.5	5	-3	-9	13	21
Obs/Exp in 15 m = 1.5–3.0	-13	-20	-4	-17	2
Obs/Exp in 15 m > 3	-3	-3	-5	7	-21
Ground squirrel clustering	586.99**	1220.50**	206.30**	916.33**	635.79**
Obs/Exp in 15 m = 0	5	4	15	16	-19
Obs/Exp in 15 m ≤ 1.14	-9	-18	-14	-6	10
Obs/Exp in 15 m > 1.14	4	14	-1	-10	10
Pocket gopher density ≤ 90 m	557.89**	5602.93**	1147.15**	155.82**	298.74**
0–1.4/ha	4	36	-42	-4	11
1.41–3.5/ha	4	-20	20	7	-12
> 3.5/ha	-8	-17	22	-2	2
Ground squirrel density ≤ 90 m	1259.93**	646.46**	795.25**	2304.09**	173.95**
0/ha	10	11	8	20	-7
0.01–5.99/ha	-9	-7	-34	-17	1
≥ 6/ha	-1	-4	26	-4	6

Table 8-15. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Clustering of all burrows	16.62**	52.46**	129.46**	86.71**	445.47**
Obs/Exp in 15 m = 0–1.2	1	-2	-5	2	12
Obs/Exp in 15 m = 1.2–3.0	0	4	14	-5	0
Obs/Exp in 15 m > 3	-1	-2	-9	3	-12
Density of all burrow systems	912.94**	2375.06**	497.64**	58.03**	122.47**
< 5/ha	11	26	-23	4	-9
5–9/ha	-8	-14	1	-1	5
> 9/ha	-3	-12	22	-3	3

Table 8-16. Chi-square tests of association between time spent flying within 50 m of the rotor zone and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less close-by flying than expected by chance, and positive values express more close-by flying.

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Turbine model	360.06**	110.57**	38.22**	262.56**	101.52**
Micon	-1	3	0	-1	-4
Bonus	-11	-19	-29	-6	-16
Danwin	4	0	-1	8	0
Flowind	24	24	48	26	24
Windmatic	2	8	-2	0	-2
Enertech	-5	-5	16	-6	-4
KCS-56	-14	-8	-39	-17	-14
KVS-33	0	-4	8	-4	15
Rotor Diameter	29.80**	16.81**	6.92	35.36**	53.94**
13.5–14.8	-3	3	14	-6	-6
16.0	-1	3	0	-1	-4
17.2–17.8	4	2	10	4	12
19.1–19.5	7	7	-20	13	-10
23.4–25.2	-8	-12	-12	-6	-7
31.4–33.2	0	-4	8	-4	15
Blade tip speed (kph)	80.71**	3.48	9.97*	56.83**	35.86**
137.77–149.64	-7	0	-3	-7	-18
173.77–194.69	20	8	42	24	32
212.39–246.18	-14	-8	-39	-17	-14
Rotor plane (m^2) swept/s	78.44**	39.38**	20.47**	37.97**	55.09**
1499–1859	21	30	62	19	14
2141	-3	-7	-17	0	-9
2780–3287	-17	-20	-53	-15	-21
4014–5646	0	-4	8	-4	15
Tower type	285.33**	66.68**	29.05**	178.43**	52.66**
Vertical axis	24	24	48	26	24
Tubular	-7	-16	-30	1	-19
Lattice	-16	-8	-17	-27	-5
Tower height	286.13**	69.71**	29.01**	169.80**	51.45**
14.0	-1	1	-2	-2	-2
18.5	-11	-14	-9	-14	-8
24.0–25.2	-11	-9	-34	-10	-14
29.5–32.3	24	24	48	26	24
36.9–43.1	-1	-2	-2	0	0

Table 8-16. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Height (m), low blade reach	213.11**	80.59**	21.01**	119.63**	47.62**
4.0–5.1	23	25	46	24	22
8.0–9.6	-9	-21	-16	-12	14
11.1–14.85	-10	-16	-16	-4	-22
15.7–17.2	-4	14	-12	-8	-13
25.2–34.2	-1	-2	-2	0	0
Height (m), high blade reach	95.81**	56.81**	5.43	59.40**	9.11*
22.9–27.4	-12	-13	-11	-16	-10
29.5–33.6	24	37	35	25	11
34.4	-3	-7	-17	0	-9
36.9–52.0	-8	-18	-7	-10	8
Derelict turbines	36.47**	1.37	1.89	71.49**	2.06
Away from derelict	-7	0	-5	-12	-2
Derelict	5	-2	-3	10	-1
Next to derelict	2	2	8	2	3
Wind wall	2.15	0.53	1.23	1.07	3.14 [t]
Not in wind wall	3	-3	12	3	7
In wind wall	-3	3	-12	-3	-7
Position in string	330.65**	54.58**	5.74	526.57**	6.93 [t]
End	24	34	32	24	6
Edge of gap	-2	-2	2	0	-9
Interior	-28	-32	-34	-37	4
Non-operational	6	-1	-1	13	-1
Location in wind farm	94.16**	3.46	2.97	131.88**	1.66
Edge of farm	2	5	7	-2	4
Edge of local cluster	14	4	14	24	-3
Interior of wind farm	-15	-8	-21	-21	0
Turbine congestion	83.23**	4.87	2.37	97.20**	12.27*
0–12 within 300 m	15	7	-2	24	2
13–24 within 300 m	-1	-8	-12	-4	19
25–36 within 300 m	-5	4	21	-7	-9
37–72 within 300 m	-9	-2	-7	-12	-12
Elevation (m)	64.68**	16.51*	3.06	71.87**	39.62**
110–85	-2	3	15	-4	-5
160–135	-10	-1	-1	-15	-12
210–185	2	-2	-3	8	-9
260–235	4	3	-3	7	0
310–285	-1	9	9	-3	-6
360–335	9	2	-9	9	17
460–385	-3	-14	-8	-2	16

Table 8-16. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Slope grade (degrees)	103.07**	7.63 [t]	1.35	99.31**	10.98*
0	-18	-12	-1	-24	-13
2–5	-2	-2	-3	-2	-3
6–14	-4	3	-10	-8	-1
15–58	24	11	14	34	17
Physical relief	80.86**	15.23*	6.24	86.68**	5.83
Peak	-1	0	9	-2	-2
Plateau	-2	5	-10	-4	-2
Ridge crest	-18	-19	-14	-23	-5
Ridgeline	11	3	-1	17	7
Slope	10	7	10	13	4
Saddle	1	4	7	0	-1
Ravine	0	0	-1	-1	-1
Canyon	8.72**	1.63	0.09	3.93*	3.54 [t]
Not in canyon	6	5	4	5	8
In canyon	-6	-5	-4	-5	-8
Slope aspect	42.54**	3.81	1.93	59.04**	11.31*
None (flat)	-12	-8	1	-21	8
East-Northeast	5	2	8	7	-6
South-Southeast	-4	7	-8	-7	-9
West-Southwest	1	1	7	2	-4
North-Northwest	11	-2	-8	19	12
Edge index at tower base	34.19**	12.99*	5.52	32.19**	4.96
No edge	-1	1	-4	-3	0
Some lateral edge	-4	-10	13	-4	0
Lots lateral edge	-10	-5	-12	-14	-6
Some vertical edge	7	4	23	14	-5
Lots vertical edge	8	10	-19	7	11
Rock piles ≤ 50 m away	4.46*	0.30	0.00	8.45**	0.95
None	5	2	0	9	-6
One or more	-5	-2	0	-9	6
Rodent control through 2002	9.40*	7.78*	0.22	1.85	5.68 [t]
None	2	5	-6	2	-4
Intermittent	-7	-14	4	-5	-11
Intense	6	9	2	3	15
Years of past rodent control	10.58*	2.95	2.81	4.59	6.58*
0	2	5	-6	2	-4
1	-5	-4	15	-4	-8
5	3	-1	-9	2	12

Table 8-16. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Cattle pats 40 m from turbines	52.66**	3.18	1.96	68.58**	9.93*
0	-3	4	-8	-6	-5
1–9	-5	2	9	-9	-7
10–25	-5	-7	-11	-5	0
> 25	12	1	10	20	12
Cattle pats at turbines	27.95**	11.54*	2.34	82.60**	4.88
0–2	-5	3	-1	-10	-8
3–9	-5	15	11	-14	0
10–25	0	-7	-22	-2	10
> 25	10	-11	12	26	-2
Cottontails 40 m from turbines	1.79	1.78	1.67	5.56 [t]	4.23
No pellets	-2	-3	-10	-3	11
Some pellets	3	0	15	6	-9
Abundant pellets	-1	3	-5	-2	-2
Cottontails at turbines	2.38	15.16**	4.47	5.09 [t]	0.80
No pellets	1	-12	-18	7	4
Some pellets	-2	1	26	-6	-1
Abundant pellets	2	11	-8	0	-3
Vegetation height (cm)	43.11**	15.93**	5.21	29.67**	2.35
0–10	10	8	27	12	6
11–20	1	7	1	1	1
21–35	0	2	-19	1	-3
> 35	-11	-17	-10	-13	-5
Pocket gopher clustering	10.11*	15.76**	No test	11.04*	4.44
Obs/Exp in 15 m = 0	5	19		-3	7
Obs/Exp in 15 m < 1.5	7	-7		16	9
Obs/Exp in 15 m = 1.5–3.0	-9	-12		-7	13
Obs/Exp in 15 m > 3	-4	0		-5	-29
Ground squirrel clustering	14.19**	15.76**	No test	20.21**	5.58 [t]
Obs/Exp in 15 m = 0	11	-6		27	-32
Obs/Exp in 15 m ≤ 1.14	-16	-24		-17	14
Obs/Exp in 15 m > 1.14	5	30		-9	17
Pocket gopher density ≤ 90 m	3.75	18.00**	No test	1.78	1.40
0–1.4/ha	8	32		-8	12
1.41–3.5/ha	-1	-3		3	-15
> 3.5/ha	-7	-28		5	2
Ground squirrel density ≤ 90 m	25.90**	0.22	No test	39.66**	3.11
0/ha	17	1		30	-9
0.01–5.99/ha	-14	-4		-18	-12
≥ 6/ha	-3	3		-12	21

Table 8-16. (cont'd)

Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Clustering of all burrows	2.61	4.28	No test	5.95*	3.28
Obs/Exp in 15 m = 0–1.2	-2	-14		0	21
Obs/Exp in 15 m = 1.2–3.0	7	15		13	-20
Obs/Exp in 15 m > 3	-5	-2		-13	-1
Density of all burrow systems	7.48*	10.44**	No test	10.74**	3.13
< 5/ha	6	26		-2	-21
5–9/ha	5	-17		18	20
> 9/ha	-11	-9		-16	2

Predicted Mortality

Golden eagles perched disproportionately more often at or near wind turbines predicted by our empirical models to more likely kill golden eagles (Table 8-17). Golden eagles, red-tailed hawks, and American kestrels flew disproportionately more often nearest wind turbines predicted by our models to more likely kill them (Table 8-17). These species flew disproportionately lower to the ground nearest wind turbines predicted by our empirical models to more likely kill them, and golden eagles and American kestrels also flew disproportionately closer to these wind turbines (Table 8-17).

Table 8-17. Chi-square tests of association between dependent variables and whether model predicted lower or higher likelihood of fatalities to occur at wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

Dependent Variable	χ^2 and percent deviation from expected value				
	Raptors	TUVU	GOEA	RTHA	AMKE
Minutes of perching	37.02**	No test	27.27**	1.27	0.43
Less likely to kill bird	-5		-23	-1	-1
More likely to kill bird	5		23	1	1
Minutes of flying	74.43**	No test	6.58*	11.70**	6.99*
Less likely to kill bird	-14		-20	-7	-12
More likely to kill bird	14		20	7	12
Mean flight height (m)	131.48**	No test	634.46**	54.52**	9.01**
Less likely to kill bird	-3		-22	-3	-3
More likely to kill bird	4		22	3	3
Mean distance from turbine (m)	463.76**	No test	2938.90**	82.37**	32.32**
Less likely to kill bird	-5		-34	2	-3
More likely to kill bird	5		34	-2	3
Flights ≤ 50 m from turbines	56.98**	No test	0.72	4.60*	2.66
Less likely to kill bird	-18		-13	-6	-10
More likely to kill bird	19		13	6	10

Red-tailed hawks and American kestrels were also observed making more than the expected number of their dangerous flights nearest wind turbines we predicted in Chapter 8 to more likely kill these species. The behavior most strongly associated with predicted mortality was mean flight distance from wind turbines by golden eagles, and total time seen flying nearest the wind turbines by red-tailed hawks and American kestrels.

8.3.4 Flight Heights Relative to Existing and Future Rotor Planes

We observed that most flights by raptors occurred within the height domains of currently operating wind turbines. The height distributions of flights and summary statistics are shown in Figures 8-13, 8-14, 8-15, and 8-16 for golden eagles, red-tailed hawks, American kestrels, and all raptors combined, respectively. No analysis was possible for burrowing owls because we did not observe burrowing owl flights during the CEC-funded behavior study, which was the study we relied on for analyzing flight heights.

The percentage of flights would be smaller within the rotor plane height domains of the proposed new wind turbines in the APWRA (Alameda County 1998, Contra Costa County 2004), but not much smaller because some of these wind turbines would have rotor planes that extend down to 13.8 m above ground, which is well within the range of rotor planes of existing wind turbines. However, the percentage of flights would be much smaller within the rotor plane of the wind turbines on the proposed tallest towers (Figures 8-13 to 8-16), ranging from half of the golden eagle flight observations to about 15% of the American kestrel flight observations. Therefore, if the repowering of the APWRA consisted only of the proposed tallest wind turbines, raptor flights within the new rotor plane height would be substantially fewer than occur currently.

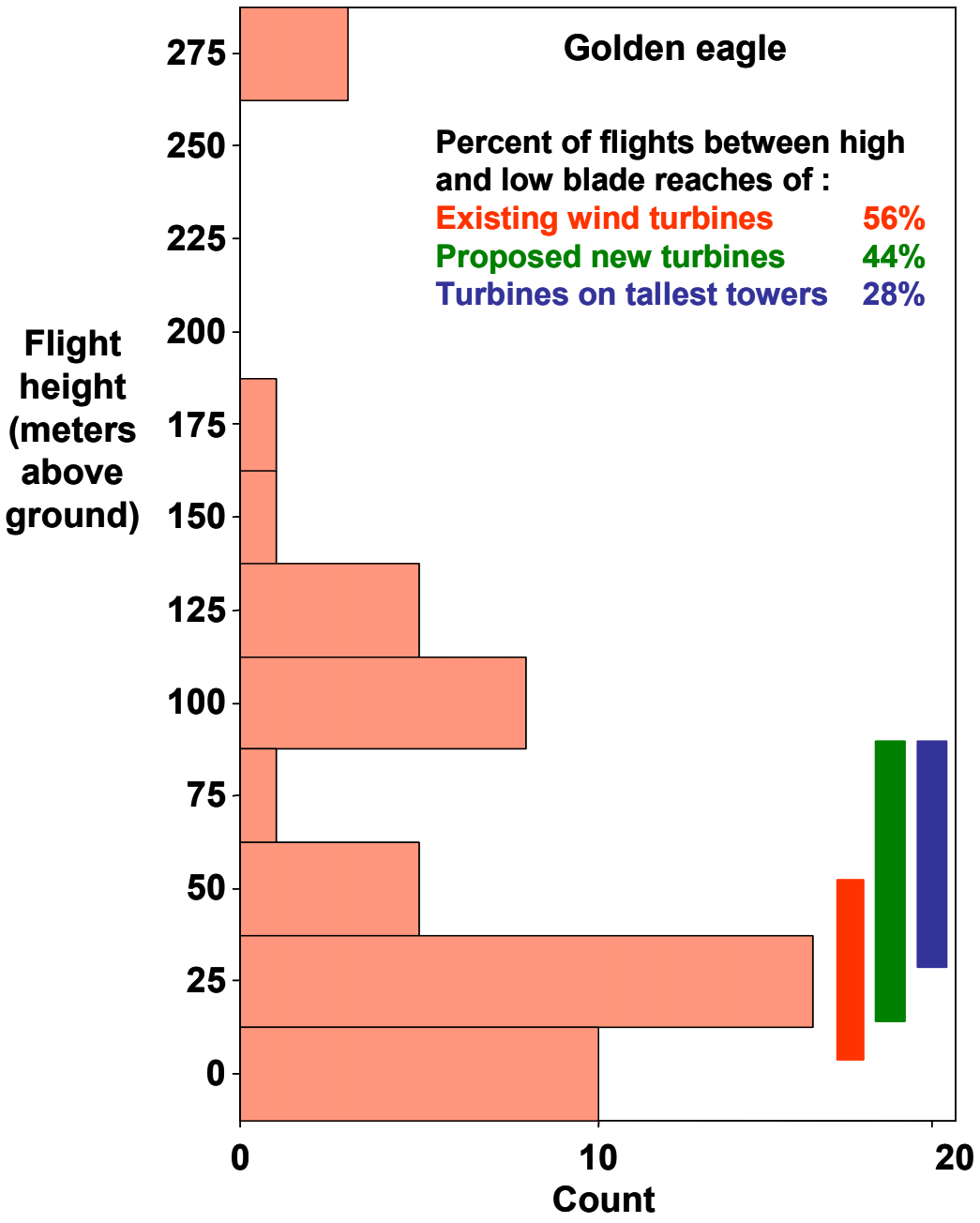


Figure 8-13. Histogram of flight heights by golden eagles and percentages of flights within the rotor height domains of existing wind turbines indicated by the red bar, proposed new wind turbines indicated by the green bar, and turbines on tallest tower indicated by the blue bar.

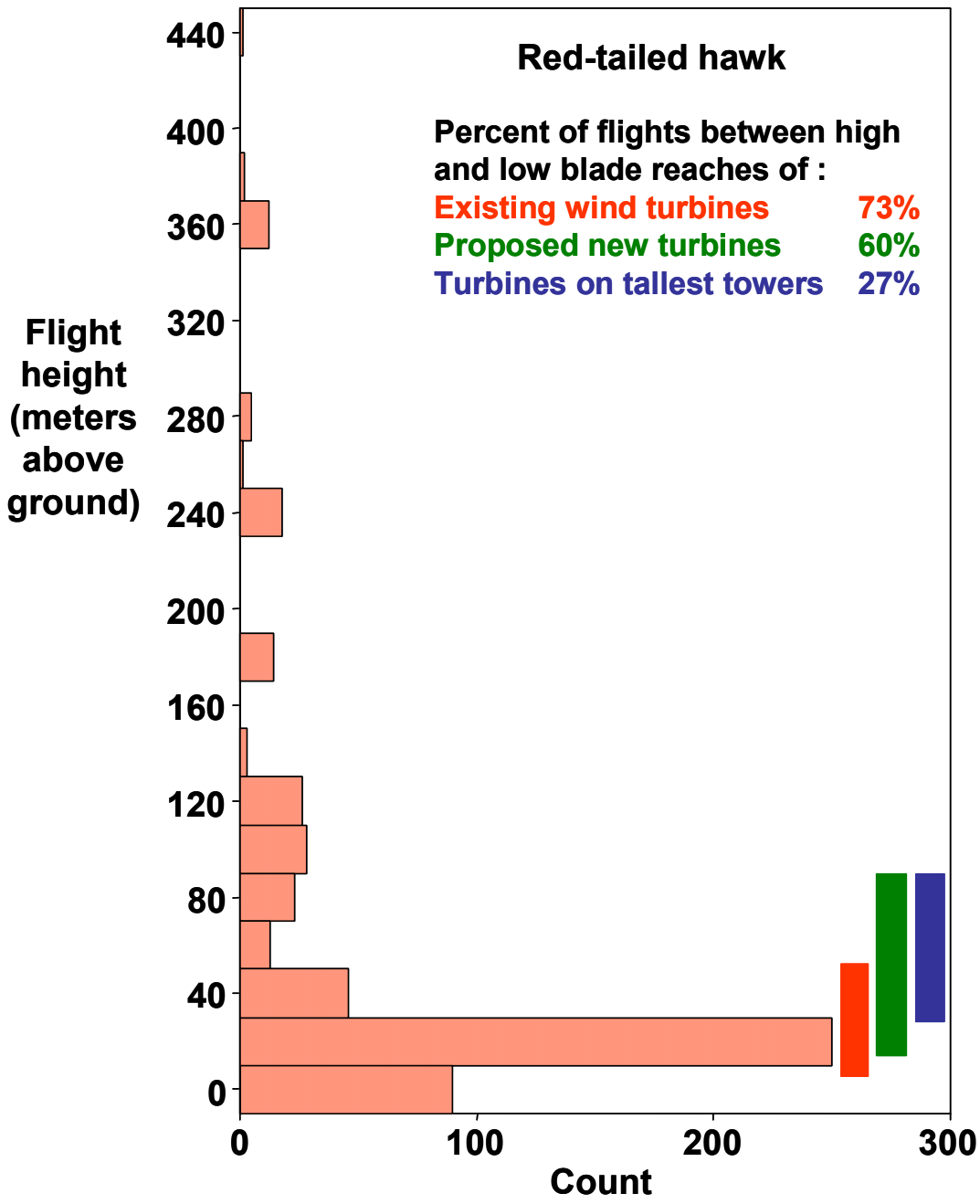


Figure 8-14. Histogram of flight heights by red-tailed hawks and percentages of flights within the rotor height domains of existing wind turbines indicated by the red bar, proposed new wind turbines indicated by the green bar, and turbines on tallest tower indicated by the blue bar.

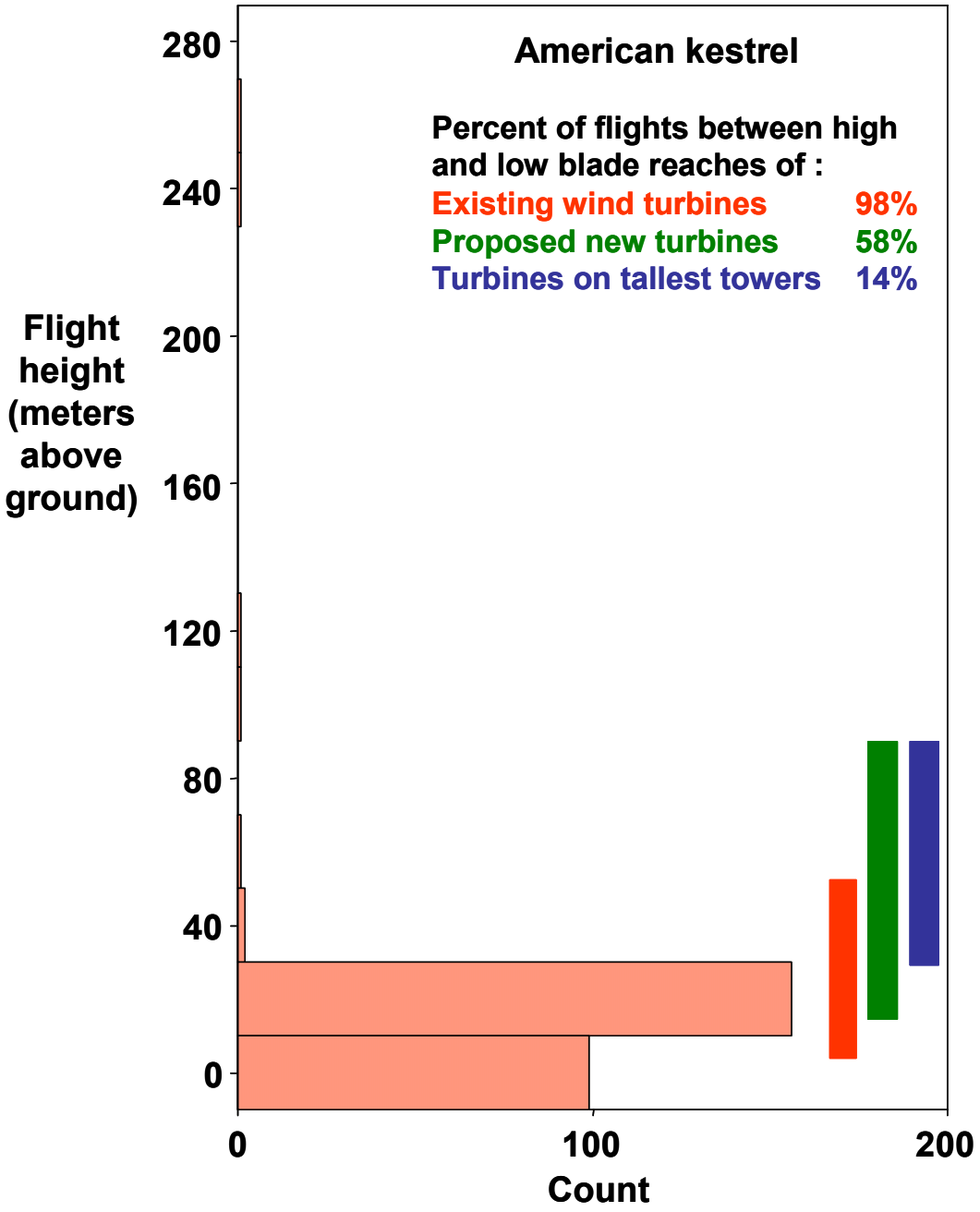


Figure 8-15. Histogram of flight heights by American kestrels and percentages of flights within the rotor height domains of existing wind turbines indicated by the red bar, proposed new wind turbines indicated by the green bar, and turbines on tallest tower indicated by the blue bar.

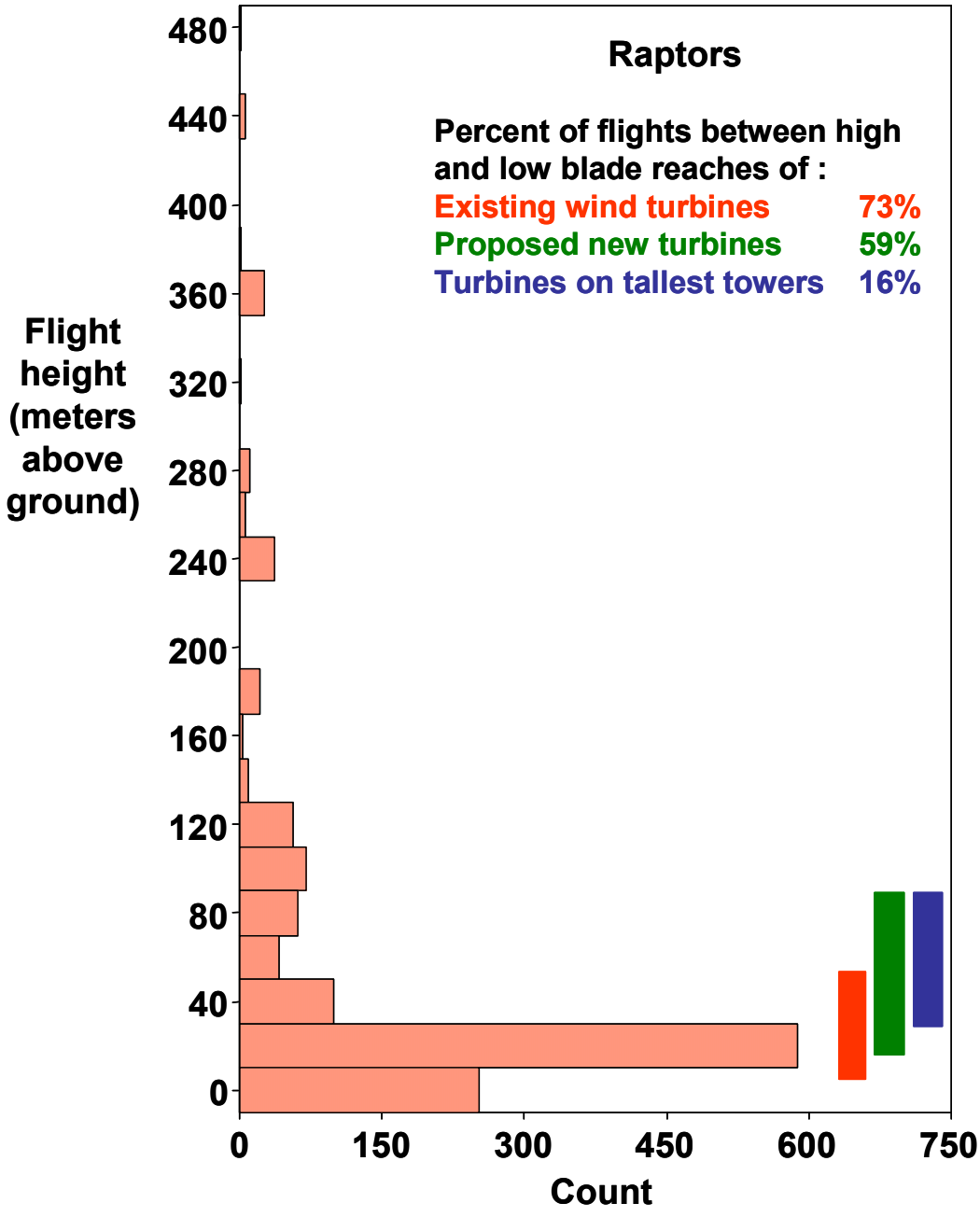


Figure 8-16. Histogram of flight heights by all raptors combined and percentages of flights within the rotor height domains of existing wind turbines indicated by the red bar, proposed new wind turbines indicated by the green bar, and turbines on tallest tower indicated by the blue bar.

8.4 DISCUSSION

Based only on significant associations, the largest measures of effect we calculated are summarized in Table 8-18 for golden eagles, Table 8-19 for red-tailed hawks, Table 8-20 for American kestrels, and Table 8-21 for turkey vultures. These results show that much of the variation in each behavior is shared among multiple association variables, groups of which obviously express common underlying factors.

8.4.1 Golden Eagle Behaviors

Golden eagles preferred to perch in areas of the APWRA with greater prey species abundance and lower vegetation, but also few cattle pats. They also preferentially selected locations where the wind turbines had smaller, slower-moving rotor blades, and they selected locations nearer turbines occurring at the ends of the strings and in less dense turbine fields. Steeper slopes were favored along with northeast- to south-facing slopes, and golden eagles spent disproportionately more time perching during mid to late morning during slow to moderate winds blowing from the northwest.

It appeared that golden eagles sought out perch locations that commanded superior views of areas where prey were abundant and available, and that were protected from the wind. Despite golden eagles' favoring prey-abundant locations, they perched disproportionately more often in areas of intense rodent control, which suggests that they choose locations not necessarily based on prey inventory, but rather on conditions of the landscape that have traditionally connoted prey availability.

Golden eagles spent disproportionately more time flying nearest wind turbines at the ends of turbine strings and at the edges of the wind farm and local clusters of turbines, and that swept the least area of the sky per second within the APWRA. They avoided flying in areas that were busier with wind turbines, such as wind walls and faster moving turbines. They also chose to fly over areas with higher pocket gopher densities, perhaps because these areas also conferred greater densities of favored prey items such as desert cottontails and ground squirrels.

Golden eagles flew lower to the ground and closer to wind turbines nearest those at the ends of turbine strings, as well as at the edges of gaps in strings. They did so also where fossorial mammal species were in lowest densities and where desert cottontail sign was absent, as well as where rodent control was applied intensively. Possibly, golden eagles use a different hunting strategy where prey species numbers are reduced. This strategy brings them closer to wind turbines and closer to the ground, which makes flights by turbines with blade reaches low to the ground more dangerous. However, golden eagles also flew disproportionately lower to the ground and nearer turbines when the turbines highest blade reach was the highest in the APWRA, so possibly golden eagles are flying low to duck under the rotor planes of these wind turbines, which also happen to be in areas of intense rodent control and reduced prey species densities. Golden eagles also fly lower than expected over ridge crests and at higher elevations, and during spring.

Dangerous flights were made disproportionately more frequently nearest wind turbines that swept less of the sky per second, including nearest vertical axis turbines. However, dangerous flights were not made more often than expected by chance near wind turbines we predicted in Chapter 8 to be

more dangerous to golden eagles (Table 8-17). In fact, golden eagles preferred to fly higher and farther away from these wind turbines (Table 8-17), indicating that they recognize them as dangerous.

8.4.2 Red-tailed Hawk Behaviors

Red-tailed hawks perched preferentially nearest wind turbines at the ends of turbine strings, as well as in areas of highest densities of small mammal prey species. Like golden eagles, they also perched preferentially nearest wind turbines that were less busy or that swept smaller areas per second. Perching was more common than expected by chance during slow winds and during January and the middle of the day, as well as at low elevations, on slopes and in areas more intensively used by cattle.

Red-tailed hawks also flew preferentially nearest wind turbines at the ends of turbine strings, but contrary to golden eagles, in areas of lowest densities of mammalian prey species. They preferred to fly during the early afternoon in moderate winds, and over northerly slopes and steeper slopes, and where the grass was shorter and cattle presence more intense. They also flew preferentially at the edges of local clusters of wind turbines, but also nearest more sparsely distributed turbines that sweep less area per second.

Flights of red-tailed hawks were lower to the ground and nearest wind turbines located interior to turbine strings, and they flew higher to the ground and farther away from wind turbines at the ends of strings. They also flew lower to the ground and closer to wind turbines when over areas supporting modest to high densities of mammalian prey species. Red-tailed hawks appeared to recognize the end-of-row turbines as more dangerous and attempted to hunt lower to the ground when farther from these end turbines, such as nearer the interior turbines. Although red-tailed hawks spent more time flying over areas of lowest densities of mammalian species, they preferred to fly low over areas of highest densities of mammalian species.

Red-tailed hawks performed dangerous flights disproportionately more often over the steepest slopes and over ridgelines, and also where no ground squirrels occurred or only where all small mammal species studied occurred in moderate densities. Dangerous flights of red-tailed hawks were more common over more intensively grazed areas with shorter vegetation. They performed disproportionately more of their dangerous flights nearest vertical axis turbines and near end turbines, despite the finding that they also preferred to fly higher and farther away from end turbines. Apparently, they attempted to avoid end-of-row turbines, but still ended up making more of their dangerous flights by these turbines. Dangerous flights also occurred disproportionately near turbines at the edges of local turbine clusters and in areas of lowest density of turbines. And they occurred preferentially near derelict turbines and near where rocks had been piled after being cleared from the tower laydown areas.

8.4.3 American Kestrel Behaviors

American kestrels perched preferentially during the winter months compared to late fall or spring, and they did so during moderate winds and relatively cool temperatures. They perched preferentially nearest wind turbines at the ends of rows, and at the edges of the APWRA and local clusters of wind turbines. They also did so at the highest elevations in the APWRA and on the steepest slopes, and where fossorial mammal species occurred in moderate densities. They also chose to perch nearest wind turbines with the slowest tip speeds.

American kestrels favored flying in the APWRA at the highest elevations and where fossorial mammals occurred at the highest densities. They preferred to fly in low density turbine fields, nearest turbines at the ends of strings, and near vertical axis turbines. They also flew preferentially near wind turbines with rock piles nearby and where cattle grazed intensively.

American kestrels flew lower to the ground and closer to wind turbines disproportionately more often in areas of moderate pocket gopher density and where ground squirrels were lacking. They also did during the spring months and during the morning hours. They flew lower to the ground in southwest winds, slower winds, and over ridge crests and in less dense turbine fields.

American kestrels performed disproportionately more of their dangerous flights at highest elevations and in moderately fast winds, winds blowing from the southwest, and during mid- to late afternoon. They performed more of their dangerous flights where ground squirrels occurred within 15 m of wind turbines, in areas of intense rodent control, and where cattle grazed more intensively. They also preferentially performed more of these flights on the steepest slopes and in sparse turbine fields nearest the end-of-row turbines.

Table 8-18. The directions and magnitudes of significant associations between measured golden eagle behaviors and independent variables

Variable	Difference between observed and expected values as percent of total
	Time spent perching
Burrow system density	70 in areas of intermediate gopher density; 71 in areas of highest ground squirrel density; 67 in areas of highest mammal density
Burrow clustering	58 in areas of intermediate ground squirrel clustering; 71 in areas of no fossorial mammal burrow systems
Blade tip speed	63 at turbines with slowest tip speed
Rotor diameter	55 at turbines with small rotors
Cattle pats	53 in areas with fewer cattle pats
Vegetation height	52 in areas of tallest vegetation
Position in string	51 at end turbines

Table 8-18. (cont'd)

Variable	Difference between observed and expected values as percent of total
	Time spent perching (cont'd)
Elevation	43 at lowest elevations
Wind speed	39 in slow-moderate winds
Physical relief	38 on slopes
Wind direction	36 in north winds; 16 in no winds
Location in APWRA	33 at edge of APWRA, 17 at edge of local cluster of turbines
Time of day	26 in early to mid morning
Slope grade	22 on steepest slopes
Cottontail abundance	21 in areas of abundant pellets near wind turbines
Temperature	21 in 70–79 ˚F
Rodent control	19 in areas of intense poisoning
Slope aspect	17 on northeast, east, southeast and south slopes
Rock piles	13 in areas of no rock piles
Wind wall	12 at turbines outside of wind walls
Turbine congestion	12 at sparsest turbine fields
Canyon	12 in canyons
Tower type	11 at or near tubular towers
	Time spent flying
Position in string	43 at end turbines
Rotor plane swept/s	22 at turbines with slowest rates of sweeping the rotor plane
Burrow system density	21 in areas of highest gopher density
Location in wind farm	20 at edge of APWRA or local cluster
Cottontail abundance	17 at wind turbines with some pellets
Rotor diameter	15 at turbines with small rotors
Wind wall	12 at turbines outside wind walls
Tower type	9 at vertical axis turbines
Burrow clustering	5 in areas of no ground squirrels; 4 in areas of moderate clustering of all fossorial mammals
	Flight height
Position in string	-42 at turbines in string interior; -6 at edge of gaps
Burrow system density	-42 at turbines with lowest densities of pocket gophers; -39 at turbines with intermediate ground squirrel densities; -36 at turbines with lowest densities of all mammal species
Cottontail abundance	-33 at turbines with no cottontail pellets
Rodent control	-29 in areas of intense rodent control
Cattle pats	-27 at turbines with the most cattle pats nearby
Time of day	-27 in early to mid morning
Location of wind farm	-25 in interior of APWRA
Blade tip speed	-23 at turbines with slowest to intermediate tip speeds
High blade reach	-23 at wind turbines with highest blade reach
Vegetation height	-22 at turbines with taller vegetation nearby

Table 8-18. (cont'd)

Variable	Difference between observed and expected values as percent of total
	Flight height (cont'd)
Month	-22 in March and April
Turbine congestion	-17 in areas most densely packed with wind turbines
Elevation	-17 at highest elevations
Burrow clustering	-15 at turbines with no clustering of ground squirrel burrows; -17 at turbines with greatest clustering of all fossorial mammals
Turbine model	-16 near KCS-56
Physical relief	-14 over ridge crests
Edge index	-12 at turbines with little or no lateral edge
Wind wall	-12 at wind walls
Slope grade	-12 over flat terrain
Tower type	-10 at tubular towers
Canyons	-8 in canyons
	Distance from turbines
Position in string	-46 at string interior; -4 at gaps in string
Burrow system density	-42 in areas of lowest pocket gopher density; -34 in areas of low to moderate ground squirrel density; -23 in areas of lowest densities of all burrow systems
Location in wind farm	-30 in APWRA interior
Slope grade	-24 on shallow to moderate slopes
Cattle pats	-23 at turbines with the most cattle pats nearby
Blade tip speed	-23 at turbines with faster tip speeds
Cottontail abundance	-21 at turbines with no sign of cottontails
Rodent control	-19 in areas of rodent control
Burrow clustering	-18 at turbines with gophers clustered close by; -14 at turbines with squirrels nearby but not clustered at turbine
Turbine model	-18 at KCS-56; -6 at Bonus
High blade reach	-17 at turbines with higher blade reaches
Physical relief	-16 on ridge crests
Turbine congestion	-15 in areas of highest turbine density
Month	-14 during March and April
Time of day	-13 during early to mid morning
Wind wall	-12 at wind walls
Canyon	-8 outside of canyons
Rock piles	-4 at turbines with rock piles nearby
	Dangerous flights
Rotor plane swept/s	62 at turbines with slowest rates of sweeping the rotor plane
Turbine model	48 at Flowind

Table 8-19. The directions and magnitudes of significant associations between measured red-tailed hawk behaviors and independent variables

Variable	Difference between observed and expected values as percent of total
	Time spent perching
Position in string	36 at end turbines
Burrow clustering	23 where ground squirrels occur, but uniformly distributed
Burrow system density	8 in areas of highest pocket gopher densities; 12 in areas of highest ground squirrel densities; 23 in areas of highest densities of all fossorial mammals
Rotor plane swept/s	21 at turbines with slowest rates of sweeping the rotor plane
Wind speed	20 in slow winds
Month	17 in January
Elevation	17 at low elevations
Physical relief	16 on slopes
Edge index	12 at turbines with lots of vertical edge nearby
Wind direction	10 in east winds
Time of day	9 in the middle of the day
Tower type	8 at vertical axis turbines
Wind wall	8 at turbines outside wind walls
Cattle pats	8 at turbines with more cattle pats nearby
Slope aspect	8 on east and northeast slopes
Turbine congestion	7 in areas of low turbine density
Rock piles	6 at wind turbines with no rock piles nearby
Vegetation height	6 in areas of taller vegetation
Derelict turbines	4 at derelict turbines
Location in wind farm	4 at edge of local cluster
Rodent control	4 in areas of intermittent rodent control
	Time spent flying
Position in string	33 at end turbines
Burrow clustering	14 in areas with no gophers; 8 in areas of moderate gopher clustering; 29 in areas with no ground squirrels near wind turbines
Burrow system density	25 in areas with no ground squirrel burrow systems nearby turbines; 8 in areas of lowest mammal burrow system densities
Time of day	21 in early afternoon
Slope aspect	19 over northwest to northeast slopes
Wind speed	18 in moderate winds
Wind direction	17 in north and northwest winds
Slope grade	17 over steepest slopes
Edge index	17 at turbines with some to lots of vertical edge
Physical relief	15 over slopes; 8 over ridgelines
Location in wind farm	15 at edge of local cluster; 4 at edge of APWRA
Turbine congestion	14 in areas of lowest turbine density
Turbine model	12 at Flowind

Table 8-19. (cont'd)

Variable	Difference between observed and expected values as percent of total
	Time spent flying (cont'd)
Rotor plane swept/s	12 at turbines with slowest rates of sweeping the rotor plane
Cattle pats	12 at turbines with the most cattle pats
Elevation	10 in areas of intermediate elevation
Month	9 in November; 9 in March/April
Vegetation height	8 at turbines with shorter vegetation nearby
Rock piles	7 at turbines without rock piles nearby
Cottontail abundance	6 at turbines with some pellets
Derelict turbine	4 at derelict turbines
Rodent control	4 in areas of no rodent control
	Flight height
Burrow clustering	-37 in areas of greatest gopher clustering at turbines; -10 in areas of ground squirrel clustering at turbines; -21 in areas of modest clustering of mammal burrows at turbines
Time of day	-19 during early to mid morning
Burrow system density	-18 in areas of highest pocket gopher density near turbines; -13 in areas of modest density of ground squirrels; -12 in areas of modes to high density of all mammal burrows
Position in string	-16 at turbines in the string interior; -3 at turbines at gaps
Wind direction	-15 in southwest and west winds
Edge index	-14 at turbines with some or lots of lateral edge
Rotor diameter	-9 at turbines with larger rotor diameters
Slope aspect	-9 over south and southeast slopes
Location in wind farm	-8 in APWRA interior
Elevation	-8 at highest elevations
Vegetation height	-7 at turbines with the tallest vegetation nearby
Rock piles	-7 at turbines with rock piles nearby
Wind speed	-5 in slowest winds; -5 in strong winds
Tower type	-5 at tubular towers
Slope grade	-5 over steepest slopes
Canyon	-5 in canyons
Physical relief	-4 over ridge crests
Rodent control	-4 in areas of intermittent rodent control
	Distance from turbines
Position in string	-34 at turbines in the string interior
Burrow system density	-4 in areas of no pocket gophers near wind turbines; -21 at turbines with ground squirrel burrows within 90 m
Burrow clustering	-17 in areas of moderate gopher clustering at turbines; -10 in areas of ground squirrel clustering at turbines; -5 in areas of modest clustering of mammal species at turbines

Table 8-19. (cont'd)

Variable	Difference between observed and expected values as percent of total
	Distance from turbines
Location in wind farm	-14 in APWRA interior
Cottontail abundance	-11 at turbines with no pellets nearby
Turbine congestion	-10 in areas of highest turbine density
Rotor plane swept/s	-10 at turbines with highest rates of sweeping the rotor plane
Rotor diameter	-9 at turbines with largest rotor diameters
Rodent control	-7 in areas of rodent control
Wind speed	-5 in slowest winds; -7 in strong winds
Tower type	-7 at tubular towers
Physical relief	-7 over ridge crests
Canyon	-5 in canyons
Rock piles	-3 at turbines with rock piles nearby
	Dangerous flights
Slope grade	34 on steepest slopes
Burrow system density	30 at turbines with no ground squirrel burrows nearby; 18 with moderate densities of all mammal burrows nearby
Burrow clustering	16 at turbines with uniformly distributed gopher burrow systems; 27 at turbines with no ground squirrel burrows nearby 13 at turbines with moderate clustering of all mammal burrows
Turbine model	26 at Flowind
Cattle pats	26 at turbines with the most cattle pats nearby
Position in string	24 at end turbines
Location in wind farm	24 at edge of local clusters of turbines
Turbine congestion	24 in areas of lowest turbine density
Wind speed	24 in moderate winds
Time of day	22 in early afternoon
Edge index	21 at turbines with some or lots of vertical edge
Rotor plane swept/s	19 at turbines with slowest rates of sweeping the rotor plane
Slope aspect	19 on north and northwest slopes
Physical relief	17 on ridgeline; 13 on slope
Month	12 in November; 13 in March
Vegetation height	12 at turbines with the shortest vegetation nearby
Derelict turbine	10 at derelict turbines
Wind direction	10 in northwest winds; 10 in southwest winds
Rock piles	9 at turbines with no rock piles nearby

Table 8-20. The directions and magnitudes of significant associations between measured American kestrel behaviors and independent variables

Variable	Difference between observed and expected values as percent of total
	Time spent perching
Month	35 in December through February
Position in string	31 at end turbines
Wind speed	15 in moderate winds
Temperature	13 in 50–59 ˚F
Burrow system density	13 in areas of moderate gopher density; 9 in areas of moderate to high density of all mammal burrows
Elevation	8 at highest elevations
Slope grade	8 on steepest slopes
Location in wind farm	7 at APWRA edge; 4 at edge of local turbine cluster
Wind direction	6 in northwest winds; 7 in no winds
Time of day	5 in late morning
Rodent control	4 in areas of intense rodent control
Blade tip speed	4 at turbines with the slowest tip speeds
Derelict turbine	3 at derelict turbines
	Time spent flying
Elevation	32 at highest elevations
Burrow system density	27 in areas of highest ground squirrel density; 28 in areas of higher density of all mammal burrows
Burrow clustering	28 where ground squirrels occur uniformly around wind turbines; 23 where all mammal burrows occur in uniform distribution
Turbine congestion	26 in less dense turbine fields
Wind speed	26 during intermediate winds
Time of day	19 after noon
Turbine model	18 at KVS-33
Slope grade	16 on steepest slopes
Rodent control	13 in areas of intense rodent control
Tower type	13 at vertical axis
Wind direction	12 in southwest winds
Position in string	11 at end turbines
Cattle pats	11 at turbines with most cattle pats nearby
Cottontail abundance	10 at turbines with no pellets nearby
Rock piles	9 at turbines with rock piles nearby
Wind wall	8 at turbines outside wind walls
	Flight height
Burrow system density	-33 in areas of modest gopher density out to 90 m; -6 in areas of no ground squirrels out to 90 m from turbines
Month	-26 during spring months

Table 8-20. (cont'd)

Variable	Difference between observed and expected values as percent of total
	Flight height (cont'd)
Burrow clustering	-24 in areas with no pocket gophers within 15 m of turbines; -12 in areas of ground squirrels uniformly distributed by turbines; -20 in areas of modest clustering of all burrows around turbines
Tower height	-17 at intermediate to shortest towers
Time of day	-17 during morning and early afternoon
Cattle pats	-14 at turbines with fewest cattle pats nearby
Vegetation height	-13 at turbines with tallest vegetation nearby
Turbine model	-12 at KCS-56; -4 at Bonus
Blade tip speed	-12 at turbines with fastest tip speeds
Wind direction	-12 in southwest winds
Edge index	-12 at turbines with no vertical edge
Rock piles	-12 at turbines with no rock piles nearby
Slope grade	-11 on shallow to intermediate slopes
Position in string	-10 at turbines in string; -4 at edges of gaps
Turbine congestion	-9 at turbines in dense turbine fields
Wind speed	-8 in slow winds
Wind wall	-7 near wind walls
Physical relief	-6 over ridge crests
Rodent control	-3 in areas of intense rodent control
	Distance from turbines
Position in string	-24 at turbines in string interior; -3 at edge of gap
Burrow clustering	-21 in areas of greatest gopher clustering at wind turbines; -19 at turbines lacking ground squirrels within 15 m; -12 at turbines with greatest clustering of all mammal burrows
Elevation	-15 at middle and lower elevations
Month	-14 during April and May
Turbine congestion	-13 in areas of greater turbine density
Burrow system density	-12 in areas of moderate gopher density to 90 m; -7 at turbines lacking ground squirrels out to 90 m; -9 at turbines with lowest densities of mammal burrows to 90 m
Cattle pats	-10 at turbines with the most cattle pats nearby
Location in wind farm	-10 at turbines interior to APWRA
Time of day	-8 during the morning
Slope grade	-6 on shallower slopes
Slope aspect	-6 on east and northeast slopes
Rodent control	-6 in areas of intermittent rodent control
Wind wall	-6 by wind walls
Tower type	-4 at tubular towers
Blade tip speed	-3 at turbines with fastest tip speeds

Table 8-20. (cont'd)

Variable	Difference between observed and expected values as percent of total
	Dangerous flights
Elevation	33 at highest elevations
Burrow clustering	31 at turbines with ground squirrels occurring within 15 m
Wind speed	26 in moderately fast winds
Wind direction	25 in southwest, west and northwest winds
Turbine model	24 at Flowind; 15 at KVS-33
Time of day	22 during mid to late afternoon
Turbine congestion	21 in sparsely distributed turbine fields
Slope grade	17 on steepest slopes
Rodent control	15 in areas of intense rodent control
Slope aspect	12 on northwest slopes
Cattle pats	12 at turbines with the most cattle pats nearby
Wind wall	7 at turbines outside wind walls
Position in string	6 at end turbines

Table 8-21. The directions and magnitudes of significant associations between measured turkey vulture behaviors and independent variables

Variable	Difference between observed and expected values as percent of total
	Time spent flying
Position in string	38 by end turbines
Burrow system density	26 at turbines with low to moderate gopher densities to 90 m; 9 at turbines with no ground squirrels to 90 m; 31 at turbines with no mammal burrows to 90 m
Time of day	26 during noon to early afternoon
Burrow clustering	23 at turbines with no or few gophers within 15 m; 10 at turbines with burrows of all mammals clustered within 15 m
Rotor plane swept/s	22 at turbines with slowest rates of sweeping the rotor plane
Location in wind farm	19 at edge of APWRA or local clusters of turbines
Month	19 during March
Vegetation height	16 at turbines with shorter vegetation nearby
Wind speed	16 at moderate wind speeds
Cattle pats	14 at turbines with fewest cattle pats nearby
Physical relief	13 on slopes
Rotor diameter	12 at turbines with smaller rotor diameters
Wind direction	11 in northwest winds
Tower type	11 at vertical axis

Table 8-21. (cont'd)

Variable	Difference between observed and expected values as percent of total
	Time spent flying (cont'd)
Edge index	11 at turbines with vertical edge
Rodent control	11 in areas of no rodent control
Cottontail abundance	11 at turbines with pellets counted nearby
	Flight height
Position in string	-28 at turbines in string interior
Burrow clustering	-27 in areas of greatest gopher clustering at turbines; -12 at turbines with ground squirrels uniformly distributed nearby
Rotor plane swept/s	-23 at turbines with fastest rates of sweeping the rotor plane
Burrow system density	-22 in areas of highest gopher density to 90 m -10 in areas of highest ground squirrel density to 90 m; -17 in areas of highest density of burrows of all mammals to 90 m
Physical relief	-22 over ridge crests
Vegetation height	-17 at turbines with taller vegetation nearby
Cottontail abundance	-14 at turbines with no pellets nearby
Temperature	-13 during 50–59 ˚F
Turbine model	-13 at Bonus; -9 at KCS-56
Rotor diameter	-12 at turbines with largest rotor diameters
Time of day	-12 during morning hours
Elevation	-11 at highest elevations
Slope grade	-11 on shallowest slopes
Canyon	-10 in canyon
Rodent control	-10 in areas of rodent control
Month	-10 during November and December
Wind direction	-9 during no winds
Blade tip speed	-9 at turbines with fastest tip speeds
Wind wall	-6 by wind walls
Location in wind farm	-6 in APWRA interior
Turbine congestion	-5 in sparsest turbine fields
	Distance from turbines
Burrow system density	-37 at turbines with moderate to high gopher density to 90 m; -11 at turbines with moderate to high ground squirrel density; -26 at turbines with moderate to high density of all mammals
Position in string	-32 at turbines in string interior; -3 at gaps
Rotor plane swept/s	-27 at turbines with faster rates of sweeping the rotor plane
Location in wind farm	-27 in APWRA interior
Burrow clustering	-23 at turbines with gopher burrows clustered within 15 m; -18 in areas where ground squirrels occur uniformly by turbines
Turbine model	-22 at Bonus

Table 8-21. (cont'd)

Variable	Difference between observed and expected values as percent of total
	Distance from turbines (cont'd)
Rotor diameter	-20 at turbines with larger rotor diameters
Rodent control	-19 in areas of rodent control
Physical relief	-19 over ridge crests
Time of day	-17 during morning
Temperature	-13 during coolest temperatures
Vegetation height	-13 at turbines with taller vegetation nearby
Edge index	-12 at turbines with no vertical edge nearby
Cattle pats	-12 at turbines with more cattle pats nearby
Month	-11 during January
Canyon	-11 in canyons
Wind direction	-9 in no winds
Rock piles	-8 at turbines with rock piles nearby
Slope aspect	-7 on north and northwest slopes
Cottontail abundance	-7 at turbines with no pellets nearby
Slope grade	-5 on shallowest slopes
	Dangerous flights
Position in string	34 at end turbines
Burrow system density	32 at turbines with no gophers within 90 m; 26 at turbines with lowest densities of mammal burrows to 90 m
Burrow clustering	19 at turbines with no gophers within 15 m; 30 at turbines with ground squirrels clustered within 15 m
Rotor plane swept/s	30 at turbines with slowest rates of sweeping the rotor plane
Time of day	25 during early and mid afternoon
Rotor diameter	25 at turbines with moderate to smallest rotor diameters
Tower type	24 at vertical axis
Wind speed	19 in stronger winds
Cattle pats	18 at turbines with fewer cattle pats nearby
Wind direction	16 in northwest winds
Vegetation height	15 at turbines with shorter vegetation nearby
Elevation	14 at mid-elevations
Slope grade	14 on steeper slopes
Month	12 during March; 12 during May
Edge index	14 at turbines with vertical edge nearby
Cottontail abundance	11 at turbines with abundant pellets nearby
Rodent control	9 in areas of intense control; 5 in areas of no control

8.4.4 Bird Behaviors and Fatalities

Tables 8-22 through 8-24 present the fatality associations chosen for development of the indicators of relative threat to golden eagle, red-tailed hawk, and American kestrel summarized in this chapter, and these tables compare their magnitude of effect to those of the behaviors associated with the same variables. In other words, we compared the measures of effect of the relationships between fatalities and their most effective predictor variables to the measures of effect of the relationships between measured behaviors and the same predictor variables that most effectively associated with fatalities. Thus, these predictor variables are not the only associations that were statistically significant in either the behavior or fatality studies, but were those that we chose due to their easily interpretable patterns of association and relative degree of independence from other measured variables in representing underlying factors associated with fatalities. Blank cells in the tables indicate statistically insignificant test results or where tests were not performed due to inadequate sample sizes. The caption for Table 8-22 provides examples of how to interpret the numbers presented in Tables 8-22 to 8-24.

Where golden eagles collided with wind turbines disproportionately more often at highest mammal burrow system densities, they also perched disproportionately more often and they flew lower to the ground and closer to wind turbines where mammal burrow system densities were highest. It is possible that golden eagles perch and launch more dangerous flights for hunting purposes where small mammals more densely occur near wind turbines. Augmenting this pattern, golden eagles collided with wind turbines disproportionately less often in areas of intense rodent control, which is where they also perched disproportionately more often and flew lower to the ground and closer to wind turbines.

Golden eagles were killed disproportionately more often by wind turbines with lower heights of the high blade reach, but flew lower to the ground and closer to wind turbines with highest reaches of the high blade reach. It appears that golden eagles make an effort to fly under the rotor planes of wind turbines, and perhaps more frequently fail to fly under the rotor planes that reach lower to the ground. These results were consistent with our observations that golden eagles give a wider flight berth to those wind turbines we predicted to be more dangerous to golden eagles (Table 17).

Golden eagles were disproportionately killed by wind turbines in sparse turbine fields, and they perched preferentially in the lowest-density turbine fields. However, they flew preferentially lower to the ground in the highest-density turbine fields. That they flew preferentially closer to wind turbines in the densest turbine fields is likely an artifact of the average distances being forced closer as the density of turbine fields increases. However, all evidence considered, golden eagles appear to seek out areas that are more sparsely occupied by wind turbines.

Collisions of golden eagles occurred at turbines on ridgelines more often than expected by chance, but these are not the locations where golden eagles preferred to perch or to fly low to the ground. However, collisions occurred disproportionately more often in canyons and on steeper slopes, which is also where golden eagles preferred to perch. Also, golden eagles preferred to fly lower to the ground in canyons. Golden eagles appear to prefer to hunt from perch sites and to ambush prey items within the larger drainage structures of the APWRA, and in doing so they tend to fly higher

while maneuvering over ridgelines in these drainage systems. It is this rise in altitude over ridgelines that may lead to more than the expected number of fatalities at wind turbines on ridgelines.

Whereas golden eagles preferred to perch in areas with fewer cattle pats, they flew lower to the ground and closer to wind turbines where cattle pats were most abundant, and this is also where they were killed disproportionately more often. Possibly, golden eagles expect to ambush prey where many cattle pats cover the ground because this is also where the grass is shortest, which is why they fly in close to wind turbines and low to the ground in these areas of high cattle pat abundance.

Golden eagles preferred to both perch and fly near end-of-row wind turbines, where they also flew disproportionately lower to the ground and closer to wind turbines, and where they died disproportionately more often. Contrary to red-tailed hawks, golden eagles do not appear to be making any extra effort to avoid end-of-row turbines, unless it is the lower flight that is the avoidance measure. However, this dangerous flight pattern appears to contribute significantly to golden eagle mortality.

Red-tailed hawks died at wind turbines disproportionately more often on steep slopes with lots of vertical edge and in canyons, and it was over these conditions red-tailed hawks also preferred to perch and fly and where they flew lower to the ground, closer to wind turbines, and where they performed disproportionately more of their dangerous flights. They also collided disproportionately more often with end-of-row turbines, where they also preferred to perch and fly and to make their dangerous flights. Their disproportionate collisions at wind turbines with larger rotor diameters and on tubular towers also corresponded with preferential perching and flight time and with the frequency of dangerous flights associated with these turbine characteristics. The same was true for wind turbines at the edges of local clusters, and to a smaller extent at wind turbines in areas of intermittent rodent control.

American kestrels died at wind turbines disproportionately more often at highest elevations within the APWRA, and this is where they preferred to perch and fly, and to make more of their dangerous flights by wind turbines. They collided with KVS-33 turbines disproportionately more often, and these turbines happened to also occur at the highest elevations, so the correspondence with behavior variables was likely a result of shared variation in conditions.

Table 8-22. Correspondence between measures of the magnitude and directions of fatalities with independent variables and behaviors with independent variables for golden eagles. As an example, the first cell under fatalities means, "33% of total golden eagle fatalities can be attributed to wind turbines in areas of highest mammal burrow system density within a 90-m radius of the wind turbines." The first cell under perching time means, "67% of total observed golden eagle perching time can be attributed to locations within areas of highest mammal burrow system density." The first cell under flight height means, "36% less of the summed golden eagle flight heights can be attributed to locations of highest mammal burrow system density," meaning that golden eagles flew considerably lower to the ground where mammal burrow systems were abundant.

	Percent of total of dependent variable attributed to accompanying category or level of wind turbine					
Variable	**Fatalities**	**Perching time**	**Flight time**	**Flight height**	**Flight distance from turbines**	**Dangerous flight time**
Mammal burrow density to 90 m	33 at highest	67 at highest		-36 at lowest	-23 at lowest	
Pocket gopher density to 90 m	30 at highest	70 at highest	21 at highest	-42 at lowest	-42 at lowest	
Edge index	27 with more vertical edge			-12 with little or no edge		
Height of high blade reach	25 at lower			-23 at highest	-17 at highest	
Turbine density	21 low	12 lowest		-17 highest	-15 highest	
Physical relief	21 on ridgeline	38 on slopes 14 on flat		-14 on ridge crest	-16 on ridge crest	
Areas of intense rodent control	-20	19		-29	-13	
Cattle pat abundance	19 with more	53 with fewer		-27 with most	-23 with most	
Position in string: At the string end At the edges of gaps	 17 2	51	43	 -42 -6	 -46 -4	
In canyons	13	12		-8	8	
Slope grade	13 on steeper slopes	22 on steepest slopes		-12 on flat terrain	-24 on shallow-moderate slopes	
Turbines *not* in wind walls	12	12	12	12	12	
Location in APWRA	12 cluster edge	33 farm edge 17 cluster edge	14 farm edge 6 cluster edge	-25 in interior	-30 in interior	

Table 8-23. Correspondence between measures of the magnitude and directions of fatalities with independent variables and behaviors with independent variables for red-tailed hawks. As an example, the first cell under fatalities means, "15% of total red-tailed hawk fatalities can be attributed to wind turbines located in 'canyons.'"

	Percent of total of dependent variable attributed to accompanying category or level of wind turbine					
Variable	**Fatalities**	**Perching time**	**Flight time**	**Flight height**	**Flight distance from turbines**	**Dangerous flight time**
Whether in canyon	15 in canyon			-5 in canyon	-5 in canyon	
Edge index	13 at greater vertical edge	12 with greater vertical edge	17 at greater vertical edge	-14 at greater vertical edge		21 at greater vertical edge
Slope grade	11 on steeper slopes		17 on steepest slopes	-5 on steepest slopes		34 on steepest
Position in turbine string	11 at string end 1 at gap edge	36 at string end	33 at string end	-16 at interior -3 at gap edge	-34 at interior	24 at string end
Rotor diameter	10 at larger	12 from intermediate	12 from intermediate	-9 from largest	-9 from largest	17 from intermediate
Height of highest blade reach	9 at highest	10 at intermediate	18 at intermediate	11 at intermediate	4 at lowest	25 at intermediate
Location in wind farm	9 cluster edge	4 at cluster edge	15 at cluster edge	-8 in interior	-14 in interior	24 at cluster edge
Turbine density	8 at lower	7 at lower	14 at lowest		-10 at highest	24 in lowest
Elevation	8 at middle	17 at low	10 at middle	-8 at highest		
Rodent control	8 at intermittent control	4 at intermittent control	4 at no control	-4 at intermittent control	-7 at intermittent control	
Tower type	7 at tubular	8 at vertical axis	12 at vertical axis	-5 at tubular	-7 at tubular	26 at vertical axis
Slope aspect	5 on North/ NW 4 on South/SE	8 on East/NE	19 NW to NE	-9 on S/SE		19 on N/NW

Table 8-24. Correspondence between measures of the magnitude and directions of fatalities with independent variables and behaviors with independent variables for American kestrels

	Percent of total of dependent variable attributed to accompanying category or level of wind turbine					
Variable	**Fatalities**	**Perching time**	**Flight time**	**Flight height**	**Flight distance from turbines**	**Dangerous flight time**
Elevation	12 at highest 5 at lowest	8 at highest	32 at highest	-10 at lowest	13 at highest	33 at highest
Rotor-swept area/second	10 at highest rates	4 at low-moderate rates	18 at highest rates	-14 at moderate high rates	-6 at low-moderate rates	15 at highest 14 at lowest
Physical relief	10 on ridgeline 5 on ridge crest	5 on ridge crest 3 on saddle		-6 on ridge crest		

8.4.5 Wind Turbine Perceptions by Birds

As was the case for the NREL study (Smallwood and Thelander, in review), we found evidence that raptors recognize wind turbines as dangerous and that they take measures to avoid wind turbines, such as attempting to fly around the turbines at the ends of strings, and flying lower to the ground or higher to the ground around the end turbines (to name two examples), depending on the species. Nevertheless, dangerous flights are still made, and these are made disproportionately more often under certain conditions. Also, raptors perform disproportionately more of their perching and flying within 50 m of wind turbines, despite the evidence that they generally attempt to avoid wind turbines while perching and flying. Raptors apparently are drawn to the vicinity of wind turbines while also minimizing their nearness to busier turbine fields and turbines with faster tip speeds and larger rotor diameters. Also, red-tailed hawks and American kestrels appear to attempt to avoid end-of-row wind turbines, which happen to be where they get killed more often.

Raptors were more likely to fly close to wind turbines with slower-moving rotor blades and mounted on tubular towers, as well as to vertical axis turbines. They also were more likely to fly close by wind turbines that are more widely spaced apart.

These results indicate that wind turbines may be able to reduce mortality if they were more closely spaced and if they appeared "busier" on the landscape. They could also be flanked by inert structures that raptors can see and attempt to avoid by flying wide around them, thereby reducing the frequency of flying into the rotor zone of the end-of-row turbines.

In conclusion, behavior observation studies and studies of bird activity levels should precede the installation of wind turbines at new wind farms. Bird flight patterns could help guide the design of the wind farm, including the appropriate heights of wind turbines, the spatial arrangement of wind turbines, and the specific locations of wind turbines relative to the topography and land use practices. Additionally, pre-project behavior observation studies enable the measurement of the contributions of species susceptibility and project-induced vulnerability in leading to impacts after the wind farm is installed and operating. Our study supported the findings of Smallwood and Thelander (in review) that bird behaviors were likely changed by the ongoing activities of the wind farm, as exemplified by the apparent strong attraction of most bird species for the vicinity of wind turbines. However, the only way to know for certain whether birds are attracted to the vicinity of wind turbines is to perform behavior studies with a before-after control impact (BACI) design.

Typical of scientific investigations, ours left many new questions and unsatisfactory answers, even though much was learned. To satisfactorily answer many of the remaining questions, future behavioral studies at wind energy generating facilities will require much greater sampling effort and therefore much more funding. It will also require a BACI design.

One promising technology that could to be applied to the APWRA and other wind energy facilities is radar sampling with three-dimensional resolution. Radar would allow for more data to be collected over the study period and generate data representative of nighttime conditions, as well—a representation that we did not address. Radar, in combination with point counts, could inform us more effectively about the flight patterns of various groups of species in the APWRA and at other

new wind farms, and information of the new wind turbines could be combined to forecast bird impacts under various wind farm design scenarios.

8.4.6 Flight Heights Relative to Existing and Proposed Future Rotor Planes

One of the most useful results of our behavior study may be the comparison of the frequencies of flight height above ground to the rotor planes of existing wind turbines, and what may imply for the rotor plane heights of wind turbines proposed for the APWRA repowering program. These comparisons reveal that for raptors most flights occur at heights that are within the rotor planes of currently operating wind turbines. This strongly suggests that the rotor plane heights contribute substantially to raptor mortality.

The heights of rotor blades on turbines proposed for repowering the APWRA overlap considerably with the rotor plane heights on wind turbines currently operating in the APWRA. While fewer raptor flights would be made within the proposed rotor plane heights, the difference would probably fail to substantially reduce raptor mortality. The wind turbines with the tallest towers being proposed for repowering will, however, operate at heights well above the majority of raptor flights we recorded. This difference in flight frequency at the tallest proposed rotor height is substantial and may have significant implications.

Flight behavior data we collected indicate that the frequency that golden eagles will fly at the tallest rotor plane heights being proposed for repowering is 50% less than the frequency they currently fly within the rotor plane heights of the smaller turbines now in use. American kestrels will fly at the heights of the tallest rotor plane only 15% as frequently as they do at the heights of the current rotor planes. Overall, raptors would fly at the heights of the proposed tallest wind turbines at only 21% of the frequency as they fly at the heights of the current rotor planes. If the frequency of raptor flights at rotor plane heights contributes significantly to raptor mortality, then a potential ~80% reduction in frequency of flights at rotor plane height (assuming the tallest turbines being proposed are installed) could reduce raptor mortality significantly. This can be achieved if the new towers used for repowering have rotor planes greater than 29 m from the ground.

Combining rigorous turbine siting guidelines, based on research findings presented herein, with the installation of turbines with rotor planes greater than 29 m above the ground may result in a substantial reduction in raptor mortality.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

This report summarizes the findings of a four-year research effort involving more than 4,000 wind turbines, and aimed at better understanding bird mortality at the world's largest wind farm, the Altamont Pass Wind Resource Area. Yet, as with most research efforts, we finished with many questions remaining unanswered about the factors associated with fatalities at wind turbines, and about the biological significance of the mortality we estimated.

Additional research that adjusts its methodology based on what we have learned, and that addresses the questions left unanswered, may one day result in additional solutions to the perplexing problems facing the wind industry in the APWRA. We trust that the findings presented here are sufficient for the wind industry to begin implementing a series of mitigation measures that will more effectively avoid, reduce, and offset impacts caused by existing and future wind turbines in the APWRA. We believe that the results presented here provide the foundation for the aggressive implementation of management strategies that appear most likely to substantially reduce bird mortality. Lastly, it is our hope that our recommendations will help to reduce bird morality at wind farms throughout the world, and help to avoid similar situations in the future.

9.1 ASSESSMENT AND RECOMMENDATION OF MITIGATION MEASURES

The most recent phase of our study has allowed us to test some rudimentary fatality reduction experiments that had begun in the APWRA. For example, we were able to relate mortality to blade-painting schemes which were implemented in the past (and which still exist) and to perch deterrents on lattice towers. Additionally, we were able to further test the effectiveness of the current rodent control program. What follows are our recommended mitigation measures, or suggested changes for turbine management/operations. These are not provided in any order of priority. For that recommendation, see 9-2.0 below.

- No. 1. Replace the WRRS with scientifically defensible monitoring program

The Wildlife Reporting and Response System (WRRS) relies on volunteer reporting of bird carcasses discovered by turbine workers during routine but unsystematic maintenance or repair services, and is therefore not a scientific sampling program. The WRRS documents only 18%–26% of the red-tailed hawk fatalities our monitoring documented, and only 24%–41% of the golden eagles, and these are the two largest and most easily found species. The WRRS is not only inadequate as a monitoring program for golden eagle and red-tailed hawk mortality, but is very unlikely to detect more than a tiny fraction of the burrowing owl fatalities or the fatalities of many smaller-bodied species of bird. The WRRS should be replaced by a scientifically defensible monitoring program performed by independent, trained professionals.

Results of the monitoring program should be regularly published in outlets readily accessible to the public and in standardized formats. Reports should include the identification of the personnel involved, their qualifications for performing the work, detailed descriptions of methods used, dates of site visits, analytical methods, and results presented in a consistent fashion. The Energy Commission's documents page on its Web site (http://www.energy.ca.gov/sitingcases/alphabetical.html) is a good example of a standardized approach for presenting environmental documentation related to the site licensing of power plants. A similar page could be developed for the reporting of mortality monitoring results in the APWRA and other wind resource areas.

- No. 2. Cease the rodent control program

Our evidence indicates that rodent control has not changed bird behaviors in the APWRA in the manners we assume were expected. Raptors have not abandoned the areas subjected to rodent control, and substantial numbers of them continue to be killed by wind turbines. We suggest that the rodent control program be terminated because it is ineffective, and because of the adverse effects the program is likely having on special-status species such as burrowing owl, California red-legged frog, California tiger salamander, and San Joaquin kit fox.

Even if the rodent control program managed to eradicate rodents, raptors would likely continue to visit the APWRA because it is a migratory route and because birds are known to recognize prey-bearing habitat by gestalt rather than by enumeration and inventory methods. And even if the program managed to displace raptors after eradicating rodents (assuming that they could eradicate rodents), this displacement necessarily would result in a net loss of raptors from the remaining habitat. Populations would be reduced through displacement because these species cannot be crowded into smaller spaces. The social behaviors of these species are rather inflexible regarding home range size and plural occupancy of territories.

Should the wind turbine owners seek to continue the rodent control program, we recommend an environmental assessment pursuant to California Environmental Quality Act (CEQA) requirements, to fully examine the potential effects to special-status species.

- No. 3. Alter habitat to reduce raptor foraging near wind turbines

It may be possible to alter habitat conditions within 50 m of wind turbines in order to reduce prey vulnerability to raptor predation near wind turbines, thereby reducing raptor use of these areas as well as mortality. Habitat alterations other than the use of rodenticides remain untested in the APWRA. However, the U.S. Fish and Wildlife Service expressed some skepticism that such localized habitat alterations would shift raptor foraging from near the vicinity of wind turbines to farther away, and the Service might be correct. Still, it might be worth studying cattle exclusion around some select wind turbines, allowing the grass to grow tall, and encouraging fossorial animals at locations farther from the wind turbines.

- No. 3a. Reduce and minimize vertical and lateral edge

Cuts into hillsides for wind turbine lay-down areas and access roads (e.g., Photo 9-1) might be re-contoured in order to reduce the vertical edge in the landscape that is preferred by pocket gophers and some other species of small mammal. Also, access roads should be minimized, along with buried pipelines near wind turbines. This measure should be applied wherever it is needed across the APWRA.

Photo 9-1. Vertical edge is often abundant along the string of wind turbines, which attracts certain small mammals and likely attracts foraging raptors.

- No. 3b. Move rock piles

Rocks were piled near wind turbines as a mitigation measure for the APWRA (Photo 9-2). These rocks were moved from the laydown areas and piled as cover for prey species of San Joaquin kit fox. The measure worked to harbor prey species of the kit fox, but these same prey species are also targeted by large foraging raptors. Also, burrowing owls use the rock piles as den sites and as perches. Relocating rock piles away from the wind turbines might reduce the mortality of some species, based on results of association analysis performed on fatalities found at the 1,536 wind turbines that were searched longest. However, we believe this measure would not substantially reduce mortality by itself. Moving the artificial rock piles to locations farthest from wind turbines (e.g., to the bottoms of ravines or the lower slopes) would cost little, so this measure ought to be pursued.

Photo 9-2. Rocks gathered from wind turbine laydown areas and piled nearby.

- No. 3c. Exclude cattle from around wind turbines

Cattle congregate around wind turbines, perhaps due to the shade or wind-breaks afforded by the towers (Photos 9-3 and 9-4). This concentration of cattle activity also concentrates the distribution of cattle pats (Photo 9-5), which are fed upon by hundreds of grasshoppers per pat and serve as a principal base of a food web attracting birds to the near vicinity of wind turbines. It might be possible to encourage this food web to proliferate more distant from the wind turbines by fencing off the area immediately surrounding the wind turbines and excluding cattle from that area. A 50-m exclusion area might suffice; however, the fence may attract burrowing owls, which readily perch on cattle fences where they are available. It may be necessary to fence cattle out of groups of wind turbine strings, thereby minimizing the length of fencing occurring relatively near to wind turbines.

Photo 9-3. Cattle routinely congregate in the shade of wind towers on hot days.

Photo 9-4. Cattle congregate around wind turbine for shade and foraging, and they reduce grass height and expose small mammals to foraging raptors.

Photo 9-5. Cattle pats abound where cattle congregate near the shadow of a wind turbine. These pats attract numerous grasshoppers, which in turn attracts raptors that feed on the grasshoppers close to turbine blades.

- No. 3d. Retrofit turbine-tower pads to prevent burrowing by small mammals

Small mammals often burrow under the concrete pads of the wind turbines and the junction boxes (Photo 9-6). It might be helpful to apply gravel to the perimeters of these concrete pads as a means to discourage such under-burrowing. Also, it might help to apply fill to pads when gaps form under them due to long-term burrowing or other forms of erosion.

A more practical solution to this problem in the long-term is to rely on wind towers that do not require concrete pads. Many of the wind turbines in the APWRA do not require concrete pads and therefore do not experience under-burrowing. As the repowering program proceeds, perhaps new wind turbines could be installed without concrete pads.

Photo 9-6. Burrows appear under concrete pads in the APWRA, and these might attract foraging raptors into close proximity of wind turbines.

- No. 4. Perch Guards

The results of our behavior study suggest that perching on wind turbines and their towers is likely not the problem that it was portrayed in the past. Birds are disproportionately killed by wind turbines mounted on tubular towers, which provide fewer perch sites than do lattice towers. Also, we found that birds carefully perched on turbines/towers while wind turbines were not operating

(Photos 9-7 to 9-10) or when broken (Photo 9-9). For these reasons, we do not believe perch guards will substantially reduce mortality. Additionally, we tested mortality against whether perch guards were implemented in the APWRA, and found that mortality was no different for most species and even a little greater for a couple of raptor species.

We will point out, also, that the perch guards implemented thus far in the APWRA are unlikely to thwart perching on the wind turbines. Chicken wire was erected atop horizontal supports of some lattice towers, but this wire loses its integrity relatively quickly and falls apart (Photo 9-11). Also, raptors are perching on the rotors, work platforms and engine housing of wind turbines on both lattice and tubular towers (e.g., Photos 9-7 to 9-10), and the chicken wire cannot prevent perching on these elements when the blades are still (nor does it appear to matter).

Photo 9-7. A golden eagle perches on a lattice tower while the wind turbines of the entire string are not operating.

Photo 9-8. A raptor perches on the work platform while wind turbine is not operating.

Photo 9-9. A raptor perches on the work platform of a tower that is missing its wind turbine, and while the adjacent wind turbines are not operating.

Photo 9-10. Red-tailed hawk perched on tip of wind turbine blade.

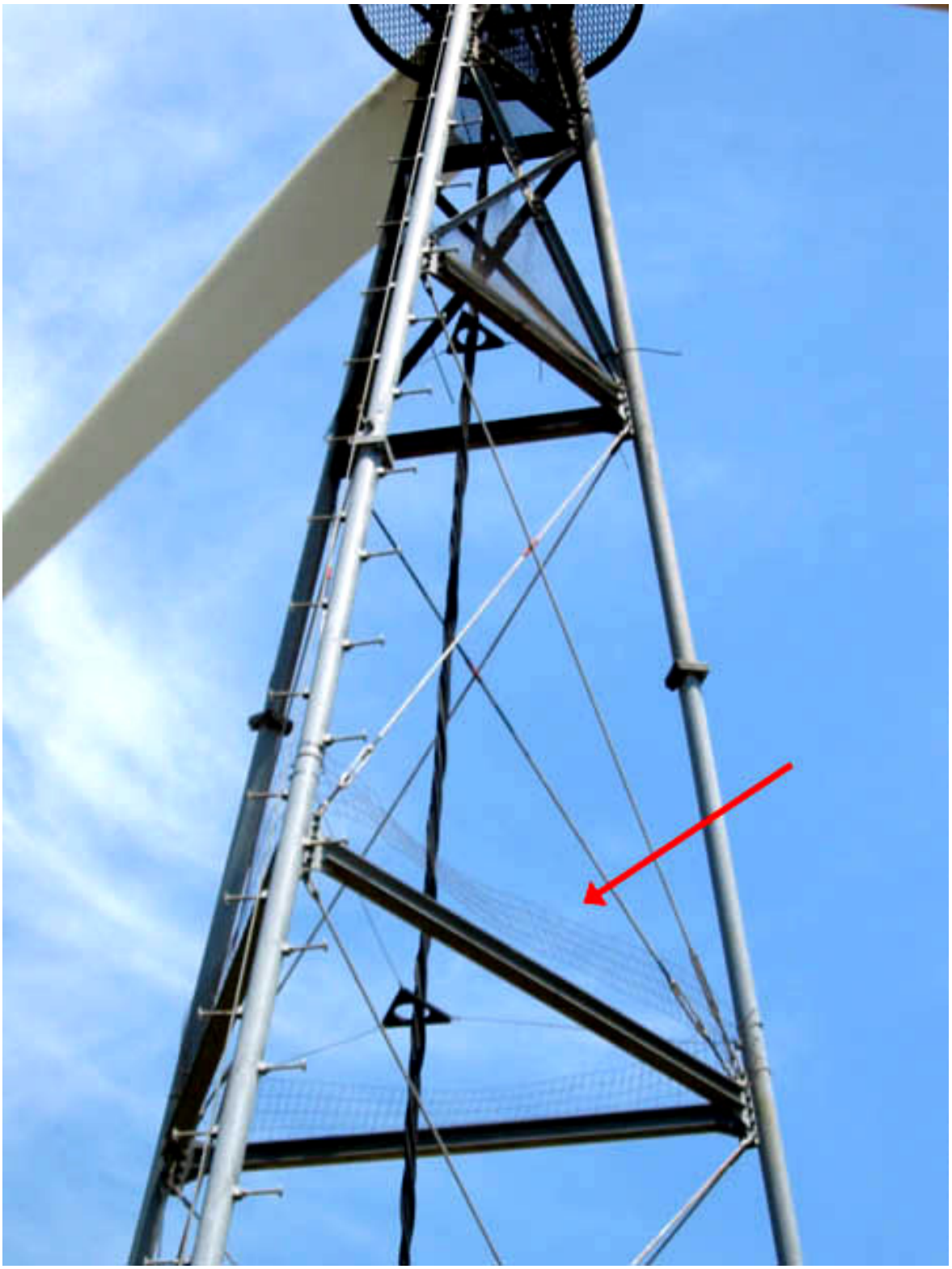


Photo 9-11. Hardware cloth (i.e., chicken wire) used as perch guard on lattice tower.

- No. 5. Install bird flight diverters

Because we found wind turbines at the ends of strings and at the edges of clusters of turbines to kill disproportionately more birds, we hypothesized that a pair of benign pole structures could serve as dummy wind turbines beyond the ends of strings and edges of turbine clusters. These poles could be placed 5 to 10 m apart and just beyond the rotor plane of the wind turbine at the end of a string, and they could extend upward to near the high reach of the turbine's blades (Photo 9-12). The idea is to encourage birds to fly wider around the end of the turbine string, thereby adding distance between the bird's flight path and the operating wind turbines.

Poles serving as flight diverters should be installed without guy wires, because guy wires pose collision hazards to flying birds. They should also be designed to disallow perching. Pointed tops might be one design to achieve this. Coarse wire mesh strung between poles might enhance the barrier effect, though it might also reduce wind reaching the rotor planes of the wind turbines. Another way to achieve the desired effect in some cases is to remove the wind turbine from an existing tower and leave the tower in place.

Photo 9-12. Two poles placed at the end of a turbine row might divert bird flights away from the end turbine, thereby reducing mortality.

- No. 6. Alternative perches

The APWRA now offers birds many perches that were not present prior to construction of the wind turbines. These perches are on thousands of wind turbines and their towers, and on many ancillary structures. We do not believe alternative perches would substantially attract perching birds away from the thousands of perches available already.

- No. 7. Barricade the rotor plane

Many who first learn of the wind turbine-caused bird mortality problem ask why barriers cannot be erected to keep birds from flying into moving blades. Simply put, this measure would be overwhelmingly costly and impractical, and it would likely reduce the wind power that could be generated because any such structure would impede wind flow.

- No. 8. Paint blades using the Hodos et al. scheme

The patented (U.S. Patent No. 6,623,243) blade-painting scheme developed by Hodos et al. (2001) may reduce the distance upon which motion smear is experienced by raptors from ~10 m to ~5 m. Essentially, it involves one blade painted black and two painted white, but achieved cumulatively by precise, evenly distributed painting of black bands on all blades. We cannot predict whether this will work to reduce fatalities. However, it appears to have promise and we recommend that this painting scheme be implemented on an experimental basis, beginning with a selection of wind turbines with the worst fatality records.

- No. 9. Remove derelict and non-operating wind turbines and coordinate timing of operational turbines

We found evidence that suggests raptors are killed disproportionately more often by wind turbines adjacent to broken wind turbines. Possibly, birds often fly wide of broken wind turbines because another raptor is perched on the broken wind turbine. (Recall our results revealed that perching on wind turbines was mostly on wind turbines that were either turned off or broken.) A raptor flying through the rotor zone in which another raptor is perched atop the tower of a broken or missing wind turbine might not notice or see the moving blades of an adjacent wind turbine, subsequently getting struck. Broken or non-operational wind turbines should be fixed, replaced, or removed along with their towers and the gaps created filled with wind turbines moved from other, more dangerous locations, but while not creating gaps from where these relocated turbines are moved.

The relationship between broken wind turbines and raptor mortality, as well as our results on perching behaviors, also suggest that turbine strings are most dangerous when some wind turbines are turned on while others are turned off. Bird mortality might be reduced by coordinating the operations of the wind turbines in a string, so they are either all on or all off. In the APWRA this practice is likely made difficult by the site variation in wind speeds due to a complex topography.

- No. 10. Relocate selected wind turbines

Certain wind turbines kill disproportionately more birds because of where those wind turbines are located. Relocating some wind turbines might substantially reduce bird mortality. For example, wind turbines could be moved out of canyons, and more isolated wind turbines could be moved closer to clusters of other wind turbines. If relocations are pursued, we recommend prioritizing wind turbines that are more isolated and in canyons or on steep slopes, especially those at lower elevations. They could be moved to fill existing gaps in strings of wind turbines, or to replace derelict wind turbines or towers lacking turbines.

- No. 11. Install wind turbine designs beneficial to the APWRA

Based on our findings that raptors appear to avoid operating wind turbines as well as densely packed turbine fields and wind walls, we hypothesize that increasing the busy appearance of a wind farm might discourage many bird species from flying there. We suggested rearranging the APWRA so that gaps are filled and isolated wind turbines are moved into groups of others, but this concept could be taken in a different direction, as well. Another wind turbine design—one that appears busy—might be preferable for use in the APWRA over conventional horizontal- and vertical-axis rotor designs.

Busy turbine designs could be installed in between the larger wind turbines, thereby forming wind walls. These wind walls could be developed on the most prominent ridge crests, where raptor mortality has been disproportionately less than on other landscape features. We predict that such wind walls, covering a smaller and less dangerous portion of the APWRA, could substantially reduce bird mortality.

- No. 12. Install accelerometers to improve turbine operation safety

Researchers and others familiar with the wind turbine-caused mortality problem have frequently suggested shutting down wind turbines during more dangerous times of the year. We found, however, that periods of the year during which birds are most susceptible vary substantially among species. For example, shutting down wind turbines during summer to protect golden eagles will do little to curb the mortality of red-tailed hawk, burrowing owl, and many other species.

Upon further research it might be learned that wind turbine operations during specific times of the day are more hazardous to birds. For example, operations during the night might be more dangerous, or operations during the early morning (this is only speculation on our part, and serves as examples). Precise periods of greatest danger might be ascertained by installing specially designed accelerometers. These devices, properly designed and installed, may be able to detect the precise time of each bird collision. With sufficient data on times and conditions of bird collisions, patterns might emerge that inform manages of opportune times of the day, or year, when temporary shutdowns of certain wind turbines can substantially lessen bird mortality.

- No. 13. Implement the means to effectively monitor each wind turbine's operation

We suspect that the proportion of time the wind turbine operates also relates to the number of bird fatalities occurring at that turbine. The distribution of times each wind turbine operates throughout the day and throughout the year also likely influences bird mortality specific to each turbine. However, we were unable to measure these factors because we were unable to produce adequate data on individual wind turbine operations. By installing the appropriate equipment and the appropriate database structure and software, and by employing qualified administrators of the system, the information gained would contribute substantially toward more resolute and therefore reliable estimates of future mortality. Such an improved monitoring system of wind turbine operations would also enable analysts to quantify associations between mortality and other measured factors more reliably, because the system would then account for much of the current noise in the data set produced by differential operations of wind turbines in the APWRA. We suspect that such a system would also lead to more cost-effective decisions in how the APWRA is managed.

- No. 14. Retrofit hazardous electrical distribution poles

Birds continue to be electrocuted in the APWRA, so all APLIC non-compliant poles should be identified and retrofitted as soon as possible.

- No. 15. Repower using turbines with high rotor planes

Flight heights recorded for raptors indicate that taller rotor planes may reduce mortality. We recommend that wind turbine designs used for repowering should have rotor planes with the lowest reach no lower than 29 meters above ground.

- No. 16. Acquire off-site conservation easements

Because the bird mortality caused by wind turbines in the APWRA will likely never be reduced to zero, the wind industry ought to provide compensatory mitigation. The purchase of conservation easements on lands surrounding the APWRA would contribute to raptor conservation because the Altamont Hills and surrounding areas are under intense pressure to convert to homes, industrial facilities, and a highway. Conservation easements should include conditions, such as no rodent control, and they should permanently protect the land from conversions to uses incompatible with its use as wildlife habitat. The appropriate spatial area to be put in conservation easements could be arrived at by first estimating the species-specific mortalities that will remain after other mitigation measures are implemented. Second, the spatial areas typically used by the numbers of birds killed could by tallied and multiplied by a factor appropriate to the continuing annual loss of that number of birds. That is, a mitigation ratio could be derived that accounts for the APWRA's performance as an ecological sink.

The approach of Smallwood (2001) could be used to estimate the appropriate area needed to protect the number of individual birds of a particular species that will be taken in the APWRA following

implementation of other mitigation measures. We recommend that the estimated number of birds killed over a ten-year period be used as the input term to Smallwood's (2001) estimator of the area need to support that number of individuals killed. For example, if it is estimated that 300 golden eagles will be killed over the next ten years following the implementation of mitigation measures, then the area needed to support 300 golden eagles should be protected with conservation easements. We cannot say what that area would be until we collected a sufficient number of population estimates for reliable application of the Smallwood (2001) method.

It would be reasonable to assume that the area protected for the largest and longest-lived raptor species, i.e., golden eagle, would sufficiently protect similar proportions of other raptor species such as red-tailed hawk, American kestrel, and burrowing owl (Cousins 1990).

9.2 IMPLEMENT MEASURES TO REDUCE IMPACTS

There are two approaches available to implement mitigation measures that are intended to reduce impacts to birds in the APWRA. Each has its own merits. One approach is experimental and the other is universal in implementation.

In the experimental approach, a particular mitigation measure is applied only to a sample of wind turbines, and the rest of the wind turbines are treated as experimental controls. This approach seeks to manipulate the variation in fatalities in order to attribute statistical confidence to any measured change in mortality due to the mitigation measure. A positive aspect of this approach is the accumulation of scientific certainty in the effectiveness of the mitigation measure as sample sizes of fatalities increase. This approach hedges expenditures against a potentially ineffective mitigation measure, or against one that causes unforeseen additional impacts. Should the experiment reveal the measure to be ineffective, then the measure can be withdrawn with less financial loss than would be realized by a universal implementation of the measure. Another positive aspect of this approach is that a withdrawal of an ineffective measure allows for the mitigation funds to be redirected toward a potentially more effective measure. A negative aspect of this approach is the unabated mortality that will take place amongst wind turbines treated as experimental controls. If this unabated mortality is unacceptable, then a different approach is warranted.

Universal implementation of a treatment is typical of conservation applications, such as endangered species habitat restoration. It is typical of situations where the resource managers cannot afford the luxury of experimental manipulations when enough is known to apply a remedy with a reasonable likelihood of success. Sometimes it is important to act universally in order to stem a dire outcome, and at times like these experimentation might hasten or contribute to the dire outcome. In this case the public and the regulatory agencies must decide whether knowingly allowing continued mortality for the sake of experimentation is warranted. It may be that enough is known about the likely effectiveness of certain mitigation measures to warrant their universal implementation. Perhaps certain other measures ought to be applied in an experimental fashion.

The context of this decision on approach is also important. In the case of the APWRA, a decade of research has provided an empirical foundation of mortality patterns against which future mortality patterns can be compared in the context of a mensurative experiment (*sensu* Hurlbert 1984), even if

certain mitigation measures are universally applied. Associations between fatalities and a suite of factors in the measured set of wind turbines can be compared to similarly quantified future associations in order to assess the effectiveness of a universally applied mitigation measure. For example, it should be possible to detect the effectiveness of cessation of rodent control across the entire APWRA because we currently have measured associations between mortality and levels of rodent control, including where rodent control has not been implemented. In essence, we have the foundation of a before-after, control-impact (BACI) experimental design for ceasing rodent control. Even universal applications of certain mitigation measures can be studied in the context of an experiment.

The implementation of multiple mitigation measures will likely change the attributes of wind turbines that continue to operate in the same locations. For example, the removal of isolated wind turbines from canyons to fill gaps in wind turbine strings on ridge crests would fundamentally change the attributes of the wind turbines moved, as well as the attributes of their new neighbor wind turbines that formerly were positioned next to a gap. As the attributes of wind turbines change due to the implementation of multiple mitigation measures, our predictions of the wind turbines' relative threat to birds will also change. For this reason we do not recommend over-reliance on our indicators of relative threat (Chapter 7) for selecting wind turbines as priority targets of mitigation. Our indicators of relative threat should be useful as one of multiple tools in developing a management plan for the APWRA. The principal tool will be familiarity with the relationships described in this report, as well as with the shortcomings and strengths of the supporting study.

It is important to also recognize that the APWRA is composed of thousands of outdated wind turbines, machines that are not going to be installed elsewhere in the future. Certain mitigation measures that prove effective in the APWRA might be relevant to other wind farms, whereas others may be irrelevant to other wind farms or new wind turbines to be installed in the APWRA. Additional insights into patterns of mortality caused by existing wind turbines in the APWRA largely pertain to the remaining period of operations of these wind turbines in the APWRA, which may be relatively short. Experiments with broader implications to wind energy generation might be more effectively performed at wind farms with modern wind turbines or perhaps in the APWRA while modern wind turbines are installed during the repowering process.

We recommend that the following measures be withdrawn from further consideration as mitigation for bird fatalities in the APWRA.

- Installing perch Guards
- Providing alternative perches
- Barricading the rotor planes of turbines
- Rodent control
- The use of WRRS as a monitoring program

We suggest that the following measures be considered for implementation throughout the APWRA.

- Replace the WRRS monitoring approach with a more scientifically defensible monitoring program (see above)
- Cease the rodent control program (see above)
- Move rock piles away from wind turbines
- Reduce vertical and lateral edge in slope cuts and nearby roads
- Retrofit tower pads to prevent under-burrowing by small mammals
- Install flight diverters
- Remove broken and non-operating wind turbines
- Relocate selected, highly dangerous wind turbines
- Install wind turbine designs beneficial to the APWRA bird fatality issue
- Implement the means to effectively monitor each wind turbine's output
- Retrofit, using APLIC guidelines, noncompliant power poles
- Acquire conservation easements offsite

The following measures would be appropriately applied experimentally due to the degree of uncertainty in their likely effectiveness. However, these measures could also be applied universally, but with the understanding that they might not substantially reduce bird mortality.

- Exclude cattle from wind turbines
- Install flight diverters
- Paint blades using Hodos et al. scheme
- Experiment with devices that will identify when to operate problem wind turbines with the least effect on birds.

We recommend implementing mitigation measures generally in the following order of priority.

Priority	***Mitigation Measure***
(1)	• Cease rodent control program
	• Acquire conservation easements offsite
	• Replace the WRRS with a scientifically defensible monitoring program
	• Install flight diverters
	• Paint blades using Hodos scheme
	• Remove broken and non-operating wind turbines
	• Relocate wind turbines
	• Install wind turbine designs appropriate to the APWRA
	• Retrofit APLIC non-compliant power poles
(2)	• Reduce vertical and lateral edge
	• Move rock piles
	• Exclude cattle from wind turbines
	• Retrofit tower pads to prevent under-burrowing by small mammals
	• Install accelerometers to learn when to shutdown wind turbines
	• Implement the means to effectively monitor each wind turbine's operation

We recommend that scientifically defensible monitoring be conducted by qualified, independent scientists in concert with the implementation of any and all other mitigation measures. Also, thresholds of success should be decided upon prior to implementation of the monitoring program so that it is understood by all parties what level of mortality reduction is expected. Alternative prescriptions should also be decided upon so that if the success thresholds are not met it is understood what will happen next. One prescription could include taking certain turbines out of production in some portion of the APWRA, and another could be universally applying a measure that proves useful in limited, experimental trials.

9.3 FUTURE RESEARCH NEEDS FOR IMPROVED PERFORMANCE OF THE PREDICTIVE MODEL

We mapped and characterized 4,074 wind turbines, but we did not map or characterize 1,326 others in the APWRA. Therefore, we were unable to extend our model predictions to these wind turbines. It would be beneficial to return to the APWRA to complete our database of wind turbines so that mortality predictions could be extended across the entire wind farm. This would be especially useful if turbine siting or repowering occurs in areas where we collected no data.

More thorough mapping of animal burrows would be helpful, whereby we map all animal burrow systems within 90 m of many more of the wind turbine strings in the APWRA. This increased level of effort would be most productive in areas where rodent control is not implemented, such as in the northwestern portion of the APWRA.

Another small mammal burrow-system mapping effort should be performed at locations in the APWRA where there are no wind turbines but where wind turbines could be sited based on physical relief. This mapping effort would enable a comparison of natural fossorial animal distributions and those that occur around wind turbines.

9.4 WHAT HAVE WE LEARNED?

The research findings presented in this report offer insights, and hopefully solutions, to some long-standing and perplexing issues that confront the wind industry in the Altamont Pass Wind Resource Area. We have learned that these issues are complex and many of them may never be resolved. Research began in the APWRA with the goal of learning about the scope of the problem and searches for dead birds were the main focus. Studies soon moved toward learning more about the underlying causes of these fatalities. This research led us next to learn more about the complex ecological relationships that govern bird use and behavior, and how those translate into bird fatalities. We eventually honed the focus of the research into learning how raptors and their prey distribute themselves on the landscape, and how their interactions affect turbine-caused mortality. Lastly, we attempted to integrate these fragments of information into a coherent and useful predictive model. The purpose of this model is to provide a tool that will direct operational changes in the APWRA to achieve a reduction in fatalities. Eventually, as the next generation of fewer but larger turbines is installed, this same information will hopefully contribute to turbine siting criteria that will minimize bird mortality, at least for certain species.

As with most studies of this type and scale, we set out to achieve some specific objectives. We believe we met them, but in the process we learned that there are many more new questions that were uncovered and remain unanswered. Our research has left the door open for more research, but more importantly, for a next step in the process, to effectively reduce fatalities in a timely manner and with the least cost to the wind industry.

Through this research we have learned that more birds are being killed by the wind turbines in the APWRA than the habitat within its boundaries can support, a situation which many define as an ecological sink. For example, Hunt (2002) monitored about 60 pairs of golden eagles in his 9,000

km^2 study area, which overlapped the APWRA. Those 60 pairs translate to 0.013 golden eagles per km^2. Extrapolating Hunt's reported density for golden eagles to the 160-km^2 APWRA, we can expect its habitat capacity to support the equivalent to two golden eagles, or one pair. Therefore, our estimated annual death of 75 to 116 golden eagles far exceeds the APWRA's habitat capacity based on a regional comparison and, therefore, it is reasonable to conclude that the APWRA is an ecological sink for golden eagles. This is probably true for other bird species as well, especially some raptors.

Every year many golden eagles enter the APWRA but they do not leave. Many of these are subadults and 'floaters' (see Hunt 1998, Hunt 2002). Many originated in other portions of the species' geographic range, and not necessarily from the APWRA region. The annual loss of these important age classes is a cumulative impact attributable to the APWRA, but the biological significance of these losses is unknown.

As with golden eagles, the APWRA is likely an ecological sink for many other bird species, but again with unknown consequences to the species or the ecosystems of which they are a part. Given that the biological significance of these impacts are unknown, it is prudent, and consistent with state and federal regulatory policy, to consider the biological impacts of the APWRA to be significant and to require substantial measures to avoid, minimize, or otherwise compensate to offset these impacts.

In our study we considered multiple factors that may potentially influence bird mortality caused by wind turbines in the APWRA. Some of the factors we addressed were added to our study as it progressed. The more we studied the situation, the more we realized the complexity of the ecological inter-relationships that were affecting how and why certain species collide with wind turbines.

In addition to the ecological complexity of the APWRA, our study design was constrained by its post-hoc nature. We had little to no control over the replication and interspersion of treatments, including control treatments. Thus, our results were prone to inflation of measured effects and to confounding. We also had little control over the application of sampling effort across the APWRA, and so the differential sampling effort we applied precluded multivariate statistical methods, which would have been useful for managing the shared variation among measured variables. These factors required us to rely on univariate statistical tests. Our experience in performing this study taught us that the use of a before-after, control-impact (BACI) design will be critical to reducing fatalities in the near future, and to ensure that long term repowering efforts in the APWRA will result in significantly fewer bird kills.

Despite our experimental design limitations, we still learned enough about wind turbine-caused bird fatalities to recommend a series of useful mitigation measures. Most of these recommended mitigation measures assume that: (1) universal rather than experimental implementation is preferable, and (2) the current mix of wind turbines will be operating for an extended period and that repowering is at least 3-5 years in the future.

If the APWRA were repowered within the next 3 - 5 years, then experimental testing of mitigation measures would reduce mortality only where mitigation treatments were applied as tests. No

progress at reducing mortality would occur at those wind turbines used as control treatments, or those not included in the experiment(s). Furthermore, the outcome of some experiment(s) may not apply to the repowered APWRA since there will be significant differences in wind turbine hardware designs and the wind farm configuration. The desired effects that could result from implementing our recommended mitigation measures are dependent upon their rapid implementation over most, if not all, of the APWRA.

If some of our mitigation measures are tested experimentally in the APWRA, then we recommend that the experiment(s) include an adequate sample size of wind turbines and a sufficiently long duration to detect treatment differences, as well as appropriate replication and interspersion of treatments. The appropriate sample size of wind turbines should be estimated by use of our data applied to power analysis. We determined that reliable estimates of mortality require at least three years of monitoring of bird carcasses under and around wind turbines. Therefore, three years should be the minimum duration of any experiment(s) of mitigation measures in the APWRA. An experiment lasting less than three years, and including only a few hundred wind turbines per treatment, would likely generate unreliable results, as would a pseudoreplicated experimental design. Mitigation experiments performed on a small portion of a nearly obsolete wind farm is not an effective solution to the bird mortality problem.

We predict that the near-universal implementation of all our recommended mitigation measures may reduce mortality by 20 to 40%, or perhaps as much as 50% if the mitigation measures act synergistically. These levels of mortality reduction may be unacceptable to some since the remaining level of mortality, which would be seemingly unavoidable, would represent continued violation of the federal Migratory Bird Treaty Act, plus other state and federal environmental laws and regulations. The environmental consequences of such long-term cumulative impacts to birds remain undetermined.

If avoidance and minimization techniques cannot entirely offset the number of bird kills, then compensatory mitigation may be warranted to offset the portion of unavoidable impacts. This compensatory mitigation typically involves the purchase and conservation of habitat, the amount of which is reached through negotiations with the appropriate agencies. Compensatory mitigation should be negotiated and implemented sooner than later because the impacts of the APWRA are on-going, as is habitat destruction due to other human activities throughout the region.

Potentially, the most substantial and the quickest means of reducing and minimizing wind turbine-caused bird mortality, short of decommissioning the APWRA, may be repowering the APWRA with fewer wind turbines mounted on taller towers and with larger individual output capacities. This is technically feasible given recent improvements in turbine design. Our flight height data indicate that the repowered APWRA would kill many fewer raptors than the current APWRA, especially if the repowered APWRA included using only the tallest proposed towers.

Turbines with blades that extend no closer to the ground than 29 m would sweep a portion of the sky that is visited rarely by American kestrels, perhaps never by burrowing owls, on far fewer occasions by red-tailed hawks, and about half as often by golden eagles. We believe that serious consideration should be given to wind turbine models and tower designs that significantly raise the rotor planes in the APWRA. Coupled with this consideration, a carefully designed new APWRA,

in which wind turbines are sited on the portions of the landscape that were associated least with raptor fatalities, will likely result in more reduction and minimization of bird impacts than will the implementation of our palette of proposed mitigation measures and the continued operation of the existing turbines in the APWRA.

If a repowered APWRA is pursued, then an appropriate BACI monitoring design should be added to the careful siting of sufficiently tall wind turbines. At least one year of scientifically defensible behavior observations should precede wind turbine installation, both where the wind turbines are to be installed as well as at locations with similar conditions and that are to be used as experimental control sites. Pre- and post-project carcass searches should also be performed in order to reliably estimate the impacts of the repowered APWRA. Also, rodents and lagomorphs should be sampled and mapped prior to and following the installation of the new wind turbines, so that ecological changes can be factored into analyses of the mortality and behavior monitoring data. Future study designs should closely follow the protocols established in this report to allow for a reliable BACI experiment with comparable results that are necessary for robust statistical analyses.

We are optimistic that bird mortality can be reduced substantially if the wind turbine owners/operators implement most, if not all, of the recommended mitigation measures over much, if not all, of the APWRA. We have learned enough to develop an aggressive, practical, and cost effective implementation plan. We believe that thoughtful repowering of the APWRA in the long term offers the greatest potential for reducing bird mortality. But until that occurs, this report offers the means to reduce bird mortality while the existing turbines continue to operate.

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APPENDIX A

MEASURING IMPACTS TO BIRDS CAUSED BY WIND TURBINES

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1.0 INTRODUCTION

Differential composition of wind turbines at wind energy generating facilities (e.g., the number of turbines installed, differences in height, energy output, rotor diameter, turbine manufacturer, and tower type) is a source of confusion when comparing bird mortality within and among wind energy generating facilities. The standard measurement of mortality currently being used is the number of fatalities per wind turbine per year (Anderson et al. 1999). This metric has little meaning to those lacking experience with bird mortality at wind energy generating facilities. More importantly, it has lost much of its usefulness for comparing the effects of wind energy generating facilities as more facilities have been installed because the newer wind turbines are much larger than the older ones and each sweeps a much larger area of the sky.

We propose that bird mortality at wind energy generating facilities and other energy generating facilities should be reported in the future as the number of fatalities/megawatt (MW)/year, where MW is the amount of electrical energy generated by the facility that was sampled for bird fatalities. Where the actual energy generated cannot be determined, MW would be based on the rated output of the sampled wind turbines. This measure of mortality would be applicable to other types of energy generating facilities, thus facilitating comparisons between various sources of energy generation (e.g., see Erickson et al. 2001). Replacing the number of wind turbines with MW in the mortality measure will facilitate consumer-oriented measurements, such as the number of fatalities/household/year. Also, it would allow the number and composition of wind turbines to be used as predictor variables that can then be related to bird mortality.

2.0 METHODS

The field methods and most data management and analysis methods we used are described in Chapter 3, *Bird Mortality in the Altamont Pass Wind Resource Area*.

We divided the number of recent wind turbine-caused fatalities (i.e., < 90 days since death) in the APWRA by: (1) the number of wind turbines composing any particular turbine string, and (2) the rated generation output in megawatts of the turbines in the string. Each of these ratios was then divided by the span of years during which carcass searches were performed. Ninety days was added to all year spans in order to include the 90 days preceding the initiation of the searches on each string, during which fresh carcasses could have accumulated. The metrics generated were the number of fatalities/turbine/year and the number of fatalities/MW/year. These two metrics were then compared to each other using scatterplots and linear regression analysis to reveal how they related to each other.

3.0 RESULTS

Bird mortality caused by wind turbines can be measured on a per-megawatt or per-turbine basis, with nearly the same precision. However, the relationship between the number of fatalities per MW and the number of fatalities per wind turbine is a function of the size of the generating capacity of the wind turbine(s) (Figures A1 and A2). One measurement can be derived directly from the other if the analyst knows the composition of the models and generating capacity of the wind turbines making up the sample.

The number of fatalities per wind turbine can be misleading when the sample of wind turbines includes turbines built by different manufacturers that generate different amounts of energy, or have different rotor-swept areas (RSA) due to differences in blade length. Also, mortality expressed in terms of MW relates more precisely to mortality in terms of the windswept area of the turbine string (sum of the RSAs among turbines in the string) (Figure A3A) than mortality expressed in terms of the number of wind turbines (Figure A3B).

Assume a comparison between two wind energy generating facilities of equal power generation. One facility is composed of ten 400-kW wind turbines. The other facility is composed of 100 40-kW turbines. In the wind farm composed of the larger turbines, 10 dead birds found in one year will result in a calculated mortality of one death/wind turbine/year. In the wind farm composed of smaller turbines, 10 dead birds result in a calculated mortality of 0.1 deaths/wind turbine/year. In this comparison the mortality will appear greater at the wind farm with larger turbines, based on the number of wind turbines in the facility. However, mortality would appear equal between the two sites if it were measured as the number of deaths/MW/year; that is, mortality would be calculated as 2.5 deaths/MW/year at either site.

Figure A1 illustrates that the metric based on deaths/wind turbine/year is more sensitive to changes in number of fatalities as the component wind turbines' rated power generation increases. This is true, if one assumes that fewer but larger wind turbines are installed in a given wind farm. Conversely, deaths/MW/year is more sensitive to changes in the number of fatalities as the component wind turbines' rated power generation lessens, assuming that more of these smaller wind turbines would be deployed in a wind farm to generate an equivalent total output. In the APWRA, it is likely that smaller turbines will be replaced with fewer, larger turbines. This process of replacing older equipment with newer models is termed "repowering."

Based on our data from the APWRA put to multiple regression analysis, the number of fatalities/wind turbine/year accounted for a larger proportion of the regression sum of squares of bird mortality than did the number of fatalities/MW/year (Table A1), which suggests that the former measure of mortality is more efficient than the latter. In one of these regressions, we entered MW as a predictor variable first and the number of wind turbines in the sample second. In the other, we entered the number of wind turbines first and the MW second. Entering the number of MW first into the regression model left 33%

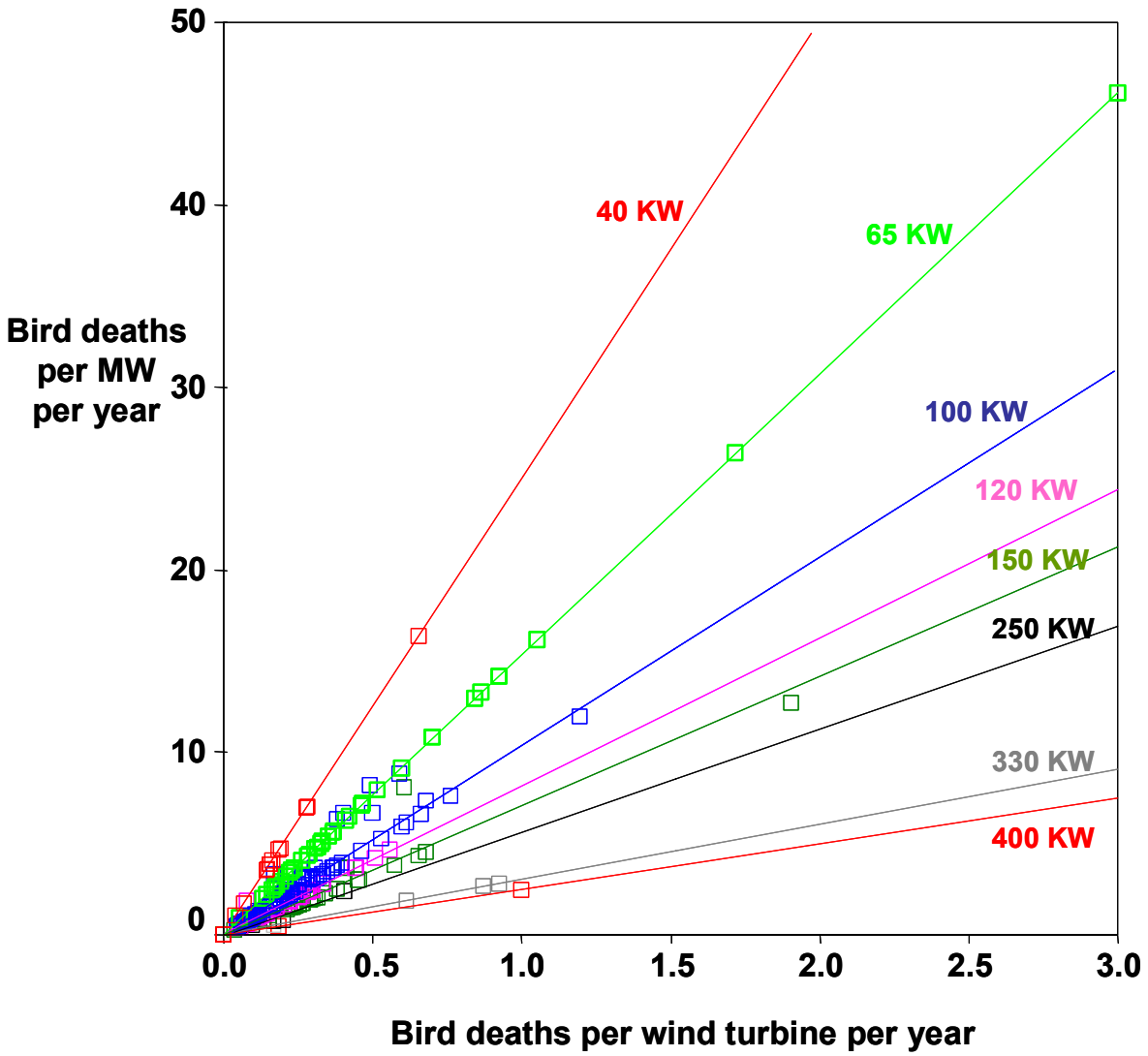

Figure A1. Mortality measured as per-MW increases linearly with mortality measured as per-wind turbine, but the linear relationship is unique to the size of the wind turbine. This uniqueness is expressed as the slope of the regression.

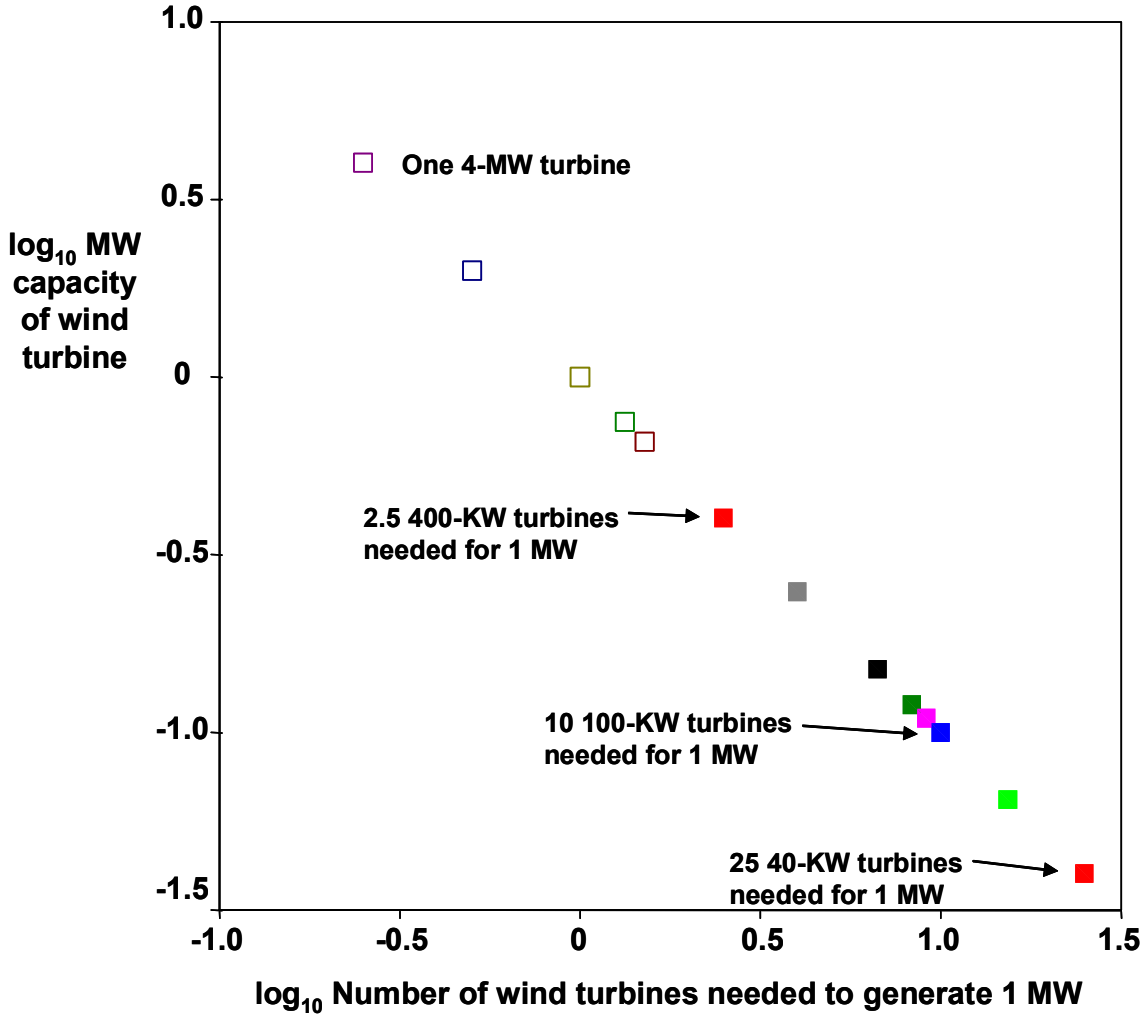

Figure A2. The slope of mortality measured as per-MW regressed on mortality measured as per-turbine is the generating capacity of the wind turbine, and relates as an inverse power function to the number of wind turbines needed to generate 1 MW of electrical energy.

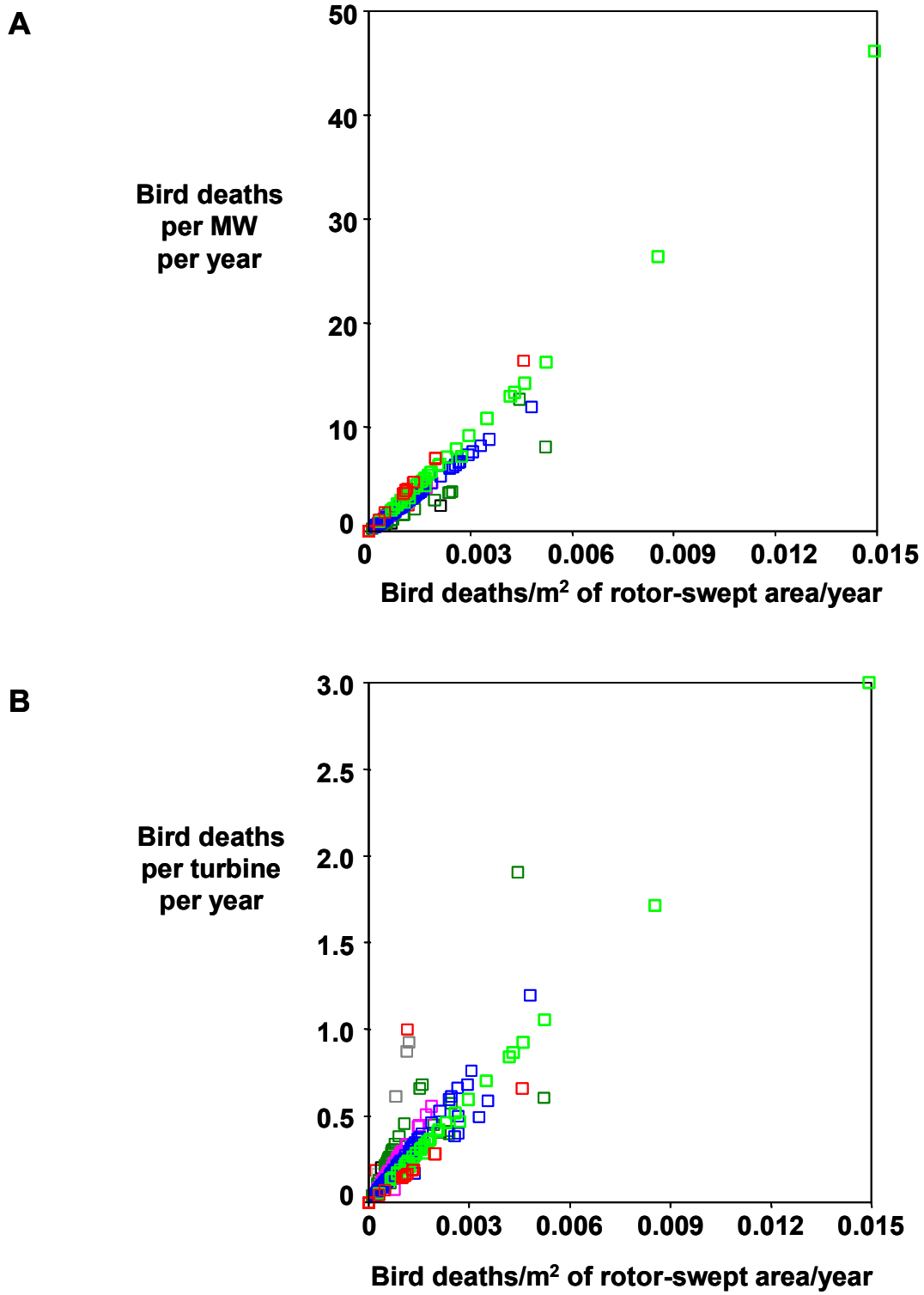

Figure A3. Mortality in terms of MW related to mortality in terms of rotor-swept area (A) more precisely than mortality in terms of number of wind turbines (B).

Table A1. Multiple regression models of bird fatalities/year, in which MW entered first left 33% of the 653.207 sum of squares to be explained by number of wind turbines in the sample, and entered second added only 0.63% of those 653.207 sum of squares.

Source	Regression sum of squares	df	Mean square	F	P
Model 1					
MW	437.840	1	437.840	133.163	~0
No. turbines	653.207	2	326.603	115.409	~0
Model 2					
No. turbines	649.110	1	649.111	229.150	~0
MW	653.207	2	326.603	115.409	~0
Either model					
Error	1310.271	463	2.830		
Total	1963.478	465			

of the variation in bird fatalities per year to be explained by the number of wind turbines, whereas entering the number of wind turbines into the model first left only 0.6% of the variation in bird fatalities per year to be explained by MW.

However, the number of fatalities/MW/year is nearly equally efficient at measuring raptor mortality as the number of fatalities/wind turbine/year (Table A2). Entering MW into the model first left the number of wind turbines to explain 8.2% of the variation in number of raptor fatalities per year, but entering the number of wind turbines first left 5.8% of the variation to be explained by MW. The difference between these percentages is inconsequential, and so the metrics are equally efficient.

An important point to consider when comparing any standardized measure of mortality between sites is whether the variation in mortality was partly a function of the duration of monitoring used to derive the mortality estimate. Variation in mortality estimates will decline as the monitoring duration increases, and this decline will be most rapid for estimates derived from monitoring that lasts less than a year (Figure A4A). The reason for this pattern is largely mathematical. Considering MW (or number of turbines) as a constant in the metric, the numerator (fatalities) and the second denominator (years of monitoring) are variable, but the variability of the number of fatalities is likely to be less than that of the number of years. When a fatality is found, mortality will relate to number of years of fatality searches as an inverse power function until the next fatality is found, and then this relationship will apply to the new mortality estimate until the next fatality is found (Figure A4B). Given enough time, wind turbines where no fatalities were found initially will kill birds eventually, and non-zero mortality estimates will be added to a growing pool of non-zero estimates (Figures A4B and A5).

Table A2. Multiple regression models of raptor fatalities/year, in which MW entered first left 8.2% of the 229.017 sum of squares to be explained by number of wind turbines in the sample, and entered second added 5.8% of those 229.017 sum of squares.

Source	Regression sum of squares	DFdf	Mean square	F	P
Model 1					
MW	210.338	1	210.338	123.738	~0
No. turbines	229.017	2	114.509	68.849	~0
Model 2					
No. turbines	215.787	1	215.787	127.826	~0
MW	229.017	2	114.509	68.849	~0
Either model					
Error	770.059	463	1.663		
Total	999.076	465			

Our data indicate that an asymptote in the percentage of wind turbine strings that caused fatalities is reached after three years of monitoring (Figure A6). We found that the number of fatalities increases with increasing proportion of the total time the turbines in the sample were searched (Figure A7A). This latter pattern is consistent with the pattern depicted in Figure A6. It serves to suggest that most of the wind turbines were not sampled long enough to robustly estimate mortality. The matter of robustness relates here not to whether the estimates are too high or too low, but rather to their reliability and precision. It also indicates that long term monitoring improves the precision of mortality estimates. Figure A7B, which is consistent with Figures A4 and A5, shows the transformation of estimates of both high mortality values and zero values into a narrower value range as more time was devoted to search effort. Looking to the bottom right of the scatterplot, one can see that given sufficient search time all turbines generate non-zero mortality values, i.e., all wind turbines eventually kill birds in the APWRA.

Mortality estimates based on less than one year of searching are more variable and should be cautiously interpreted when comparing mortality between sites. However, we found that the mean mortality did not change through time, indicating that the larger estimates of mortality in shorter-duration monitoring periods are offset by the larger number of zero values (Figure A8). The real significance of the effect of monitoring period is in the error term, which is inflated by short-duration monitoring periods.

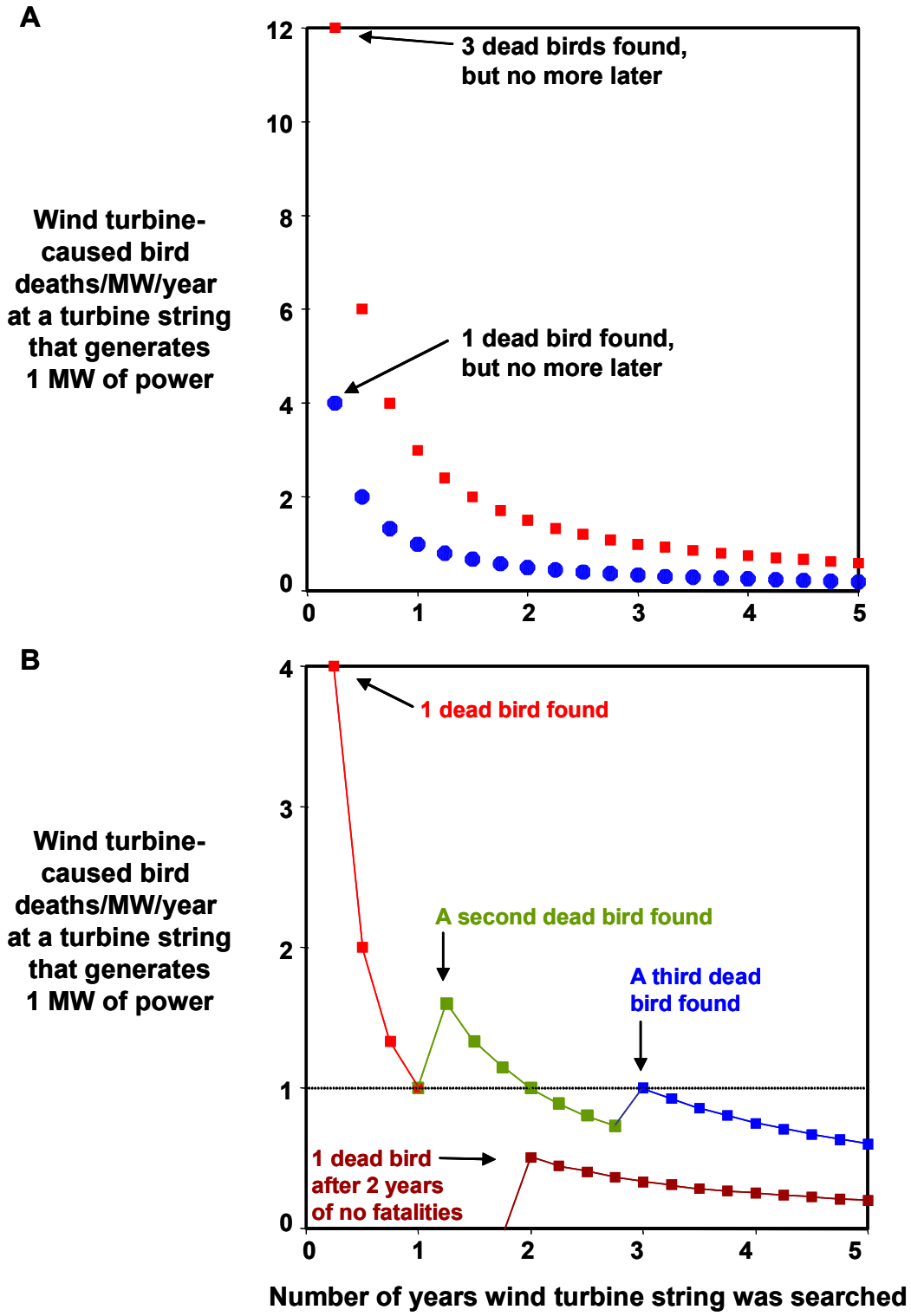

Figure A4. Mortality will relate as an inverse power function to the number of years used to generate the mortality estimate (A). This relationship will be modified by newly discovered fatalities (B).

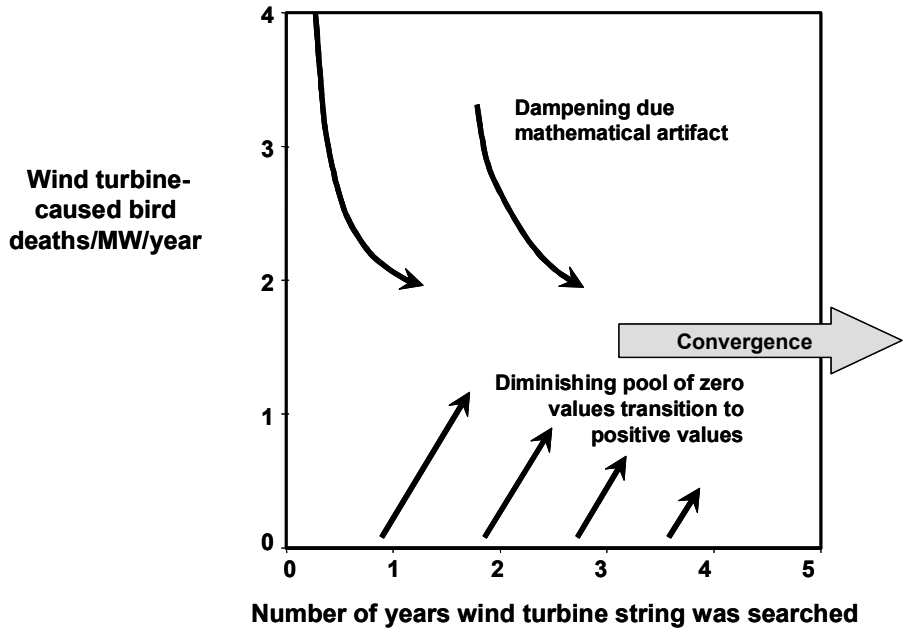

Figure A5. As monitoring continues, the inverse power function between mortality and monitoring period will dampen mortality estimates, while portions of the sample of wind turbines will transfer from the zero to non-zero mortality categories.

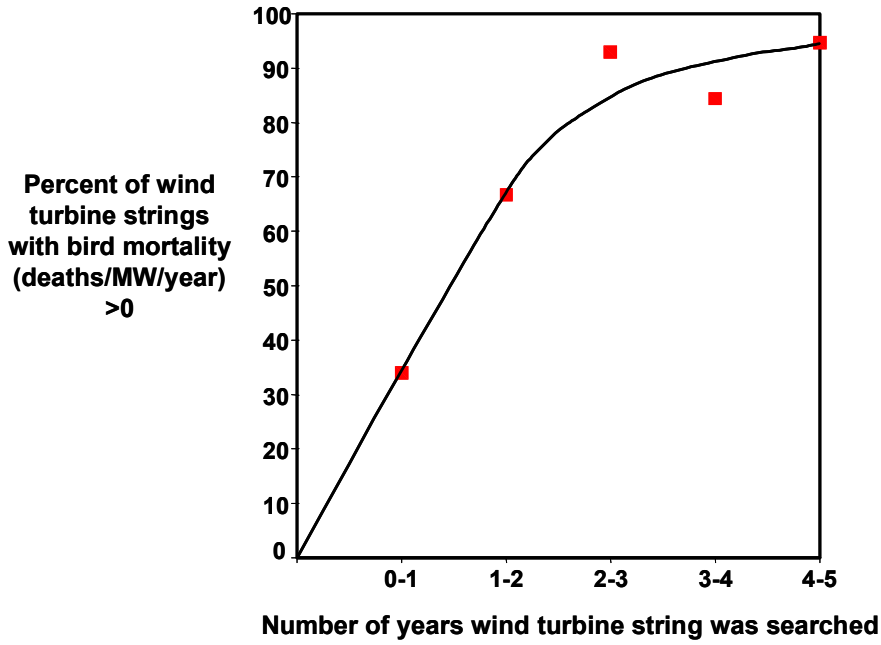

Figure A6. Data from the APWRA indicate that at least three years of carcasses searches are needed before the percentage of wind turbines with > 0 mortality estimates stabilizes.

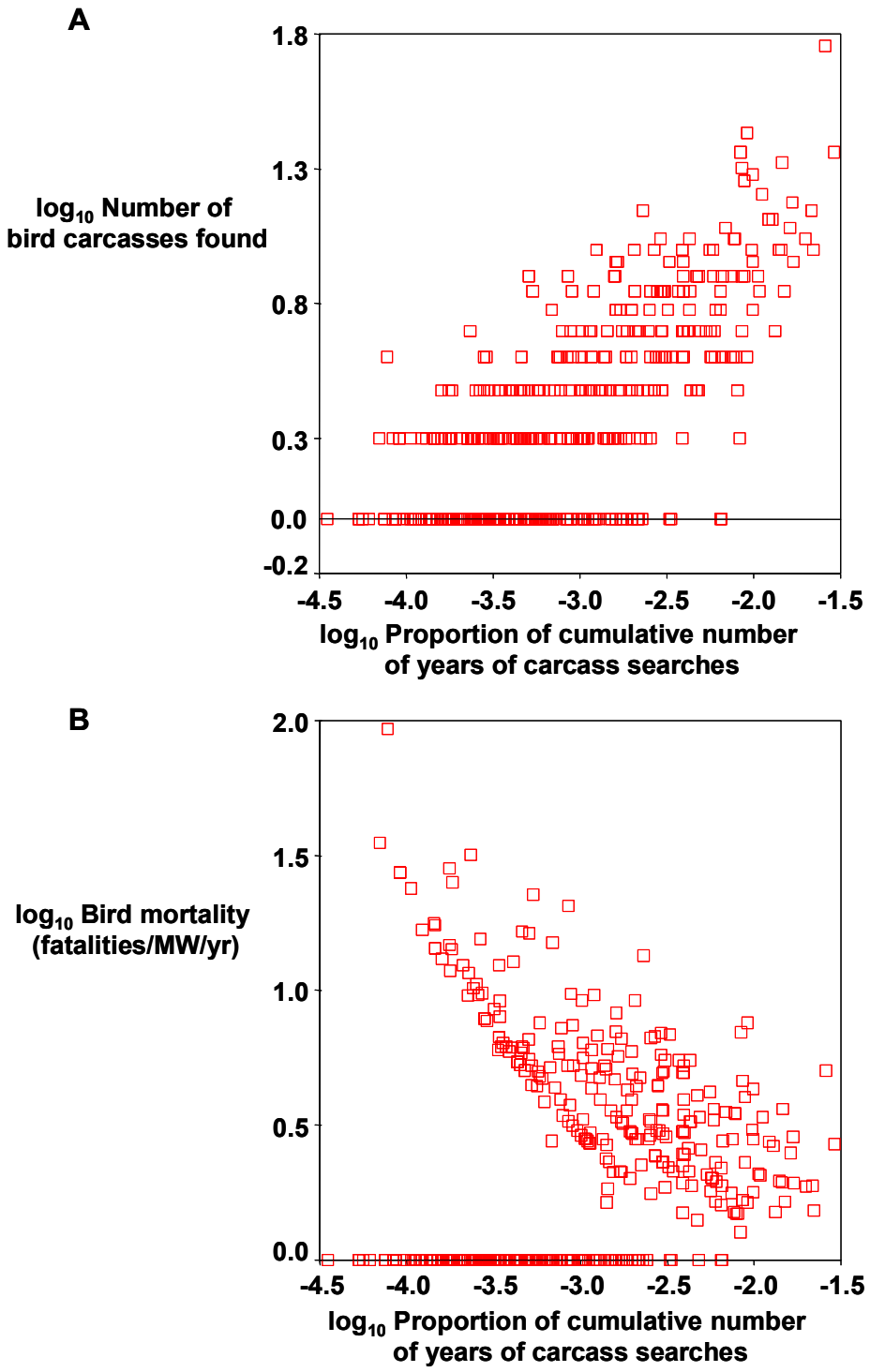

Figure A7. In the APWRA, the number of fatalities at wind turbine strings increases with search effort. Most of our sample of wind turbines had not been searched long enough to reach the asymptote shown in Figure A6 (A). Furthermore, mortality estimates converge from high and zero values to a narrower range of values as sampling effort increases (B).

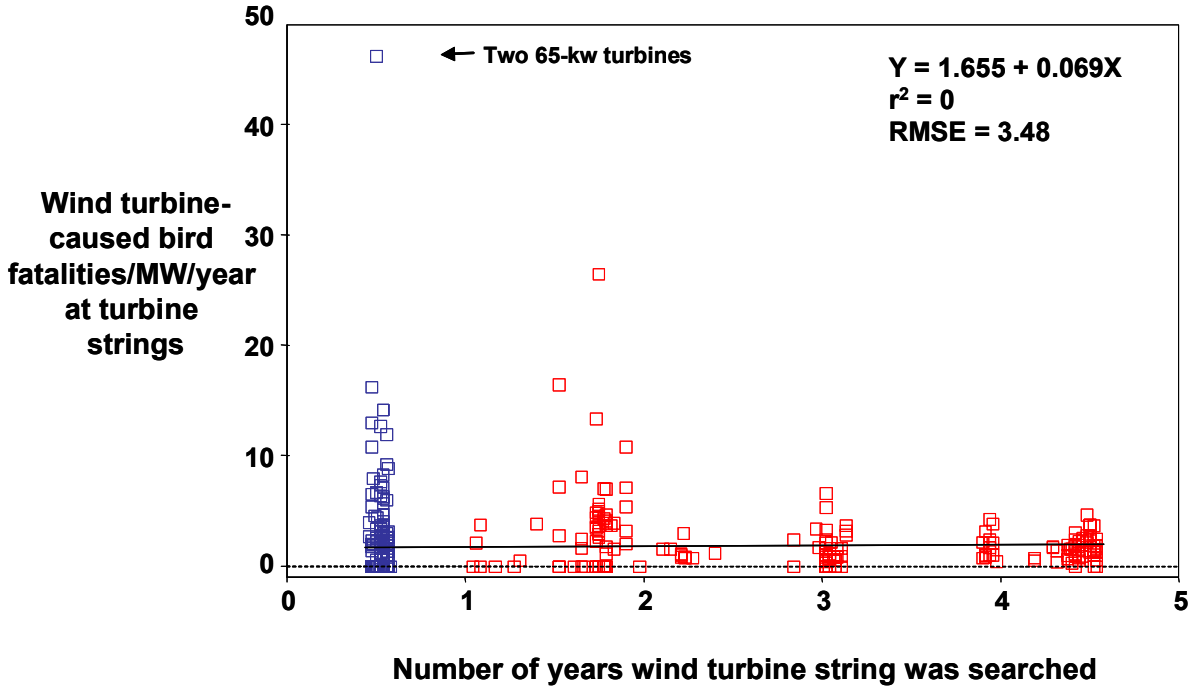

Figure A8. Bird mortality is a function of the duration used to generate the mortality estimate. During the first year of fatality searches, mortality is highly variable and declines through time. After one year of searches, mortality estimates stabilize and their precision increases.

4.0 DISCUSSION

At first glance it might appear that bird mortality can be nearly as efficiently measured per wind turbine as per megawatt, but there are additional considerations that lead us to conclude that the number of fatalities per megawatt per year is the more efficient (preferable) metric to use when reporting bird mortality caused by wind energy generating facilities. This is particularly important given the variability in turbines being installed between wind energy generating facilities.

The types and configurations of the wind turbines included in our analysis ranged in output capacity from 40 to 400 kW; whereas, many of the newer wind turbines being installed range in output capacity from 600 kW to 2 MW. Some newer models are capable of generating > 4 MW of electrical energy. These much larger wind turbines are fewer in number relative to the MW generated, but they have a larger RSA. By sweeping a larger area of sky, each of the larger wind turbines poses a greater likelihood of killing more birds per turbine, but not necessarily more per megawatt. Offsetting these likelihoods might be the greater height domain of the rotor blades on these larger wind turbines, but there is no reason to expect *a priori* that a greater height domain will kill fewer birds, all other factors being equal. In fact, a greater height domain may kill *more* birds if more birds are flying at higher altitudes, which may be true for some species.

We believe that measuring mortality as the number of fatalities/wind turbine/year has become outmoded, because wind turbines now vary too greatly in size and output to warrant this metric as the standard. The advent of fewer, larger wind turbines will likely cause the reporting of an artificial increase in mortality measured as the number of fatalities/turbine/year. Moving to mortality measured as the number of fatalities/MW/year will likely not yield the false appearance that there has been on increase in mortality with changes in turbine design.

Another reason to change to a new standard metric for reporting mortality is public perception. Many non-biologists will likely have a poor understanding of what bird mortality means when it is expressed as the number of fatalities/turbine/year. It is easier to comprehend bird mortality when it is expressed in terms of the number of MWs of energy generated. Furthermore, expressing mortality in terms of MW enables direct comparisons between wind turbine-caused mortality and the mortality caused by other forms of energy generation, which can also be expressed in terms of MW. The number of households, or persons, supported per MW of generated energy can more easily be incorporated into the measure of mortality so that other human activities not associated with energy generation can be compared in their impacts to birds.

Yet another consideration is an analytical one. Expressing mortality in terms of MW allows for the number of wind turbines to be used as a predictor variable in integrative analysis. We might, for example, be able to conclude whether a larger number of wind turbines with shorter heights is more or less dangerous to birds than a fewer number of taller wind turbines. This hypothesis test would be somewhat less confounded by relating mortality expressed as per-MW, rather than per-turbine, when comparing mortality to the number of wind turbines composing the sample.

We also found that the variation in mortality estimates is a function of the monitoring period during which carcass searches were performed. Dividing a relatively constant value by a continuous variable will relate to the continuous variable as an inverse power function. This relationship determines, to some extent, differences in mortality that are observed between wind energy generating facilities or at the same wind farm at different time periods. In the relative short term, the standardized measure of mortality (Anderson et al. 1999) is standardized in its terms and calculation, but not in its measure of impact. At least three years of carcass searches are needed before the sample of wind turbines sufficiently stabilizes in the percentage of non-zero mortality values. Any monitoring duration less than three years is likely to yield unreliable estimates of mortality.

APPENDIX B

AN EXPLANATION FOR DIFFERENCES IN REPORTED RESULTS BETWEEN THE PRESENT STUDY AND THOSE OF KERLINGER AND CURRY (2003), PLUS IDENTIFICATION OF EXPERIMENTAL DESIGN SHORTFALLS IN BOTH

APPENDIX B

AN EXPLANATION FOR DIFFERENCES IN REPORTED RESULTS BETWEEN THE PRESENT STUDY AND THOSE OF KERLINGER AND CURRY (2003), PLUS IDENTIFICATION OF EXPERIMENTAL DESIGN SHORTFALLS IN BOTH[1]

Reporting

Kerlinger and Curry's analysis relied on the Wildlife Reporting and Response System (WRRS) for raptor fatality information, but the WRRS is indefensible as a scientific monitoring program. It relies almost entirely on volunteer reporting of bird carcasses discovered incidentally by turbine maintenance workers performing maintenance or repair services at wind turbines. The WRRS database is a collection of fatality data collected without a systematic approach or sampling scheme. It reflects where maintenance workers incidentally encounter dead birds, not where birds are actually killed, throughout the APRWA. During our study we never observed turbine workers searching for carcasses in any way. We have to assume that they reported only the carcasses they happened to see while performing their monitoring and repair services.

Kerlinger and Curry (2003) claim that the WRRS is as efficient as most systematic studies, and this claim is the major premise of their 2003 report, which is a false assertion leading to faulty analyses of their results. Unfortunately, Kerlinger and Curry only presented mortality estimates for golden eagles and red-tailed hawks. Compared to earlier, less robust estimates made by researchers in the APWRA, the WRRS fell short as a reliable monitoring program. The Howell and DiDonato (1991) rate of red-tailed hawk fatalities was 4.77 times greater than the WRRS rate, and the rate of golden eagle fatalities was 1.36 times greater. The Orloff and Flannery (1992) rate of red-tailed hawk fatalities was 5.45 times greater than the WRRS rate, and the rate of golden eagle fatalities was 2.55 times greater. Compared to Howell and DiDonato (1991), the WRRS missed 68 (79%) of the red-tailed hawks and 5 (26%) of the golden eagles per year among the 3,412 turbines in the WRRS. Compared to Orloff and Flannery (1992), the WRRS missed 67 (82%) of the red-tailed hawks and 18 (60%)) of the golden eagles per year among the 3,412 turbines.

Compared to our mortality estimates for the entire APWRA, Kerlinger and Curry (2003) also underestimated mortality. Our estimate of red-tailed hawk mortality was 3.8 to 5.5 times greater than the WRRS rate, and our estimate of golden eagle mortality was 2.4 to 3.7 times greater. Compared to our study, the WRRS failed to report 154 (74%) to 245 (82%) of the red-tailed hawk fatalities and 45 (59%) to 86 (74%) of the golden eagle fatalities per year. Missing 74% to 82% of the red-tailed hawk fatalities and 59% to 74% of the golden eagle fatalities is alarming, because the carcasses of these species typically are large and remain recognizable in the field for months. Most likely, the WRRS error rates for smaller-bodied species are very large, but even for red-tailed hawk and golden eagle they are too large to consider the WRRS a reliable monitoring program that can lead to robust mortality estimates.

[1] See references to this appendix in Chapter 6.

Road Surveys

Road surveys were performed to enumerate ground squirrels, but we believe that road surveys are not as reliable as the mapping and enumeration of burrow system centroids (i.e., the approximate centers of burrow systems as viewed on the ground surface) that we performed during our study.

Confounding Factors

Rodent control intensity graded strongly across Kerlinger and Curry's sampling sites, with all the low -intensity rodent control located among the northwest sampling sites, all the medium- intensity rodent control located among the central sampling sites, and all the high- intensity rodent control located among the southern sampling sites. This strong gradient in rodent control intensity across Kerlinger and Curry's sampling sites is a form of pseudoreplication (Hurlbert 1984), and poses the strong likelihood that Kerlinger and Curry's results were confounded by one or more unmeasured factors.

One confounding factor might be inherent geographic differences in intensity of use of the APWRA by species of raptor. It is well documented, for example, that golden eagles mostly occur to the northwest and to the south of the APWRA, and telemetry results indicate that most of the golden eagle forays into the APWRA are from the nesting areas to the northwest and south of the APWRA (Hunt 2002). These forays might have more to do with the convenience of foraging close to natal areas than to the eagles' enumeration of prey.

Another confounding factor is the gradient of wind turbine types and spatial arrangements occurring north-to-south across the APWRA. Mostly well-spaced tubular towers dominate the northeastern portion of the APWRA; whereas, well-spaced tubular towers and lattice towers dominate the northwest aspect, nearly all vertical- axis turbines are located in the central aspect, and tightly grouped tubular towers and lattice towers arranged in wind walls are more common in the southern aspect. This gradient is significant because golden eagles are killed disproportionately more often at wind turbines that are mounted on tubular towers and at wind turbines that are well spaced apart. Raptors are killed less often than expected by chance in crowded wind turbine fields and at wind walls, which happen to be more common in the southern aspect of the APWRA, where the high-intensity rodent control was represented in Kerlinger and Curry's study.

Our study also was prone to confounding due to a gradient in rodent control intensity across the APWRA, but much less so than was Kerlinger and Curry's study. Our samples within areas of no rodent control were more interspersed within the other rodent control treatment intensities, and our samples within areas of intense control were also more interspersed with the other treatments. Had we been granted access to all the wind turbines earlier during the study, we could have achieved a much greater degree of treatment interspersion.

Yet another confounding factor might be the greater need for maintenance of wind turbines in the south versus the north of the APWRA, due to differences in composition of wind turbine type, as an example. Should turbine workers spend more time in one part of the APWRA over another, then the WRRS will reflect different mortalities, accordingly.

Fatality Rates

Fatality rates were compared between rodent control intensities using chi-square tests, which are ill-suited for comparison of rates.

Comparisons of Mortality

Multiple comparisons of mortality were made in the absence of associated error terms or statistical tests results. Small differences in mortality were identified as significant, but again, without the use of error terms or inferential statistics.

BACI Design

The Kerlinger and Curry analysis lacks a before-after, control-impact (BACI) design, which means it cannot distinguish variation in mortality due to rodent control as opposed to other potentially confounding factors. Our study suffers this same design shortfall. A consequence of this shortfall is the inability to conclude with *high* confidence the effects of the rodent control program. The most convincing way to have concluded that the rodent control program had the desired effect in the absence of a BACI design would have been if our data had demonstrated a *substantial* shift in effect (e.g., 80-%–90%); the results of both research efforts fail to meet this criterion.

APPENDIX C

CHI-SQUARE TEST STATISTICS AND DERIVED MEASURES OF EFFECT FOR VARIOUS BIRDS

APPENDIX C

CHI-SQUARE TEST STATISTICS AND DERIVED MEASURES OF EFFECT FOR VARIOUS BIRDS

Table C1. Chi-square test statistics and derived measures of effect for golden eagles.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model [t]				
Micon	2	3.84	0.52	-3
Bonus	17	15.18	1.12	3
Danwin	0	0.28	0	-1
Flowind	0	2.21	0	-4
Windmatic	0	0.62	0	-1
Enertech	2	2.81	0.71	-2
KCS-56	30	27.30	1.10	5
KVS-33	0	0.57	0	-1
Howden	2	0.24	8.20	3
Nordtank	1	0.89	1.12	0
W.E.G.	0	0.06	0	0
Rated turbine power (kW) [t]				
40	2	2.81	0.71	-2
65	3	5.35	0.56	-4
100	30	27.30	1.10	5
110	0	0.28	0	-1
120	10	10.04	1.00	0
150	7	7.02	1.00	0
250	0	0.40	0	-1
330	2	0.24	8.20	3
400	0	0.57	0	-1
Rotor diameter (m)				
13.5 – –14.8	2	3.43	0.58	-3
16.0	3	4.73	0.63	-3
17.2 – –17.8	30	29.18	1.03	2
19.1 – –19.5	10	10.65	0.94	-1
23.4 – –25.2	7	5.20	1.35	3
31.4 – –33.2	2	0.81	2.47	2
Blade tip speed (kph) [t]				
136.77	0	0.62	0	-1
143.20	1	0.89	1.12	0
146.42	10	10.04	1.00	0
148.03	2	2.81	0.71	-2
149.64	2	3.84	0.52	-3
173.77	7	5.14	1.36	3
180.21	0	0.57	0	-1
193.08	0	2.15	0	-4
194.69	0	0.34	0	-1

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39	0	0.06	0	0
239.74	2	0.24	8.20	3
246.18	30	27.30	1.10	5
Blade tip speed (kph)				
137.77 – –149.64	15	18.20	0.82	-6
173.77 – –194.69	7	8.20	0.85	-2
212.39 – –246.18	32	27.60	1.16	8
Seconds/sweep at blade tip				
0.272583	30	27.30	1.10	5
0.343807	2	2.81	0.71	-2
0.374882	0	0.28	0	-1
0.403091	2	3.84	0.52	-3
0.407945	0	0.62	0	-1
0.421219	1	0.89	1.12	0
0.447299	0	0.06	0	0
0.493765	2	0.24	8.20	3
0.502071	10	10.04	1	0
0.503748	0	1.87	0	-3
0.507659	7	5.14	1.36	3
0.554769	0	0.34	0	-1
0.694529	0	0.57	0	-1
Seconds/sweep at blade tip				
0.2726	30	27.30	1.10	5
0.3438 – –0.4938	7	8.74	0.80	-3
0.5021 – –0.6945	17	17.96	0.95	-2
Rotor plane (m^2) swept/s				
1498.8	2	2.81	0.71	-2
1518.1	0	0.62	0	-1
1660.5	0	1.87	0	-3
1718.4	1	0.89	1.12	0
1795.7	2	3.84	0.52	-3
1859.3	0	0.34	0	-1
2141.4	10	10.04	1	0
2780.4	0	0.28	0	-1
3049.7	7	5.14	1.36	3
3286.5	30	27.30	1.10	5
4014.2	0	0.06	0	0
4487.2	0	0.57	0	-1
5645.9	2	0.24	8.20	3
Rotor plane (m^2) swept/s				
1499 - –1859	5	10.38	0.48	-10
2141	10	10.04	1.00	0
2780 - –3287	37	32.72	1.13	8
4014 - –5646	2	0.87	2.31	2
Tower type				
Vertical axis	0	2.21	0	-4
Tubular	22	20.53	1.07	3

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Lattice	32	31.26	1.02	1
Tower height (m) [t]				
14.0	0	1.41	0	-3
18.5	31	20.00	1.55	20
24.0	0	0.28	0	-1
24.6	15	23.62	0.64	-16
25.2	7	5.11	1.37	4
29.5	0	1.87	0	-3
32.3	0	0.34	0	-1
36.9	0	0.04	0	0
43.1	1	1.33	0.75	-1
Tower height (m) *				
14.0	0	1.41	0	-3
18.5	31	20.00	1.55	20
24.0 – –25.2	22	29.00	0.76	-13
29.5 – –32.3	0	2.21	0	-4
36.9 – –43.1	1	1.38	0.73	-1
Rotor orientation to wind *				
Faces wind	22	29.80	0.74	-14
Away from wind	32	21.99	1.46	19
Vertical axis	0	2.21	0	-4
Blade color scheme				
White	51	52.71	0.97	-3
Black stripes	0	0.22	0	0
Red stripes	0	0.05	0	0
Red tips	1	0.46	2.17	1
Green tips	2	0.57	3.54	3
Perch guard [t]				
None	52	53.41	0.97	-3
Wire netting	2	0.59	3.41	3
Derelict turbines				
Operating and away from derelict	49	49.80	0.98	-1
Derelict	2	1.88	1.07	0
Next to derelict	3	2.32	1.29	1
Height (m) of low blade reach **				
4.0	0	2.21	0	-4
5.1	0	1.41	0	-3
8.0	0	0.57	0	-1
8.9	2	0.24	8.20	3
9.6	29	16.61	1.75	23
11.1	0	0.58	0	-1
11.8	2	2.81	0.71	-2
12.0	0	0.06	0	0
13.5	7	5.11	1.37	4
14.4	0	0.28	0	-1
14.9	10	10.04	1	0
15.7	0	7.95	0	-15

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
16.6	3	4.72	0.64	-3
17.2	0	0.04	0	0
25.2	0	0.03	0	0
28.9	0	0.01	0	0
34.2	1	1.33	0.75	-1
Height (m) of low blade reach **				
4.0 – –5.1	0	3.62	0	-7
8.0 – –9.6	31	17.42	1.78	25
11.1 – –14.85	19	18.87	1.01	0
15.7 – –17.2	3	12.71	0.24	-18
25.2 – –34.2	1	1.38	0.73	-1
Height (m) of high blade reach **				
22.9	0	1.41	0	-3
25.3	2	2.81	0.71	-2
25.9	0	0.58	0	-1
27.4	29	16.61	1.75	23
29.5	0	1.87	0	-3
32.0	0	0.04	0	0
32.3	0	0.34	0	-1
32.6	3	4.72	0.64	-3
33.5	0	7.95	0	-15
33.6	0	0.28	0	-1
34.4	10	10.04	1	0
36.9	7	5.11	1.37	4
37.2	0	0.06	0	0
40.3	2	0.24	8.20	3
41.2	0	0.57	0	-1
44.9	0	0.01	0	0
48.6	0	0.03	0	0
52.0	1	1.33	0.75	-1
Height (m) of high blade reach **				
22.9 – –27.4	31	21.41	1.45	18
29.5 – –33.6	3	15.20	0.20	-23
34.4	10	10.04	1.00	0
36.9 – –52.0	10	7.35	1.36	5
Wind wall *				
Not in wind wall	53	46.43	1.14	12
In wind wall	1	7.57	0.13	-12
Position in string *				
End	21	11.97	1.75	17
Edge of gap	6	4.84	1.24	2
Interior	27	36.97	0.73	-18
Non-operational	0	0.18	0	0
Location in wind farm *				
Edge of farm	7	7.06	0.99	0
Edge of local cluster	12	5.60	2.14	12
Interior of wind farm	35	41.18	0.85	-11

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine congestion (no. in 300 m) *				
0 - –12	7	6.19	1.13	1
13 - –24	35	24.43	1.43	20
25 - –36	8	13.22	0.61	-10
37 - –72	4	10.10	0.40	-11
Elevation (m)				
85 - –135	6	8.05	0.75	-4
135 - –185	12	11.38	1.05	1
185 - –235	10	7.26	1.38	5
235 - –285	5	3.37	1.48	3
285 - –335	4	9.35	0.43	-10
335 - –385	11	6.22	1.77	9
385 - –535	6	8.35	0.72	-4
Slope grade (degrees) *				
0	11	21.47	0.51	-19
2 - –5	8	4.26	1.88	7
6 - –14	13	13.21	0.98	0
15 - –58	22	15.03	1.46	13
Physical relief *				
Peak	1	0.93	1.08	0
Plateau	1	3.75	0.27	-5
Ridge crest	10	17.38	0.58	-14
Ridgeline	22	10.93	2.01	21
Slope	17	18.21	0.93	-2
Saddle	2	2.39	0.84	-1
Ravine	1	0.41	2.47	1
Canyon *				
Not in canyon	39	45.77	0.85	-13
In canyon	15	8.23	1.82	13
Slope aspect				
None (flat)	11	15.61	0.70	-9
North-facing	7	7.83	0.89	-2
Northeast	2	3.50	0.57	-3
East	4	4.55	0.88	-1
Southeast	7	6.13	1.14	2
South	5	4.45	1.12	1
Southwest	1	0.94	1.06	0
West	6	2.00	3.00	7
Northwest	11	8.89	1.24	4
Slope aspect				
None (flat)	11	15.61	0.70	-9
East-northeast	6	8.05	0.75	-4
South-southeast	12	10.58	1.13	3
West-southwest	7	2.94	2.38	8
North-northwest	18	16.72	1.08	2
Edge index at tower base **				
No edge	1	2.06	0.48	-2

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Some lateral edge	6	5.16	1.16	2
Lots lateral edge	7	16.90	0.41	-18
Some vertical edge	13	17.24	0.75	-8
Lots vertical edge	18	11.09	1.62	13
Lots vertical and lateral edge	9	1.55	5.80	14
Rockpiles ≤ 50 m away				
None	40	42.64	0.94	-5
1	6	4.69	1.28	3
≥ 2	5	3.67	1.36	3
Rodent control through 2001 *				
Unknown	1	0.65	1.53	1
None	20	12.46	1.61	14
Control	17	14.45	1.18	5
Intense control	16	26.44	0.61	-19
Rodent control through 2002 *				
Unknown	1	0.65	1.53	1
None	17	9.20	1.85	14
Control	17	14.46	1.18	5
Intense control	19	29.69	0.64	-20
Cattle pats 40 m from turbines				
0	0	2.19	0	-10
1 - –9	11	10.98	1.00	0
10 - –25	9	7.35	1.22	7
> 25	3	2.48	1.21	2
Cattle pats at turbines *				
0 - –2	0	2.99	0	-13
3 - –9	7	7.81	0.90	-4
10 - –25	7	7.53	0.93	-2
> 25	9	4.67	1.93	19
Cottontails 40 m from turbines				
No pellets	17	17.89	0.95	-4
Some pellets	5	4.05	1.24	4
Abundant pellets	1	1.06	0.94	0
Cottontails at turbines				
No pellets	18	17.52	1.03	2
Some pellets	4	4.01	1.00	0
Abundant pellets	1	1.47	0.68	-2
Vegetation height (cm) *				
0 - –10	3	3.96	0.76	-4
11 - –20	5	7.46	0.67	-11
21 - –35	5	7.00	0.71	-9
> 35	10	4.59	2.18	24
Pocket gopher clusting				
Obs/Exp in 15 m = 0	2	1.08	1.85	6
Obs/Exp in 15 m < 1.5	2	1.79	1.12	1
Obs/Exp in 15 m = 1.5–-3.0	6	6.11	0.98	-1
Obs/Exp in 15 m > 3	6	7.02	0.86	-6

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Ground squirrel clustering				
Obs/Exp in 15 m = 0	5	5.64	0.89	-4
Obs/Exp in 15 m ≤ 1.14	9	6.20	1.45	17
Obs/Exp in 15 m > 1.14	2	4.16	0.48	-13
Pocket gopher density ≤ 90 m *				
0 – –1.4/ha	3	5.51	0.54	-16
1.41 – –3.5/ha	3	5.21	0.58	-14
> 3.5/ha	10	5.25	1.90	30
Ground squirrel density ≤ 90 m				
0/ha	1	2.85	0.35	-12
0.01 – –5.99/ha	9	9.36	0.96	-2
≥ 6/ha	6	3.79	1.58	14
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	3	3.32	0.90	-2
Obs/Exp in 15 m = 1.2–-3.0	11	8.30	1.33	17
Obs/Exp in 15 m > 3	2	4.38	0.46	-15
Density of all burrow systems *				
< 5/ha	1	6.16	0.16	-32
5 – –9/ha	8	4.71	1.70	21
> 9/ha	7	5.13	1.36	12
Season of the year				
Spring	5	7.00	0.71	-8
Summer	10	6.24	1.60	15
Fall	3	4.39	0.68	-6
Winter	7	7.36	0.95	-1

Table C2. Chi-square test statistics and derived measures of effect for red-tailed hawks.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model *				
Micon	11	15.15	0.73	-2
Bonus	73	59.88	1.22	6
Danwin	1	1.10	0.91	0
Flowind	3	8.73	0.34	-3
Windmatic	2	2.45	0.82	0
Enertech	4	11.09	0.36	-3
KCS-56	106	107.69	0.98	-1
KVS-33	3	2.23	1.35	0
Howden	3	0.96	3.12	1
Nordtank	7	3.51	2.00	2
W.E.G.	0	0.22	0	0
Rated turbine power (kW) *				
40	4	11.09	0.36	-3
65	20	21.11	0.95	-1
100	106	107.69	0.98	-1
110	1	1.10	0.91	0
120	34	39.59	0.86	-3
150	41	27.67	1.48	6
250	1	1.56	0.64	0
330	3	0.96	3.12	1
400	3	2.23	1.35	0
Rotor diameter (m) **				
13.5 – –14.8	6	13.54	0.44	-4
16.0	18	18.66	0.96	0
17.2 – –17.8	108	115.08	0.94	-3
19.1 – –19.5	36	42.03	0.86	-3
23.4 – –25.2	39	20.50	1.90	9
31.4 – –33.2	6	3.19	1.88	1
Blade tip speed (kph) **				
136.77	2	2.45	0.82	0
143.20	7	3.51	2.00	2
146.42	34	39.59	0.86	-3
148.03	4	11.09	0.36	-3
149.64	11	15.15	0.73	-2
173.77	39	20.28	1.92	9
180.21	3	2.23	1.35	0
193.08	3	8.49	0.35	-3
194.69	1	1.34	0.75	0
212.39	0	0.22	0	0
239.74	3	0.96	3.12	1
246.18	106	107.69	0.98	-1
Blade tip speed (kph) *				
137.77 – –149.64	58	71.80	0.81	-6
173.77 – –194.69	46	32.33	1.42	6

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	109	108.87	1.00	0
Seconds/sweep at blade tip **				
0.272583	106	107.69	0.98	-1
0.343807	4	11.09	0.36	-3
0.374882	1	1.10	0.91	0
0.403091	11	15.15	0.73	-2
0.407945	2	2.45	0.82	0
0.421219	7	3.51	2.00	2
0.447299	0	0.22	0	0
0.493765	3	0.96	3.12	1
0.502071	34	39.59	0.86	-3
0.503748	2	7.39	0.27	-3
0.507659	39	20.28	1.92	9
0.554769	1	1.34	0.75	0
0.694529	3	2.23	1.35	0
Seconds/sweep at blade tip				
0.2726	106	107.69	0.98	-1
0.3438 – –0.4938	28	34.48	0.81	-3
0.5021 – –0.6945	79	70.83	1.12	4
Rotor plane (m^2) swept/s **				
1498.8	4	11.09	0.36	-3
1518.1	2	2.45	0.82	0
1660.5	2	7.39	0.27	-3
1718.4	7	3.51	2.00	2
1795.7	11	15.15	0.73	-2
1859.3	1	1.34	0.75	0
2141.4	34	39.59	0.86	-3
2780.4	1	1.10	0.91	0
3049.7	39	20.28	1.92	9
3286.5	106	107.69	0.98	-1
4014.2	0	0.22	0	0
4487.2	3	2.23	1.35	0
5645.9	3	0.96	3.12	1
Rotor plane (m^2) swept/s *				
1499 - –1859	27	40.93	0.66	-7
2141	34	39.59	0.86	-3
2780 - –3287	146	129.07	1.13	8
4014 - –5646	6	3.41	1.76	1
Tower type *				
Vertical axis	3	8.73	0.34	-3
Tubular	95	80.98	1.17	7
Lattice	115	123.29	0.93	-4
Tower height (m) **				
14.0	3	5.56	0.54	-1
18.5	70	78.88	0.89	-4
24.0	1	1.10	0.91	0
24.6	93	93.16	1.00	0

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	39	20.15	1.94	9
29.5	2	7.39	0.27	-3
32.3	1	1.34	0.75	0
36.9	0	0.17	0	0
43.1	4	5.26	0.76	-1
Tower height (m) [t]				
14.0	3	5.56	0.54	-1
18.5	70	78.88	0.89	-4
24.0 – –25.2	133	114.40	1.16	9
29.5 – –32.3	3	8.73	0.34	-3
36.9 – –43.1	4	5.43	0.74	-1
Rotor orientation to wind *				
Faces wind	132	117.53	1.12	7
Away from wind	78	86.75	0.90	-4
Vertical axis	3	8.73	0.34	-3
Blade color scheme **				
White	204	207.90	0.98	-2
Black stripes	1	0.88	1.14	0
Red stripes	2	0.18	11.30	1
Red tips	4	1.82	2.20	1
Green tips	2	2.23	0.90	0
Perch guard **				
None	205	210.69	0.97	-3
Wire netting	8	2.32	3.46	3
Derelict turbines [t]				
Operating and away from derelict	205	196.45	1.04	4
Derelict	3	7.40	0.41	-2
Next to derelict	5	9.15	0.55	-2
Height (m) of low blade reach *				
4.0	3	8.73	0.34	-3
5.1	3	5.56	0.54	-1
8.0	3	2.23	1.35	0
8.9	3	0.96	3.12	1
9.6	64	65.51	0.98	-1
11.1	2	2.28	0.88	0
11.8	4	11.09	0.36	-3
12.0	0	0.22	0	0
13.5	39	20.15	1.94	9
14.4	1	1.10	0.91	0
14.9	34	39.59	0.86	-3
15.7	35	31.36	1.12	2
16.6	18	18.62	0.97	0
17.2	0	0.16	0	0
25.2	0	0.13	0	0
28.9	0	0.04	0	0
34.2	4	5.26	0.76	-1
Height (m) of low blade reach				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	6	14.29	0.42	-4
8.0 – –9.6	70	68.70	1.02	1
11.1 – –14.85	80	74.44	1.07	3
15.7 – –17.2	53	50.15	1.06	1
25.2 – –34.2	4	5.43	0.74	-1
Height (m) of high blade reach *				
22.9	3	5.56	0.54	-1
25.3	4	11.09	0.36	-3
25.9	2	2.28	0.88	0
27.4	64	65.51	0.98	-1
29.5	2	7.39	0.27	-3
32.0	0	0.16	0	0
32.3	1	1.34	0.75	0
32.6	18	18.62	0.97	0
33.5	35	31.36	1.12	2
33.6	1	1.10	0.91	0
34.4	34	39.59	0.86	-3
36.9	39	20.15	1.94	9
37.2	0	0.22	0	0
40.3	3	0.96	3.12	1
41.2	3	2.23	1.35	0
44.9	0	0.04	0	0
48.6	0	0.13	0	0
52.0	4	5.26	0.76	-1
Height (m) of high blade reach **				
22.9 – –27.4	73	84.44	0.86	-5
29.5 – –33.6	57	59.97	0.95	-1
34.4	34	39.59	0.86	-3
36.9 – –52.0	49	28.99	1.69	9
Wind wall				
Not in wind wall	185	183.13	1.01	1
In wind wall	28	29.87	0.94	-1
Position in string **				
End	70	47.22	1.48	11
Edge of gap	21	19.08	1.10	1
Interior	122	145.84	0.84	-11
Non-operational	0	0.70	0	0
Location in wind farm **				
Edge of farm	28	27.57	1.02	0
Edge of local cluster	41	21.87	1.87	9
Interior of wind farm	142	160.90	0.88	-9
Turbine congestion (no. in 300 m) **				
0 - –12	41	24.43	1.68	8
13 - –24	88	96.37	0.91	-4
25 - –36	58	52.14	1.11	3
37 - –72	26	39.86	0.65	-7
Elevation (m)[t]				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	31	31.74	0.98	0
135 - –185	42	44.88	0.94	-1
185 - –235	36	28.63	1.26	3
235 - –285	18	13.29	1.35	2
285 - –335	43	36.89	1.17	3
335 - –385	25	24.52	1.02	0
385 - –535	18	32.93	0.55	-7
Slope grade (degrees) *				
0	63	84.70	0.74	-10
2 - –5	23	16.81	1.37	3
6 - –14	62	52.09	1.19	5
15 - –58	65	59.27	1.10	3
Physical relief				
Peak	2	3.66	0.55	-1
Plateau	8	14.78	0.54	-3
Ridge crest	67	68.53	0.98	-1
Ridgeline	53	43.10	1.23	5
Slope	67	71.83	0.93	-2
Saddle	15	9.44	1.59	3
Ravine	1	1.60	0.63	0
Canyon **				
Not in canyon	148	180.52	0.82	-15
In canyon	65	32.48	2.00	15
Slope aspect *				
None (flat)	41	61.58	0.67	-10
North-facing	26	30.88	0.84	-2
Northeast	16	13.81	1.16	1
East	14	17.95	0.78	-2
Southeast	27	24.20	1.12	1
South	24	17.54	1.37	3
Southwest	6	3.72	1.61	1
West	9	7.90	1.14	1
Northwest	50	35.06	1.43	7
Slope aspect *				
None (flat)	41	61.58	0.67	-10
East-northeast	30	31.77	0.94	-1
South-southeast	51	41.73	1.22	4
West-southwest	15	11.61	1.29	2
North-northwest	76	65.94	1.15	5
Edge index at tower base **				
No edge	4	8.14	0.49	-2
Some lateral edge	19	20.35	0.93	-1
Lots lateral edge	45	66.65	0.68	-10
Some vertical edge	74	67.99	1.09	3
Lots vertical edge	54	43.76	1.23	5
Lots vertical and lateral edge	17	6.12	2.78	5
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	154	161.37	0.95	-4
1	25	17.75	1.41	4
≥ 2	14	13.87	1.01	0
Rodent control through 2001 [t]				
Unknown	1	2.58	0.39	-1
None	45	49.14	0.92	-2
Control	74	56.99	1.30	8
Intense control	93	104.29	0.89	-5
Rodent control through 2002 *				
Unknown	1	2.58	0.39	-1
None	41	36.29	1.13	2
Control	74	57.05	1.30	8
Intense control	97	117.09	0.83	-9
Cattle pats 40 m from turbines *				
0	26	14.94	1.74	7
1 - –9	68	74.98	0.91	-4
10 - –25	46	50.19	0.92	-3
> 25	17	16.90	1.01	0
Cattle pats at turbines				
0 - –2	21	20.40	1.03	0
3 - –9	43	53.33	0.81	-7
10 - –25	58	51.38	1.13	4
> 25	35	31.89	1.10	2
Cottontails 40 m from turbines [t]				
No pellets	131	122.12	1.07	6
Some pellets	17	27.62	0.62	-7
Abundant pellets	9	7.26	1.24	1
Cottontails at turbines [t]				
No pellets	132	119.61	1.10	8
Some pellets	18	27.37	0.66	-6
Abundant pellets	7	10.02	0.70	-2
Vegetation height (cm)				
0 - –10	19	27.00	0.70	-5
11 - –20	53	50.93	1.04	1
21 - –35	47	47.77	0.98	0
> 35	38	31.30	1.21	4
Pocket gopher clusting				
Obs/Exp in 15 m = 0	6	6.28	0.96	0
Obs/Exp in 15 m < 1.5	9	10.42	0.86	-2
Obs/Exp in 15 m = 1.5-3.0	29	35.53	0.82	-7
Obs/Exp in 15 m > 3	49	40.77	1.20	9
Ground squirrel clustering				
Obs/Exp in 15 m = 0	33	32.78	1.01	0
Obs/Exp in 15 m ≤ 1.14	34	36.05	0.94	-2
Obs/Exp in 15 m > 1.14	26	24.17	1.08	2
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	40	32.01	1.25	9

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	29	30.29	0.96	-1
> 3.5/ha	24	30.54	0.79	-7
Ground squirrel density ≤ 90 m				
0/ha	15	16.56	0.91	-2
0.01 – –5.99/ha	63	54.41	1.16	9
≥ 6/ha	15	22.02	0.68	-8
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	19	19.28	0.99	0
Obs/Exp in 15 m = 1.2–-3.0	43	48.25	0.89	-6
Obs/Exp in 15 m > 3	31	25.48	1.22	6
Density of all burrow systems				
< 5/ha	45	35.82	1.26	10
5 – –9/ha	25	27.37	0.91	-3
> 9/ha	23	29.81	0.77	-7
Season of the year**				
Spring	11	42.30	0.26	-21
Summer	45	37.70	1.19	5
Fall	35	26.51	1.32	6
Winter	60	44.48	1.35	10

Table C3. Chi-square test statistics and derived measures of effect for American kestrels.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model **				
Micon	5	4.20	1.19	1
Bonus	10	16.59	0.60	-11
Danwin	0	0.30	0	-1
Flowind	1	2.42	0.41	-2
Windmatic	0	0.68	0	-1
Enertech	0	3.07	0	-5
KCS-56	33	29.83	1.11	5
KVS-33	7	0.62	11.35	11
Howden	0	0.27	0	0
Nordtank	3	0.97	3.09	3
W.E.G.	0	0.06	0	0
Rated turbine power (kW) **				
40	0	3.07	0	-5
65	8	5.85	1.37	4
100	33	29.83	1.11	5
110	0	0.30	0	-1
120	7	10.97	0.64	-7
150	4	7.67	0.52	-6
250	0	0.43	0	-1
330	0	0.27	0	0
400	7	0.62	11.35	11
Rotor diameter (m) **				
13.5 – –14.8	0	3.75	0	-6
16.0	8	5.17	1.55	5
17.2 – –17.8	34	31.88	1.07	4
19.1 – –19.5	7	11.64	0.60	-8
23.4 – –25.2	3	5.68	0.53	-5
31.4 – –33.2	7	0.88	7.92	10
Blade tip speed (kph) **				
136.77	0	0.68	0	-1
143.20	3	0.97	3.09	3
146.42	7	10.97	0.64	-7
148.03	0	3.07	0	-5
149.64	5	4.20	1.19	1
173.77	3	5.62	0.53	-4
180.21	7	0.62	11.35	11
193.08	1	2.35	0.43	-2
194.69	0	0.37	0	-1
212.39	0	0.06	0	0
239.74	0	0.27	0	0
246.18	33	29.83	1.11	5
Blade tip speed (kph)				
137.77 – –149.64	15	19.89	0.75	-8

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
173.77 – –194.69	11	8.96	1.23	3
212.39 – –246.18	33	30.16	1.09	5
Seconds/sweep at blade tip **				
0.272583	33	29.83	1.11	5
0.343807	0	3.07	0	-5
0.374882	0	0.30	0	-1
0.403091	5	4.20	1.19	1
0.407945	0	0.68	0	-1
0.421219	3	0.97	3.09	3
0.447299	0	0.06	0	0
0.493765	0	0.27	0	0
0.502071	7	10.97	0.64	-7
0.503748	1	2.05	0.49	-2
0.507659	3	5.62	0.53	-4
0.554769	0	0.37	0	-1
0.694529	7	0.62	11.35	11
Seconds/sweep at blade tip				
0.2726	33	29.83	1.11	5
0.3438 – –0.4938	8	9.55	0.84	-3
0.5021 – –0.6945	18	19.62	0.92	-3
Rotor plane (m^2) swept/s **				
1498.8	0	3.07	0	-5
1518.1	0	0.68	0	-1
1660.5	1	2.05	0.49	-2
1718.4	3	0.97	3.09	3
1795.7	5	4.20	1.19	1
1859.3	0	0.37	0	-1
2141.4	7	10.97	0.64	-7
2780.4	0	0.30	0	-1
3049.7	3	5.62	0.53	-4
3286.5	33	29.83	1.11	5
4014.2	0	0.06	0	0
4487.2	7	0.62	11.35	11
5645.9	0	0.27	0	0
Rotor plane (m^2) swept/s **				
1499 - –1859	9	11.34	0.79	-4
2141	7	10.97	0.64	-7
2780 - –3287	36	35.75	1.01	0
4014 - –5646	7	0.95	7.41	10
Tower type				
Vertical axis	1	2.42	0.41	-2
Tubular	18	22.43	0.80	-8
Lattice	40	34.15	1.17	10
Tower height (m)				
14.0	2	1.54	1.30	1
18.5	20	21.85	0.92	-3

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
24.0	0	0.30	0	-1
24.6	33	25.80	1.28	12
25.2	3	5.58	0.54	-4
29.5	1	2.05	0.49	-2
32.3	0	0.37	0	-1
36.9	0	0.05	0	0
43.1	0	1.46	0	-2
Tower height (m)				
14.0	2	1.54	1.30	1
18.5	20	21.85	0.92	-3
24.0 – –25.2	36	31.69	1.14	7
29.5 – –32.3	1	2.42	0.41	-2
36.9 – –43.1	0	1.50	0	-3
Rotor orientation to wind				
Faces wind	29	32.55	0.89	-6
Away from wind	29	24.03	1.21	8
Vertical axis	1	2.42	0.41	-2
Blade color scheme **				
White	53	57.59	0.92	-8
Black stripes	3	0.24	12.38	5
Red stripes	0	0.05	0	0
Red tips	1	0.50	1.98	1
Green tips	2	0.62	3.24	2
Perch guard				
None	58	58.36	0.99	-1
Wire netting	1	0.64	1.56	1
Derelict turbines				
Operating and away from derelict	58	54.42	1.07	6
Derelict	0	2.05	0	-3
Next to derelict	1	2.53	0.39	-3
Height (m) of low blade reach **				
4.0	1	2.42	0.41	-2
5.1	2	1.54	1.30	1
8.0	7	0.62	11.35	11
8.9	0	0.27	0	0
9.6	20	18.15	1.10	3
11.1	0	0.63	0	-1
11.8	0	3.07	0	-5
12.0	0	0.06	0	0
13.5	3	5.58	0.54	-4
14.4	0	0.30	0	-1
14.9	7	10.97	0.64	-7
15.7	11	8.69	1.27	4
16.6	8	5.16	1.55	5
17.2	0	0.05	0	0
25.2	0	0.04	0	0

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
28.9	0	0.01	0	0
34.2	0	1.46	0	-2
Height (m) of low blade reach *				
4.0 – –5.1	3	3.96	0.76	-2
8.0 – –9.6	27	19.03	1.42	14
11.1 – –14.85	10	20.62	0.48	-18
15.7 – –17.2	19	13.89	1.37	9
25.2 – –34.2	0	1.50	0	-3
Height (m) of high blade reach **				
22.9	2	1.54	1.30	1
25.3	0	3.07	0	-5
25.9	0	0.63	0	-1
27.4	20	18.15	1.10	3
29.5	1	2.05	0.49	-2
32.0	0	0.05	0	0
32.3	0	0.37	0	-1
32.6	8	5.16	1.55	5
33.5	11	8.69	1.27	4
33.6	0	0.30	0	-1
34.4	7	10.97	0.64	-7
36.9	3	5.58	0.54	-4
37.2	0	0.06	0	0
40.3	0	0.27	0	0
41.2	7	0.62	11.35	11
44.9	0	0.01	0	0
48.6	0	0.04	0	0
52.0	0	1.46	0	-2
Height (m) of high blade reach				
22.9 – –27.4	22	23.39	0.94	-2
29.5 – –33.6	20	16.61	1.20	6
34.4	7	10.97	0.64	-7
36.9 – –52.0	10	8.03	1.25	3
Wind wall				
Not in wind wall	50	50.73	0.99	-1
In wind wall	9	8.28	1.09	1
Position in string				
End	16	13.08	1.22	5
Edge of gap	6	5.29	1.14	1
Interior	37	40.40	0.92	-6
Non-operational	0	0.19	0	0
Location in wind farm				
Edge of farm	10	7.71	1.30	4
Edge of local cluster	9	6.12	1.47	5
Interior of wind farm	40	44.99	0.89	-8
Turbine congestion (no. in 300 m)				
0 - –12	8	6.77	1.18	2

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
13 - –24	31	26.70	1.16	7
25 - –36	11	14.44	0.76	-6
37 - –72	9	11.04	0.82	-3
Elevation (m) *				
85 - –135	12	8.79	1.36	5
135 - –185	4	12.43	0.32	-14
185 - –235	6	7.93	0.76	-3
235 - –285	6	3.68	1.63	4
285 - –335	8	10.22	0.78	-4
335 - –385	7	6.79	1.03	0
385 - –535	16	9.12	1.75	12
Slope grade (degrees)				
0	21	23.46	0.90	-4
2 - –5	9	4.65	1.93	7
6 - –14	17	14.43	1.18	4
15 - –58	12	16.42	0.73	-7
Physical relief [t]				
Peak	0	1.01	0	-2
Plateau	4	4.09	0.98	0
Ridge crest	22	18.98	1.16	5
Ridgeline	18	11.94	1.51	10
Slope	10	19.90	0.50	-17
Saddle	4	2.62	1.53	2
Ravine	1	0.44	2.26	1
Canyon				
Not in canyon	50	50.00	1.00	0
In canyon	9	9.00	1.00	0
Slope aspect				
None (flat)	16	17.06	0.94	-2
North-facing	4	8.55	0.47	-8
Northeast	5	3.83	1.31	2
East	5	4.97	1.01	0
Southeast	7	6.70	1.04	1
South	10	4.86	2.06	9
Southwest	0	1.03	0	-2
West	3	2.19	1.37	1
Northwest	9	9.71	0.93	-1
Slope aspect				
None (flat)	16	17.06	0.94	-2
East-northeast	10	8.80	1.14	2
South-southeast	17	11.56	1.47	9
West-southwest	3	3.22	0.93	0
North-northwest	13	18.27	0.71	-9
Edge index at tower base				
No edge	2	2.25	0.89	0
Some lateral edge	6	5.64	1.06	1

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Lots lateral edge	18	18.46	0.98	-1
Some vertical edge	18	18.83	0.96	-1
Lots vertical edge	11	12.12	0.91	-2
Lots vertical and lateral edge	4	1.70	2.36	4
Rockpiles ≤ 50 m away				
None	39	37.63	1.04	3
1	6	4.14	1.45	4
≥ 2	0	3.24	0	-7
Rodent control through 2001				
Unknown	1	0.71	1.40	0
None	14	13.61	1.03	1
Control	11	15.79	0.70	-8
Intense control	33	28.89	1.14	7
Rodent control through 2002				
Unknown	1	0.71	1.40	0
None	13	10.05	1.29	5
Control	11	15.80	0.70	-8
Intense control	34	32.43	1.05	3
Cattle pats 40 m from turbines				
0	4	4.19	0.96	0
1 - –9	20	21.01	0.95	-2
10 - –25	15	14.07	1.07	2
> 25	5	4.74	1.06	1
Cattle pats at turbines				
0 - –2	5	5.72	0.87	-2
3 - –9	21	14.95	1.40	14
10 - –25	10	14.40	0.69	-10
> 25	8	8.94	0.90	-2
Cottontails 40 m from turbines				
No pellets	36	34.22	1.05	4
Some pellets	6	7.74	0.78	-4
Abundant pellets	2	2.04	0.98	0
Cottontails at turbines				
No pellets	33	33.52	0.98	-1
Some pellets	7	7.67	0.91	-2
Abundant pellets	4	2.81	1.42	3
Vegetation height (cm)				
0 - –10	10	7.57	1.32	6
11 - –20	13	14.27	0.91	-3
21 - –35	9	13.39	0.67	-10
> 35	12	8.77	1.37	7
Pocket gopher clusting				
Obs/Exp in 15 m = 0	0	1.22	0	-7
Obs/Exp in 15 m < 1.5	3	2.02	1.49	5
Obs/Exp in 15 m = 1.5-3.0	6	6.88	0.87	-5
Obs/Exp in 15 m > 3	9	7.89	1.14	6

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Ground squirrel clustering [t]				
Obs/Exp in 15 m = 0	5	6.34	0.79	-7
Obs/Exp in 15 m ≤ 1.14	4	6.98	0.57	-17
Obs/Exp in 15 m > 1.14	9	4.68	1.92	24
Pocket gopher density ≤ 90 m *				
0 – –1.4/ha	12	6.20	1.94	32
1.41 – –3.5/ha	2	5.86	0.34	-21
> 3.5/ha	4	5.91	0.68	-11
Ground squirrel density ≤ 90 m				
0/ha	4	3.21	1.25	4
0.01 – –5.99/ha	12	10.53	1.14	8
≥ 6/ha	2	4.26	0.47	-13
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	2	3.73	0.54	-10
Obs/Exp in 15 m = 1.2–-3.0	11	9.34	1.18	9
Obs/Exp in 15 m > 3	5	4.93	1.01	0
Density of all burrow systems				
< 5/ha	9	6.93	1.30	11
5 – –9/ha	6	5.30	1.13	4
> 9/ha	3	5.77	0.52	-15
Season of the year [t]				
Spring	12	15.97	0.75	-7
Summer	11	14.23	0.77	-6
Fall	7	10.01	0.70	-5
Winter	27	16.79	1.61	18

Table C4. Chi-square test statistics and derived measures of effect for burrowing owls.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model **				
Micon	8	4.91	1.63	4
Bonus	31	19.40	1.60	17
Danwin	0	0.36	0	-1
Flowind	10	2.83	3.54	10
Windmatic	0	0.79	0	-1
Enertech	6	3.59	1.67	3
KCS-56	14	34.89	0.4	-30
KVS-33	0	0.72	0	-1
Howden	0	0.31	0	0
Nordtank	0	1.14	0	-2
W.E.G.	0	0.07	0	0
Rated turbine power (kW) **				
40	6	3.59	1.67	3
65	8	6.84	1.17	2
100	14	34.89	0.40	-30
110	0	0.36	0	-1
120	22	12.83	1.72	13
150	17	8.96	1.90	12
250	2	0.51	3.96	2
330	0	0.31	0	0
400	0	0.72	0	-1
Rotor diameter (m) **				
13.5 – –14.8	6	4.39	1.37	2
16.0	8	6.05	1.32	3
17.2 – –17.8	22	37.28	0.59	-22
19.1 – –19.5	24	13.61	1.76	15
23.4 – –25.2	9	6.64	1.36	3
31.4 – –33.2	0	1.03	0	-1
Blade tip speed (kph) **				
136.77	0	0.79	0	-1
143.20	0	1.14	0	-2
146.42	22	12.83	1.72	13
148.03	6	3.59	1.67	3
149.64	8	4.91	1.63	4
173.77	9	6.57	1.37	4
180.21	0	0.72	0	-1
193.08	8	2.75	2.91	8
194.69	2	0.43	4.62	2
212.39	0	0.07	0	0
239.74	0	0.31	0	0
246.18	14	34.89	0.40	-30
Blade tip speed (kph) **				
137.77 – –149.64	36	23.26	1.55	18
173.77 – –194.69	19	10.47	1.81	12

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	14	35.27	0.40	-31
Seconds/sweep at blade tip **				
0.272583	14	34.89	0.40	-30
0.343807	6	3.59	1.67	3
0.374882	0	0.36	0	-1
0.403091	8	4.91	1.63	4
0.407945	0	0.79	0	-1
0.421219	0	1.14	0	-2
0.447299	0	0.07	0	0
0.493765	0	0.31	0	0
0.502071	22	12.83	1.72	13
0.503748	8	2.39	3.34	8
0.507659	9	6.57	1.37	4
0.554769	2	0.43	4.62	2
0.694529	0	0.72	0	-1
Seconds/sweep at blade tip **				
0.2726	14	34.89	0.40	-30
0.3438 – –0.4938	14	11.17	1.25	4
0.5021 – –0.6945	41	22.95	1.79	26
Rotor plane (m^2) swept/s **				
1498.8	6	3.59	1.67	3
1518.1	0	0.79	0	-1
1660.5	8	2.39	3.34	8
1718.4	0	1.14	0	-2
1795.7	8	4.91	1.63	4
1859.3	2	0.43	4.62	2
2141.4	22	12.83	1.72	13
2780.4	0	0.36	0	-1
3049.7	9	6.57	1.37	4
3286.5	14	34.89	0.40	-30
4014.2	0	0.07	0	0
4487.2	0	0.72	0	-1
5645.9	0	0.31	0	0
Rotor plane (m^2) swept/s **				
1499 - –1859	24	13.26	1.81	16
2141	22	12.83	1.72	13
2780 - –3287	23	41.81	0.55	-27
4014 - –5646	0	1.11	0	-2
Tower type **				
Vertical axis	10	2.83	3.54	10
Tubular	39	26.23	1.49	19
Lattice	20	39.94	0.50	-29
Tower height (m) **				
14.0	0	1.80	0	-3
18.5	18	25.55	0.70	-11
24.0	0	0.36	0	-1
24.6	32	30.18	1.06	3

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	9	6.53	1.38	4
29.5	8	2.39	3.34	8
32.3	2	0.43	4.62	2
36.9	0	0.05	0	0
43.1	0	1.70	0	-2
Tower height (m) **				
14.0	0	1.80	0	-3
18.5	18	25.55	0.70	-11
24.0 – –25.2	41	37.06	1.11	6
29.5 – –32.3	10	2.83	3.54	10
36.9 – –43.1	0	1.76	0	-3
Rotor orientation to wind **				
Faces wind	40	38.07	1.05	3
Away from wind	19	28.10	0.68	-13
Vertical axis	10	2.83	3.54	10
Blade color scheme				
White	69	67.35	1.02	2
Black stripes	0	0.28	0	0
Red stripes	0	0.06	0	0
Red tips	0	0.59	0	-1
Green tips	0	0.72	0	-1
Perch guard				
None	69	68.25	1.01	1
Wire netting	0	0.75	0	-1
Derelict turbines				
Operating and away from derelict	60	63.64	0.94	-5
Derelict	5	2.40	2.08	4
Next to derelict	4	2.96	1.35	2
Height (m) of low blade reach **				
4.0	10	2.83	3.54	10
5.1	0	1.80	0	-3
8.0	0	0.72	0	-1
8.9	0	0.31	0	0
9.6	12	21.22	0.57	-13
11.1	0	0.74	0	-1
11.8	6	3.59	1.67	3
12.0	0	0.07	0	0
13.5	9	6.53	1.38	4
14.4	0	0.36	0	-1
14.9	22	12.83	1.72	13
15.7	2	10.16	0.20	-12
16.6	8	6.03	1.33	3
17.2	0	0.05	0	0
25.2	0	0.04	0	0
28.9	0	0.01	0	0
34.2	0	1.70	0	-2
Height (m) of low blade reach **				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	10	4.63	2.16	8
8.0 – –9.6	12	22.25	0.54	-15
11.1 – –14.85	37	24.11	1.53	19
15.7 – –17.2	10	16.25	0.62	-9
25.2 – –34.2	0	1.76	0	-3
Height (m) of high blade reach **				
22.9	0	1.80	0	-3
25.3	6	3.59	1.67	3
25.9	0	0.74	0	-1
27.4	12	21.22	0.57	-13
29.5	8	2.39	3.34	8
32.0	0	0.05	0	0
32.3	2	0.43	4.62	2
32.6	8	6.03	1.33	3
33.5	2	10.16	0.20	-12
33.6	0	0.36	0	-1
34.4	22	12.83	1.72	13
36.9	9	6.53	1.38	4
37.2	0	0.07	0	0
40.3	0	0.31	0	0
41.2	0	0.72	0	-1
44.9	0	0.01	0	0
48.6	0	0.04	0	0
52.0	0	1.70	0	-2
Height (m) of high blade reach *				
22.9 – –27.4	18	27.35	0.66	-14
29.5 – –33.6	20	19.43	1.03	1
34.4	22	12.83	1.72	13
36.9 – –52.0	9	9.39	0.96	-1
Wind wall **				
Not in wind wall	68	59.32	1.15	13
In wind wall	1	9.68	0.10	-13
Position in string **				
End	32	15.30	2.09	24
Edge of gap	7	6.18	1.13	1
Interior	29	47.24	0.61	-26
Non-operational	1	0.23	4.43	1
Location in wind farm				
Edge of farm	5	9.02	0.55	-6
Edge of local cluster	5	7.15	0.70	-3
Interior of wind farm	59	52.62	1.12	9
Turbine congestion (no. in 300 m)				
0 - –12	12	7.91	1.52	6
13 - –24	36	31.22	1.15	7
25 - –36	14	16.89	0.83	-4
37 - –72	7	12.91	0.54	-9
Elevation (m) **				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	17	10.28	1.65	10
135 - –185	24	14.54	1.65	14
185 - –235	23	9.27	2.48	20
235 - –285	2	4.31	0.46	-3
285 - –335	0	11.95	0	-17
335 - –385	3	7.94	0.38	-7
385 - –535	0	10.67	0	-15
Slope grade (degrees)				
0	27	27.44	0.98	-1
2 - –5	5	5.44	0.92	-1
6 - –14	13	16.87	0.77	-6
15 - –58	24	19.20	1.25	7
Physical relief				
Peak	0	1.17	0	-2
Plateau	5	4.72	1.06	0
Ridge crest	22	21.88	1.01	0
Ridgeline	8	13.76	0.58	-8
Slope	29	22.93	1.26	9
Saddle	3	3.02	1.00	0
Ravine	1	0.51	1.96	1
Canyon [t]				
Not in canyon	54	58.48	0.92	-6
In canyon	15	10.52	1.43	6
Slope aspect				
None (flat)	19	19.95	0.95	-1
North-facing	11	10.00	1.10	1
Northeast	4	4.48	0.89	-1
East	7	5.82	1.20	2
Southeast	4	7.84	0.51	-6
South	12	5.68	2.11	9
Southwest	1	1.20	0.83	0
West	1	2.56	0.39	-2
Northwest	10	11.36	0.88	-2
Slope aspect				
None (flat)	19	19.95	0.95	-1
East-northeast	11	10.29	1.07	1
South-southeast	16	13.52	1.18	4
West-southwest	2	3.76	0.53	-3
North-northwest	21	21.36	0.98	-1
Edge index at tower base				
No edge	2	2.64	0.76	-1
Some lateral edge	7	6.59	1.06	1
Lots lateral edge	13	21.59	0.60	-12
Some vertical edge	30	22.03	1.36	12
Lots vertical edge	16	14.18	1.13	3
Lots vertical and lateral edge	1	1.98	0.50	-1
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	51	56.02	0.91	-7
1	9	6.16	1.46	4
≥ 2	7	4.82	1.45	3
Rodent control through 2001 **				
Unknown	2	0.84	2.40	2
None	13	15.92	0.82	-4
Control	35	18.46	1.90	24
Intense control	19	33.79	0.56	-21
Rodent control through 2002 **				
Unknown	2	0.84	2.40	2
None	5	11.75	0.43	-10
Control	35	18.48	1.89	24
Intense control	27	37.93	0.71	-16
Cattle pats 40 m from turbines [t]				
0	0	6.18	0	-10
1 - –9	32	31.04	1.03	1
10 - –25	24	20.78	1.16	5
> 25	9	7.00	1.29	3
Cattle pats at turbines *				
0 - –2	4	8.45	0.47	-7
3 - –9	15	22.08	0.68	-11
10 - –25	25	21.27	1.18	6
> 25	21	13.20	1.59	12
Cottontails 40 m from turbines				
No pellets	50	50.56	0.99	-1
Some pellets	11	11.43	0.96	-1
Abundant pellets	4	3.01	1.33	2
Cottontails at turbines				
No pellets	46	49.52	0.93	-5
Some pellets	16	11.33	1.41	7
Abundant pellets	3	4.15	0.72	-2
Vegetation height (cm)				
0 - –10	10	11.18	0.89	-2
11 - –20	24	21.09	1.14	4
21 - –35	19	19.78	0.96	-1
> 35	12	12.96	0.93	-1
Pocket gopher clusting [t]				
Obs/Exp in 15 m = 0	1	1.89	0.53	-3
Obs/Exp in 15 m < 1.5	7	3.14	2.23	14
Obs/Exp in 15 m = 1.5–-3.0	7	10.70	0.65	-13
Obs/Exp in 15 m > 3	13	12.28	1.06	3
Ground squirrel clustering				
Obs/Exp in 15 m = 0	5	9.87	0.51	-17
Obs/Exp in 15 m ≤ 1.14	12	10.85	1.11	4
Obs/Exp in 15 m > 1.14	11	7.28	1.51	13
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	7	9.29	0.75	-8

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	12	8.79	1.36	12
> 3.5/ha	8	8.87	0.90	-3
Ground squirrel density ≤ 90 m				
0/ha	1	4.99	0.20	-14
0.01 – –5.99/ha	20	16.38	1.22	13
≥ 6/ha	7	6.63	1.06	1
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	7	5.80	1.21	4
Obs/Exp in 15 m = 1.2–-3.0	16	14.53	1.10	5
Obs/Exp in 15 m > 3	5	7.67	0.65	-10
Density of all burrow systems				
< 5/ha	8	10.79	0.74	-10
5 – –9/ha	10	8.24	1.21	6
> 9/ha	10	8.98	1.11	4
Season of the year**				
Spring	3	19.05	0.16	-24
Summer	31	16.98	1.83	21
Fall	10	11.94	0.84	-3
Winter	24	20.03	1.20	6

Table C5. Chi-square test statistics and derived measures of effect for barn owls.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model				
Micon	1	3.49	0.29	-5
Bonus	17	13.77	1.23	7
Danwin	0	0.25	0	-1
Flowind	3	2.01	1.49	2
Windmatic	0	0.56	0	-1
Enertech	0	2.55	0	-5
KCS-56	26	24.77	1.05	3
KVS-33	1	0.51	1.95	1
Howden	0	0.22	0	0
Nordtank	1	0.81	1.24	0
W.E.G.	0	0.05	0	0
Rated turbine power (kW)				
40	0	2.55	0	-5
65	2	4.86	0.41	-6
100	26	24.77	1.05	3
110	0	0.25	0	-1
120	11	9.11	1.21	4
150	9	6.37	1.41	5
250	0	0.36	0	-1
330	0	0.22	0	0
400	1	0.51	1.95	1
Rotor diameter (m)				
13.5 – –14.8	0	3.12	0	-6
16.0	2	4.29	0.47	-5
17.2 – –17.8	29	26.47	1.10	5
19.1 – –19.5	11	9.67	1.14	3
23.4 – –25.2	6	4.72	1.27	3
31.4 – –33.2	1	0.73	1.36	1
Blade tip speed (kph)				
136.77	0	0.56	0	-1
143.20	1	0.81	1.24	0
146.42	11	9.11	1.21	4
148.03	0	2.55	0	-5
149.64	1	3.49	0.29	-5
173.77	6	4.67	1.29	3
180.21	1	0.51	1.95	1
193.08	3	1.95	1.54	2
194.69	0	0.31	0	-1
212.39	0	0.05	0	0
239.74	0	0.22	0	0
246.18	26	24.77	1.05	3
Blade tip speed (kph)				
137.77 – –149.64	13	16.52	0.79	-7
173.77 – –194.69	10	7.44	1.34	5

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	26	25.05	1.04	2
Seconds/sweep at blade tip				
0.272583	26	24.77	1.05	3
0.343807	0	2.55	0	-5
0.374882	0	0.25	0	-1
0.403091	1	3.49	0.29	-5
0.407945	0	0.56	0	-1
0.421219	1	0.81	1.24	0
0.447299	0	0.05	0	0
0.493765	0	0.22	0	0
0.502071	11	9.11	1.21	4
0.503748	3	1.70	1.76	3
0.507659	6	4.67	1.29	3
0.554769	0	0.31	0	-1
0.694529	1	0.51	1.95	1
Seconds/sweep at blade tip [t]				
0.2726	26	24.77	1.05	3
0.3438 – –0.4938	2	7.93	0.25	-12
0.5021 – –0.6945	21	16.29	1.29	10
Rotor plane (m^2) swept/s				
1498.8	0	2.55	0	-5
1518.1	0	0.56	0	-1
1660.5	3	1.70	1.76	3
1718.4	1	0.81	1.24	0
1795.7	1	3.49	0.29	-5
1859.3	0	0.31	0	-1
2141.4	11	9.11	1.21	4
2780.4	0	0.25	0	-1
3049.7	6	4.67	1.29	3
3286.5	26	24.77	1.05	3
4014.2	0	0.05	0	0
4487.2	1	0.51	1.95	1
5645.9	0	0.22	0	0
Rotor plane (m^2) swept/s				
1499 - –1859	5	9.42	0.53	-9
2141	11	9.11	1.21	4
2780 - –3287	32	29.69	1.08	5
4014 - –5646	1	0.79	1.27	0
Tower type				
Vertical axis	3	2.01	1.49	2
Tubular	19	18.63	1.02	1
Lattice	27	28.36	0.95	-3
Tower height (m)				
14.0	0	1.28	0	-3
18.5	13	18.15	0.72	-11
24.0	0	0.25	0	-1
24.6	27	21.43	1.26	11

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	6	4.64	1.29	3
29.5	3	1.70	1.76	3
32.3	0	0.31	0	-1
36.9	0	0.04	0	0
43.1	0	1.21	0	-2
Tower height (m)				
14.0	0	1.28	0	-3
18.5	13	18.15	0.72	-11
24.0 – –25.2	33	26.32	1.25	14
29.5 – –32.3	3	2.01	1.49	2
36.9 – –43.1	0	1.25	0	-3
Rotor orientation to wind				
Faces wind	27	27.04	1.00	0
Away from wind	19	19.96	0.95	-2
Vertical axis	3	2.01	1.49	2
Blade color scheme **				
White	47	47.83	0.98	-2
Black stripes	0	0.20	0	0
Red stripes	1	0.04	24.56	2
Red tips	1	0.42	2.39	1
Green tips	0	0.51	0	-1
Perch guard				
None	49	48.47	1.01	1
Wire netting	0	0.53	0	-1
Derelict turbines				
Operating and away from derelict	42	45.19	0.93	-7
Derelict	3	1.70	1.76	3
Next to derelict	4	2.10	1.90	4
Height (m) of low blade reach				
4.0	3	2.01	1.49	2
5.1	0	1.28	0	-3
8.0	1	0.51	1.95	1
8.9	0	0.22	0	0
9.6	13	15.07	0.86	-4
11.1	0	0.53	0	-1
11.8	0	2.55	0	-5
12.0	0	0.05	0	0
13.5	6	4.64	1.29	3
14.4	0	0.25	0	-1
14.9	11	9.11	1.21	4
15.7	13	7.22	1.80	12
16.6	2	4.28	0.47	-5
17.2	0	0.04	0	0
25.2	0	0.03	0	0
28.9	0	0.01	0	0
34.2	0	1.21	0	-2
Height (m) of low blade reach				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	3	3.29	0.91	-1
8.0 – –9.6	14	15.80	0.89	-4
11.1 – –14.85	17	17.13	0.99	0
15.7 – –17.2	15	11.54	1.30	7
25.2 – –34.2	0	1.25	0	-3
Height (m) of high blade reach				
22.9	0	1.28	0	-3
25.3	0	2.55	0	-5
25.9	0	0.53	0	-1
27.4	13	15.07	0.86	-4
29.5	3	1.70	1.76	3
32.0	0	0.04	0	0
32.3	0	0.31	0	-1
32.6	2	4.28	0.47	-5
33.5	13	7.22	1.80	12
33.6	0	0.25	0	-1
34.4	11	9.11	1.21	4
36.9	6	4.64	1.29	3
37.2	0	0.05	0	0
40.3	0	0.22	0	0
41.2	1	0.51	1.95	1
44.9	0	0.01	0	0
48.6	0	0.03	0	0
52.0	0	1.21	0	-2
Height (m) of high blade reach				
22.9 – –27.4	13	19.43	0.67	-13
29.5 – –33.6	18	13.80	1.30	9
34.4	11	9.11	1.21	4
36.9 – –52.0	7	6.67	1.05	1
Wind wall				
Not in wind wall	43	42.13	1.02	2
In wind wall	6	6.87	0.87	-2
Position in string [t]				
End	14	10.86	1.29	6
Edge of gap	6	4.39	1.37	3
Interior	28	33.55	0.83	-11
Non-operational	1	0.16	6.24	2
Location in wind farm *				
Edge of farm	6	6.40	0.94	-1
Edge of local cluster	11	5.08	2.17	12
Interior of wind farm	32	37.37	0.86	-11
Turbine congestion (no. in 300 m) *				
0 - –12	8	5.62	1.42	5
13 - –24	31	22.17	1.40	18
25 - –36	7	11.99	0.58	-10
37 - –72	3	9.17	0.33	-13
Elevation (m)				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	4	7.30	0.55	-7
135 - –185	12	10.33	1.16	3
185 - –235	9	6.59	1.37	5
235 - –285	2	3.06	0.65	-2
285 - –335	10	8.49	1.18	3
335 - –385	9	5.64	1.60	7
385 - –535	3	7.57	0.40	-9
Slope grade (degrees) [t]				
0	8	19.49	0.41	-23
2 - –5	5	3.87	1.29	2
6 - –14	14	11.98	1.17	4
15 - –58	22	13.63	1.61	17
Physical relief				
Peak	0	0.84	0	-2
Plateau	3	3.40	0.88	-1
Ridge crest	12	15.77	0.76	-8
Ridgeline	18	9.92	1.82	16
Slope	14	16.52	0.85	-5
Saddle	2	2.17	0.92	0
Ravine	0	0.37	0	-1
Canyon **				
Not in canyon	29	41.53	0.70	-26
In canyon	20	7.47	2.68	26
Slope aspect **				
None (flat)	8	14.17	0.56	-13
North-facing	9	7.11	1.27	4
Northeast	1	3.18	0.31	-4
East	4	4.13	0.97	0
Southeast	4	5.57	0.72	-3
South	0	4.04	0	-8
Southwest	1	0.86	1.17	0
West	4	1.82	2.20	4
Northwest	18	8.07	2.23	20
Slope aspect **				
None (flat)	8	14.17	0.56	-13
East-northeast	5	7.31	0.68	-5
South-southeast	4	9.60	0.42	-11
West-southwest	5	2.67	1.87	5
North-northwest	27	15.17	1.78	24
Edge index at tower base				
No edge	2	1.87	1.07	0
Some lateral edge	3	4.68	0.64	-3
Lots lateral edge	14	15.33	0.91	-3
Some vertical edge	15	15.64	0.96	-1
Lots vertical edge	13	10.07	1.29	6
Lots vertical and lateral edge	2	1.41	1.42	1
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	35	34.28	1.02	2
1	2	3.77	0.53	-4
≥ 2	4	2.95	1.36	3
Rodent control through 2001				
Unknown	0	0.59	0	-1
None	7	11.30	0.62	-9
Control	20	13.11	1.53	14
Intense control	22	23.99	0.92	-4
Rodent control through 2002				
Unknown	0	0.59	0	-1
None	7	8.35	0.84	-3
Control	20	13.12	1.52	14
Intense control	22	26.94	0.82	-10
Cattle pats 40 m from turbines **				
0	3	3.52	0.85	-1
1 - –9	22	17.67	1.25	12
10 - –25	2	11.83	0.17	-27
> 25	10	3.98	2.51	16
Cattle pats at turbines				
0 - –2	5	4.81	1.04	1
3 - –9	9	12.57	0.72	-10
10 - –25	17	12.11	1.40	13
> 25	6	7.52	0.80	-4
Cottontails 40 m from turbines				
No pellets	29	28.78	1.01	1
Some pellets	7	6.51	1.08	1
Abundant pellets	1	1.71	0.58	-2
Cottontails at turbines				
No pellets	33	28.19	1.17	13
Some pellets	3	6.45	0.47	-9
Abundant pellets	1	2.36	0.42	-4
Vegetation height (cm)				
0 - –10	8	6.36	1.26	4
11 - –20	13	12.00	1.08	3
21 - –35	6	11.26	0.53	-14
> 35	10	7.38	1.36	7
Pocket gopher clusting				
Obs/Exp in 15 m = 0	2	1.15	1.74	5
Obs/Exp in 15 m < 1.5	0	1.91	0	-11
Obs/Exp in 15 m = 1.5–-3.0	6	6.50	0.92	-3
Obs/Exp in 15 m > 3	9	7.45	1.21	9
Ground squirrel clustering				
Obs/Exp in 15 m = 0	4	5.99	0.67	-12
Obs/Exp in 15 m ≤ 1.14	6	6.59	0.91	-3
Obs/Exp in 15 m > 1.14	7	4.42	1.58	15
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	8	5.85	1.37	13

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	5	5.54	0.90	-3
> 3.5/ha	4	5.58	0.72	-9
Ground squirrel density ≤ 90 m				
0/ha	1	3.03	0.33	-12
0.01 – –5.99/ha	14	9.95	1.41	24
≥ 6/ha	2	4.03	0.50	-12
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	5	3.52	1.42	9
Obs/Exp in 15 m = 1.2–-3.0	10	8.82	1.13	7
Obs/Exp in 15 m > 3	2	4.66	0.43	-16
Density of all burrow systems				
< 5/ha	7	6.55	1.07	3
5 – –9/ha	7	5.00	1.40	12
> 9/ha	3	5.45	0.55	-14
Season of the year				
Spring	6	11.49	0.52	-13
Summer	16	10.24	1.56	14
Fall	7	7.20	0.97	0
Winter	12	12.08	0.99	0

Table C6. Chi-square test statistics and derived measures of effect for great horned owls.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model				
Micon	2	1.28	1.56	4
Bonus	3	5.06	0.59	-11
Danwin	0	0.09	0	-1
Flowind	0	0.74	0	-4
Windmatic	0	0.21	0	-1
Enertech	0	0.94	0	-5
KCS-56	13	9.10	1.43	22
KVS-33	0	0.19	0	-1
Howden	0	0.08	0	0
Nordtank	0	0.30	0	-2
W.E.G.	0	0.02	0	0
Rated turbine power (kW)				
40	0	0.94	0	-5
65	2	1.78	1.12	1
100	13	9.10	1.43	22
110	0	0.09	0	-1
120	1	3.35	0.30	-13
150	2	2.34	0.86	-2
250	0	0.13	0	-1
330	0	0.08	0	0
400	0	0.19	0	-1
Rotor diameter (m)				
13.5 – –14.8	0	1.14	0	-6
16.0	2	1.58	1.27	2
17.2 – –17.8	13	9.73	1.34	18
19.1 – –19.5	1	3.55	0.28	-14
23.4 – –25.2	2	1.73	1.15	1
31.4 – –33.2	0	0.27	0	-1
Blade tip speed (kph)				
136.77	0	0.21	0	-1
143.20	0	0.30	0	-2
146.42	1	3.35	0.30	-13
148.03	0	0.94	0	-5
149.64	2	1.28	1.56	4
173.77	2	1.71	1.17	2
180.21	0	0.19	0	-1
193.08	0	0.72	0	-4
194.69	0	0.11	0	-1
212.39	0	0.02	0	0
239.74	0	0.08	0	0
246.18	13	9.10	1.43	22
Blade tip speed (kph)				
137.77 – –149.64	3	6.07	0.49	-17
173.77 – –194.69	2	2.73	0.73	-4

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	13	9.20	1.41	21
Seconds/sweep at blade tip				
0.272583	13	9.10	1.43	22
0.343807	0	0.94	0	-5
0.374882	0	0.09	0	-1
0.403091	2	1.28	1.56	4
0.407945	0	0.21	0	-1
0.421219	0	0.30	0	-2
0.447299	0	0.02	0	0
0.493765	0	0.08	0	0
0.502071	1	3.35	0.30	-13
0.503748	0	0.63	0	-3
0.507659	2	1.71	1.17	2
0.554769	0	0.11	0	-1
0.694529	0	0.19	0	-1
Seconds/sweep at blade tip				
0.2726	13	9.10	1.43	22
0.3438 – –0.4938	2	2.91	0.69	-5
0.5021 – –0.6945	3	5.99	0.50	-17
Rotor plane (m^2) swept/s				
1498.8	0	0.94	0	-5
1518.1	0	0.21	0	-1
1660.5	0	0.63	0	-3
1718.4	0	0.30	0	-2
1795.7	2	1.28	1.56	4
1859.3	0	0.11	0	-1
2141.4	1	3.35	0.30	-13
2780.4	0	0.09	0	-1
3049.7	2	1.71	1.17	2
3286.5	13	9.10	1.43	22
4014.2	0	0.02	0	0
4487.2	0	0.19	0	-1
5645.9	0	0.08	0	0
Rotor plane (m^2) swept/s				
1499 - –1859	2	3.46	0.58	-8
2141	1	3.35	0.30	-13
2780 - –3287	15	10.91	1.38	23
4014 - –5646	0	0.29	0	-2
Tower type				
Vertical axis	0	0.74	0	-4
Tubular	5	6.84	0.73	-10
Lattice	13	10.42	1.25	14
Tower height (m) **				
14.0	1	0.47	2.13	3
18.5	10	6.67	1.50	19
24.0	0	0.09	0	-1
24.6	5	7.87	0.64	-16

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	1	1.70	0.59	-4
29.5	0	0.63	0	-3
32.3	0	0.11	0	-1
36.9	1	0.01	70.52	5
43.1	0	0.45	0	-2
Tower height (m)				
14.0	1	0.47	2.13	3
18.5	10	6.67	1.5	19
24.0 – –25.2	6	9.67	0.62	-20
29.5 – –32.3	0	0.74	0	-4
36.9 – –43.1	1	0.46	2.18	3
Rotor orientation to wind				
Faces wind	8	9.93	0.81	-11
Away from wind	10	7.33	1.36	15
Vertical axis	0	0.74	0	-4
Blade color scheme				
White	17	17.57	0.97	-3
Black stripes	0	0.07	0	0
Red stripes	0	0.02	0	0
Red tips	0	0.15	0	-1
Green tips	1	0.19	5.31	5
Perch guard[t]				
None	17	17.80	0.95	-4
Wire netting	1	0.20	5.11	4
Derelict turbines				
Operating and away from derelict	17	16.60	1.02	2
Derelict	0	0.63	0	-3
Next to derelict	1	0.77	1.29	1
Height (m) of low blade reach **				
4.0	0	0.74	0	-4
5.1	1	0.47	2.13	3
8.0	0	0.19	0	-1
8.9	0	0.08	0	0
9.6	10	5.54	1.81	25
11.1	0	0.19	0	-1
11.8	0	0.94	0	-5
12.0	0	0.02	0	0
13.5	1	1.70	0.59	-4
14.4	0	0.09	0	-1
14.9	1	3.35	0.30	-13
15.7	2	2.65	0.75	-4
16.6	2	1.57	1.27	2
17.2	0	0.01	0	0
25.2	1	0.01	91.68	5
28.9	0	0.00	0	0
34.2	0	0.45	0	-2
Height (m) of low blade reach				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	1	1.21	0.83	-1
8.0 – –9.6	10	5.81	1.72	23
11.1 – –14.85	2	6.29	0.32	-24
15.7 – –17.2	4	4.24	0.94	-1
25.2 – –34.2	1	0.46	2.18	3
Height (m) of high blade reach **				
22.9	1	0.47	2.13	3
25.3	0	0.94	0	-5
25.9	0	0.19	0	-1
27.4	10	5.54	1.81	25
29.5	0	0.63	0	-3
32.0	0	0.01	0	0
32.3	0	0.11	0	-1
32.6	2	1.57	1.27	2
33.5	2	2.65	0.75	-4
33.6	0	0.09	0	-1
34.4	1	3.35	0.30	-13
36.9	1	1.70	0.59	-4
37.2	0	0.02	0	0
40.3	0	0.08	0	0
41.2	0	0.19	0	-1
44.9	0	0.00	0	0
48.6	1	0.01	91.68	5
52.0	0	0.45	0	-2
Height (m) of high blade reach				
22.9 – –27.4	11	7.14	1.54	21
29.5 – –33.6	4	5.07	0.79	-6
34.4	1	3.35	0.30	-13
36.9 – –52.0	2	2.45	0.82	-3
Wind wall				
Not in wind wall	15	15.48	0.97	-3
In wind wall	3	2.52	1.19	3
Position in string				
End	5	3.99	1.25	6
Edge of gap	3	1.61	1.86	8
Interior	10	12.32	0.81	-13
Non-operational	0	0.06	0	0
Location in wind farm				
Edge of farm	4	2.35	1.70	9
Edge of local cluster	2	1.87	1.07	1
Interior of wind farm	12	13.73	0.87	-10
Turbine congestion (no. in 300 m)				
0 - –12	2	2.07	0.97	0
13 - –24	8	8.14	0.98	-1
25 - –36	3	4.41	0.68	-8
37 - –72	5	3.37	1.48	9
Elevation (m)				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	2	2.68	0.75	-4
135 - –185	2	3.79	0.53	-10
185 - –235	0	2.42	0	-13
235 - –285	1	1.12	0.89	-1
285 - –335	3	3.12	0.96	-1
335 - –385	3	2.07	1.45	5
385 - –535	7	2.78	2.52	23
Slope grade (degrees)				
0	9	7.16	1.26	10
2 - –5	2	1.42	1.41	3
6 - –14	3	4.40	0.68	-8
15 - –58	4	5.01	0.80	-6
Physical relief **				
Peak	0	0.31	0	-2
Plateau	5	1.25	4	21
Ridge crest	3	5.79	0.52	-16
Ridgeline	4	3.64	1.10	2
Slope	5	6.07	0.82	-6
Saddle	0	0.80	0	-4
Ravine	1	0.14	7.42	5
Canyon				
Not in canyon	17	15.26	1.11	10
In canyon	1	2.75	0.36	-10
Slope aspect				
None (flat)	8	5.20	1.54	16
North-facing	0	2.61	0	-14
Northeast	1	1.17	0.86	-1
East	1	1.52	0.66	-3
Southeast	1	2.05	0.49	-6
South	1	1.48	0.67	-3
Southwest	1	0.31	3.18	4
West	1	0.67	1.50	2
Northwest	4	2.96	1.35	6
Slope aspect				
None (flat)	8	5.20	1.54	16
East-northeast	2	2.68	0.75	-4
South-southeast	2	3.53	0.57	-8
West-southwest	2	0.98	2.04	6
North-northwest	4	5.57	0.72	-9
Edge index at tower base				
No edge	2	0.69	2.91	7
Some lateral edge	1	1.72	0.58	-4
Lots lateral edge	6	5.63	1.07	2
Some vertical edge	6	5.75	1.04	1
Lots vertical edge	3	3.70	0.81	-4
Lots vertical and lateral edge	0	0.52	0	-3
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	10	10.87	0.92	-7
1	3	1.20	2.51	14
≥ 2	0	0.93	0	-7
Rodent control through 2001				
Unknown	0	0.22	0	-1
None	6	4.15	1.44	10
Control	1	4.82	0.21	-21
Intense control	11	8.81	1.25	12
Rodent control through 2002				
Unknown	0	0.22	0	-1
None	5	3.07	1.63	11
Control	1	4.82	0.21	-21
Intense control	12	9.90	1.21	12
Cattle pats 40 m from turbines *				
0	0	1.24	0	-10
1 - –9	8	6.21	1.29	14
10 - –25	1	4.16	0.24	-24
> 25	4	1.40	2.86	20
Cattle pats at turbines				
0 - –2	2	1.69	1.18	2
3 - –9	4	4.42	0.91	-3
10 - –25	3	4.25	0.71	-10
> 25	4	2.64	1.52	10
Cottontails 40 m from turbines				
No pellets	12	10.11	1.19	15
Some pellets	1	2.29	0.44	-10
Abundant pellets	0	0.60	0	-5
Cottontails at turbines				
No pellets	10	9.90	1.01	1
Some pellets	3	2.27	1.32	6
Abundant pellets	0	0.83	0	-6
Vegetation height (cm)				
0 - –10	1	2.24	0.45	-10
11 - –20	4	4.22	0.95	-2
21 - –35	5	3.96	1.26	8
> 35	3	2.59	1.16	3
Pocket gopher clusting				
Obs/Exp in 15 m = 0	1	0.54	1.85	6
Obs/Exp in 15 m < 1.5	2	0.90	2.23	14
Obs/Exp in 15 m = 1.5–-3.0	2	3.06	0.65	-13
Obs/Exp in 15 m > 3	3	3.51	0.86	-6
Ground squirrel clustering				
Obs/Exp in 15 m = 0	4	2.82	1.42	15
Obs/Exp in 15 m ≤ 1.14	2	3.10	0.64	-14
Obs/Exp in 15 m > 1.14	2	2.08	0.96	-1
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	3	2.75	1.09	3

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	3	2.61	1.15	5
> 3.5/ha	2	2.63	0.76	-8
Ground squirrel density ≤ 90 m				
0/ha	2	1.43	1.40	7
0.01 – –5.99/ha	4	4.68	0.85	-9
≥ 6/ha	2	1.90	1.06	1
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	2	1.66	1.21	4
Obs/Exp in 15 m = 1.2–-3.0	4	4.15	0.96	-2
Obs/Exp in 15 m > 3	2	2.19	0.91	-2
Density of all burrow systems				
< 5/ha	3	3.08	0.97	-1
5 – –9/ha	2	2.35	0.85	-4
> 9/ha	3	2.56	1.17	5
Season of the year				
Spring	5	2.80	1.78	22
Summer	2	2.50	0.80	-5
Fall	0	1.76	0	-18
Winter	3	2.95	1.02	1

Table C7. Chi-square test statistics and derived measures of effect for mallards.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model *				
Micon	6	2.35	2.56	11
Bonus	18	9.28	1.94	26
Danwin	0	0.17	0	-1
Flowind	2	1.35	1.48	2
Windmatic	1	0.38	2.64	2
Enertech	0	1.72	0	-5
KCS-56	6	16.68	0.36	-32
KVS-33	0	0.35	0	-1
Howden	0	0.15	0	0
Nordtank	0	0.54	0	-2
W.E.G.	0	0.03	0	0
Rated turbine power (kW) **				
40	0	1.72	0	-5
65	7	3.27	2.14	11
100	6	16.68	0.36	-32
110	0	0.17	0	-1
120	7	6.13	1.14	3
150	13	4.29	3.03	26
250	0	0.24	0	-1
330	0	0.15	0	0
400	0	0.35	0	-1
Rotor diameter (m) **				
13.5 – –14.8	1	2.10	0.48	-3
16.0	6	2.89	2.08	9
17.2 – –17.8	8	17.83	0.45	-30
19.1 – –19.5	7	6.51	1.08	1
23.4 – –25.2	11	3.18	3.46	24
31.4 – –33.2	0	0.49	0	-1
Blade tip speed (kph) **				
136.77	1	0.38	2.64	2
143.20	0	0.54	0	-2
146.42	7	6.13	1.14	3
148.03	0	1.72	0	-5
149.64	6	2.35	2.56	11
173.77	11	3.14	3.50	24
180.21	0	0.35	0	-1
193.08	2	1.32	1.52	2
194.69	0	0.21	0	-1
212.39	0	0.03	0	0
239.74	0	0.15	0	0
246.18	6	16.68	0.36	-32
Blade tip speed (kph) **				
137.77 – –149.64	14	11.12	1.26	9
173.77 – –194.69	13	5.01	2.60	24

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	6	16.87	0.36	-33
Seconds/sweep at blade tip **				
0.272583	6	16.68	0.36	-32
0.343807	0	1.72	0	-5
0.374882	0	0.17	0	-1
0.403091	6	2.35	2.56	11
0.407945	1	0.38	2.64	2
0.421219	0	0.54	0	-2
0.447299	0	0.03	0	0
0.493765	0	0.15	0	0
0.502071	7	6.13	1.14	3
0.503748	2	1.15	1.75	3
0.507659	11	3.14	3.50	24
0.554769	0	0.21	0	-1
0.694529	0	0.35	0	-1
Seconds/sweep at blade tip **				
0.2726	6	16.68	0.36	-32
0.3438 – –0.4938	7	5.34	1.31	5
0.5021 – –0.6945	20	10.97	1.82	27
Rotor plane (m^2) swept/s **				
1498.8	0	1.72	0	-5
1518.1	1	0.38	2.64	2
1660.5	2	1.15	1.75	3
1718.4	0	0.54	0	-2
1795.7	6	2.35	2.56	11
1859.3	0	0.21	0	-1
2141.4	7	6.13	1.14	3
2780.4	0	0.17	0	-1
3049.7	11	3.14	3.50	24
3286.5	6	16.68	0.36	-32
4014.2	0	0.03	0	0
4487.2	0	0.35	0	-1
5645.9	0	0.15	0	0
Rotor plane (m^2) swept/s				
1499 - –1859	9	6.34	1.42	8
2141	7	6.13	1.14	3
2780 - –3287	17	20.00	0.85	-9
4014 - –5646	0	0.53	0	-2
Tower type **				
Vertical axis	2	1.35	1.48	2
Tubular	24	12.55	1.91	35
Lattice	7	19.10	0.37	-37
Tower height (m) **				
14.0	0	0.86	0	-3
18.5	6	12.22	0.49	-19
24.0	0	0.17	0	-1
24.6	14	14.43	0.97	-1

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	11	3.12	3.52	24
29.5	2	1.15	1.75	3
32.3	0	0.21	0	-1
36.9	0	0.03	0	0
43.1	0	0.82	0	-2
Tower height (m) [t]				
14.0	0	0.86	0	-3
18.5	6	12.22	0.49	-19
24.0 – –25.2	25	17.72	1.41	22
29.5 – –32.3	2	1.35	1.48	2
36.9 – –43.1	0	0.84	0	-3
Rotor orientation to wind *				
Faces wind	26	18.21	1.43	24
Away from wind	5	13.44	0.37	-26
Vertical axis	2	1.35	1.48	2
Blade color scheme				
White	33	32.21	1.02	2
Black stripes	0	0.14	0	0
Red stripes	0	0.03	0	0
Red tips	0	0.28	0	-1
Green tips	0	0.35	0	-1
Perch guard				
None	33	32.64	1.01	1
Wire netting	0	0.36	0	-1
Derelict turbines				
Operating and away from derelict	32	30.44	1.05	5
Derelict	0	1.15	0	-3
Next to derelict	1	1.42	0.71	-1
Height (m) of low blade reach **				
4.0	2	1.35	1.48	2
5.1	0	0.86	0	-3
8.0	0	0.35	0	-1
8.9	0	0.15	0	0
9.6	5	10.15	0.49	-16
11.1	1	0.35	2.83	2
11.8	0	1.72	0	-5
12.0	0	0.03	0	0
13.5	11	3.12	3.52	24
14.4	0	0.17	0	-1
14.9	7	6.13	1.14	3
15.7	1	4.86	0.21	-12
16.6	6	2.89	2.08	9
17.2	0	0.03	0	0
25.2	0	0.02	0	0
28.9	0	0.01	0	0
34.2	0	0.82	0	-2
Height (m) of low blade reach [t]				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	2	2.21	0.90	-1
8.0 – –9.6	5	10.64	0.47	-17
11.1 – –14.85	19	11.53	1.65	23
15.7 – –17.2	7	7.77	0.90	-2
25.2 – –34.2	0	0.84	0	-3
Height (m) of high blade reach *				
22.9	0	0.86	0	-3
25.3	0	1.72	0	-5
25.9	1	0.35	2.83	2
27.4	5	10.15	0.49	-16
29.5	2	1.15	1.75	3
32.0	0	0.03	0	0
32.3	0	0.21	0	-1
32.6	6	2.89	2.08	9
33.5	1	4.86	0.21	-12
33.6	0	0.17	0	-1
34.4	7	6.13	1.14	3
36.9	11	3.12	3.52	24
37.2	0	0.03	0	0
40.3	0	0.15	0	0
41.2	0	0.35	0	-1
44.9	0	0.01	0	0
48.6	0	0.02	0	0
52.0	0	0.82	0	-2
Height (m) of high blade reach **				
22.9 – –27.4	6	13.08	0.46	-21
29.5 – –33.6	9	9.29	0.97	-1
34.4	7	6.13	1.14	3
36.9 – –52.0	11	4.49	2.45	20
Wind wall *				
Not in wind wall	33	28.37	1.16	14
In wind wall	0	4.63	0	-14
Position in string **				
End	12	7.32	1.64	14
Edge of gap	9	2.96	3.04	18
Interior	12	22.59	0.53	-32
Non-operational	0	0.11	0	0
Location in wind farm				
Edge of farm	3	4.31	0.70	-4
Edge of local cluster	6	3.42	1.75	8
Interior of wind farm	24	25.16	0.95	-4
Turbine congestion (no. in 300 m) *				
0 - –12	8	3.79	2.11	13
13 - –24	15	14.93	1.00	0
25 - –36	2	8.08	0.25	-18
37 - –72	8	6.18	1.3	6
Elevation (m) **				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	12	4.92	2.44	21
135 - –185	14	6.95	2.01	21
185 - –235	6	4.44	1.35	5
235 - –285	0	2.06	0	-6
285 - –335	1	5.72	0.17	-14
335 - –385	0	3.80	0	-12
385 - –535	0	5.10	0	-15
Slope grade (degrees)				
0	13	13.12	0.99	0
2 - –5	1	2.60	0.38	-5
6 - –14	7	8.07	0.87	-3
15 - –58	12	9.18	1.31	9
Physical relief *				
Peak	0	0.57	0	-2
Plateau	6	2.29	2.62	11
Ridge crest	10	10.62	0.94	-2
Ridgeline	1	6.68	0.15	-17
Slope	15	11.13	1.35	12
Saddle	1	1.46	0.68	-1
Ravine	0	0.25	0	-1
Canyon **				
Not in canyon	16	27.97	0.57	-36
In canyon	17	5.03	3.38	36
Slope aspect [t]				
None (flat)	10	9.54	1.05	1
North-facing	0	4.79	0	-14
Northeast	1	2.14	0.47	-3
East	1	2.78	0.36	-5
Southeast	6	3.75	1.60	7
South	5	2.72	1.84	7
Southwest	1	0.58	1.74	1
West	0	1.22	0	-4
Northwest	9	5.43	1.66	11
Slope aspect				
None (flat)	10	9.54	1.05	1
East-northeast	2	4.92	0.41	-9
South-southeast	11	6.47	1.70	14
West-southwest	1	1.80	0.56	-2
North-northwest	9	10.22	0.88	-4
Edge index at tower base				
No edge	1	1.26	0.79	-1
Some lateral edge	3	3.15	0.95	0
Lots lateral edge	10	10.33	0.97	-1
Some vertical edge	8	10.53	0.76	-8
Lots vertical edge	11	6.78	1.62	13
Lots vertical and lateral edge	0	0.95	0	-3
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	27	27.59	0.98	-2
1	2	3.04	0.66	-3
≥ 2	4	2.37	1.69	5
Rodent control through 2001 **				
Unknown	0	0.40	0	-1
None	8	7.61	1.05	1
Control	19	8.83	2.15	31
Intense control	6	16.16	0.37	-31
Rodent control through 2002 **				
Unknown	0	0.40	0	-1
None	4	5.62	0.71	-5
Control	19	8.84	2.15	31
Intense control	10	18.14	0.55	-25
Cattle pats 40 m from turbines				
0	2	3.04	0.66	-3
1 - –9	19	15.28	1.24	12
10 - –25	10	10.23	0.98	-1
> 25	1	3.44	0.29	-8
Cattle pats at turbines *				
0 - –2	5	4.16	1.20	3
3 - –9	3	10.87	0.28	-25
10 - –25	17	10.47	1.62	20
> 25	7	6.50	1.08	2
Cottontails 40 m from turbines				
No pellets	25	24.89	1.00	0
Some pellets	4	5.63	0.71	-5
Abundant pellets	3	1.48	2.03	5
Cottontails at turbines [t]				
No pellets	24	24.38	0.98	-1
Some pellets	3	5.58	0.54	-8
Abundant pellets	5	2.04	2.45	9
Vegetation height (cm) [t]				
0 - –10	3	5.50	0.55	-8
11 - –20	9	10.38	0.87	-4
21 - –35	8	9.74	0.82	-5
> 35	12	6.38	1.88	18
Pocket gopher clusting **				
Obs/Exp in 15 m = 0	3	1.28	2.34	9
Obs/Exp in 15 m < 1.5	6	2.13	2.82	20
Obs/Exp in 15 m = 1.5–-3.0	8	7.26	1.10	4
Obs/Exp in 15 m > 3	2	8.33	0.24	-33
Ground squirrel clustering				
Obs/Exp in 15 m = 0	5	6.70	0.75	-9
Obs/Exp in 15 m ≤ 1.14	11	7.37	1.49	19
Obs/Exp in 15 m > 1.14	3	4.94	0.61	-10
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	5	6.20	0.81	-7

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	6	5.86	1.02	1
> 3.5/ha	7	5.91	1.18	6
Ground squirrel density ≤ 90 m				
0/ha	0	3.38	0	-18
0.01 – –5.99/ha	13	11.12	1.17	10
≥ 6/ha	6	4.50	1.33	8
Clustering of all burrows **				
Obs/Exp in 15 m = 0–-1.2	12	3.94	3.05	42
Obs/Exp in 15 m = 1.2–-3.0	6	9.86	0.61	-20
Obs/Exp in 15 m > 3	1	5.21	0.19	-22
Density of all burrow systems *				
< 5/ha	3	7.32	0.41	-23
5 – –9/ha	10	5.59	1.79	23
> 9/ha	6	6.09	0.99	0
Season of the year*				
Spring	14	8.12	1.72	20
Summer	8	7.24	1.10	3
Fall	0	5.09	0	-18
Winter	7	8.54	0.82	-5

Table C8. Chi-square test statistics and derived measures of effect for California horned larks.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model				
Micon	3	1.64	1.83	6
Bonus	10	6.47	1.55	15
Danwin	0	0.12	0	-1
Flowind	1	0.94	1.06	0
Windmatic	0	0.26	0	-1
Enertech	0	1.20	0	-5
KCS-56	9	11.63	0.77	-11
KVS-33	0	0.24	0	-1
Howden	0	0.10	0	0
Nordtank	0	0.38	0	-2
W.E.G.	0	0.02	0	0
Rated turbine power (kW) *				
40	0	1.20	0	-5
65	3	2.28	1.32	3
100	9	11.63	0.77	-11
110	0	0.12	0	-1
120	10	4.28	2.34	25
150	0	2.99	0	-13
250	1	0.17	5.94	4
330	0	0.10	0	0
400	0	0.24	0	-1
Rotor diameter (m) *				
13.5 – –14.8	0	1.46	0	-6
16.0	3	2.02	1.49	4
17.2 – –17.8	9	12.43	0.72	-15
19.1 – –19.5	11	4.54	2.42	28
23.4 – –25.2	0	2.21	0	-10
31.4 – –33.2	0	0.34	0	-1
Blade tip speed (kph) *				
136.77	0	0.26	0	-1
143.20	0	0.38	0	-2
146.42	10	4.28	2.34	25
148.03	0	1.20	0	-5
149.64	3	1.64	1.83	6
173.77	0	2.19	0	-10
180.21	0	0.24	0	-1
193.08	0	0.92	0	-4
194.69	1	0.14	6.93	4
212.39	0	0.02	0	0
239.74	0	0.10	0	0
246.18	9	11.63	0.77	-11
Blade tip speed (kph) [t]				
137.77 – –149.64	13	7.75	1.68	23
173.77 – –194.69	1	3.49	0.29	-11

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	9	11.76	0.77	-12
Seconds/sweep at blade tip [t]				
0.272583	9	11.63	0.77	-11
0.343807	0	1.20	0	-5
0.374882	0	0.12	0	-1
0.403091	3	1.64	1.83	6
0.407945	0	0.26	0	-1
0.421219	0	0.38	0	-2
0.447299	0	0.02	0	0
0.493765	0	0.10	0	0
0.502071	10	4.28	2.34	25
0.503748	0	0.80	0	-3
0.507659	0	2.19	0	-10
0.554769	1	0.14	6.93	4
0.694529	0	0.24	0	-1
Seconds/sweep at blade tip				
0.2726	9	11.63	0.77	-11
0.3438 – –0.4938	3	3.72	0.81	-3
0.5021 – –0.6945	11	7.65	1.44	15
Rotor plane (m^2) swept/s [t]				
1498.8	0	1.20	0	-5
1518.1	0	0.26	0	-1
1660.5	0	0.80	0	-3
1718.4	0	0.38	0	-2
1795.7	3	1.64	1.83	6
1859.3	1	0.14	6.93	4
2141.4	10	4.28	2.34	25
2780.4	0	0.12	0	-1
3049.7	0	2.19	0	-10
3286.5	9	11.63	0.77	-11
4014.2	0	0.02	0	0
4487.2	0	0.24	0	-1
5645.9	0	0.10	0	0
Rotor plane (m^2) swept/s *				
1499 - –1859	4	4.42	0.91	-2
2141	10	4.28	2.34	25
2780 - –3287	9	13.94	0.65	-21
4014 - –5646	0	0.37	0	-2
Tower type				
Vertical axis	1	0.94	1.06	0
Tubular	13	8.74	1.49	19
Lattice	9	13.31	0.68	-19
Tower height (m) [t]				
14.0	0	0.60	0	-3
18.5	5	8.52	0.59	-15
24.0	0	0.12	0	-1
24.6	16	10.06	1.59	26

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	0	2.18	0	-9
29.5	0	0.80	0	-3
32.3	1	0.14	6.93	4
36.9	0	0.02	0	0
43.1	1	0.57	1.76	2
Tower height (m)				
14.0	0	0.60	0	-3
18.5	5	8.52	0.59	-15
24.0 – –25.2	16	12.35	1.30	16
29.5 – –32.3	1	0.94	1.06	0
36.9 – –43.1	1	0.59	1.71	2
Rotor orientation to wind				
Faces wind	14	12.69	1.10	6
Away from wind	8	9.37	0.85	-6
Vertical axis	1	0.94	1.06	0
Blade color scheme				
White	23	22.45	1.02	2
Black stripes	0	0.09	0	0
Red stripes	0	0.02	0	0
Red tips	0	0.20	0	-1
Green tips	0	0.24	0	-1
Perch guard				
None	23	22.75	1.01	1
Wire netting	0	0.25	0	-1
Derelict turbines [t]				
Operating and away from derelict	20	21.21	0.94	-5
Derelict	0	0.80	0	-3
Next to derelict	3	0.99	3.04	9
Height (m) of low blade reach				
4.0	1	0.94	1.06	0
5.1	0	0.60	0	-3
8.0	0	0.24	0	-1
8.9	0	0.10	0	0
9.6	5	7.07	0.71	-9
11.1	0	0.25	0	-1
11.8	0	1.20	0	-5
12.0	0	0.02	0	0
13.5	0	2.18	0	-9
14.4	0	0.12	0	-1
14.9	10	4.28	2.34	25
15.7	3	3.39	0.89	-2
16.6	3	2.01	1.49	4
17.2	0	0.02	0	0
25.2	0	0.01	0	0
28.9	0	0.00	0	0
34.2	1	0.57	1.76	2
Height (m) of low blade reach				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	1	1.54	0.65	-2
8.0 – –9.6	5	7.42	0.67	-11
11.1 – –14.85	10	8.04	1.24	9
15.7 – –17.2	6	5.42	1.11	3
25.2 – –34.2	1	0.59	1.71	2
Height (m) of high blade reach				
22.9	0	0.60	0	-3
25.3	0	1.20	0	-5
25.9	0	0.25	0	-1
27.4	5	7.07	0.71	-9
29.5	0	0.80	0	-3
32.0	0	0.02	0	0
32.3	1	0.14	6.93	4
32.6	3	2.01	1.49	4
33.5	3	3.39	0.89	-2
33.6	0	0.12	0	-1
34.4	10	4.28	2.34	25
36.9	0	2.18	0	-9
37.2	0	0.02	0	0
40.3	0	0.10	0	0
41.2	0	0.24	0	-1
44.9	0	0.00	0	0
48.6	0	0.01	0	0
52.0	1	0.57	1.76	2
Height (m) of high blade reach *				
22.9 – –27.4	5	9.12	0.55	-18
29.5 – –33.6	7	6.48	1.08	2
34.4	10	4.28	2.34	25
36.9 – –52.0	1	3.13	0.32	-9
Wind wall				
Not in wind wall	21	19.77	1.06	5
In wind wall	2	3.23	0.62	-5
Position in string *				
End	6	5.10	1.18	4
Edge of gap	6	2.06	2.91	17
Interior	11	15.75	0.70	-21
Non-operational	0	0.08	0	0
Location in wind farm				
Edge of farm	5	2.88	1.74	10
Edge of local cluster	1	2.28	0.44	-6
Interior of wind farm	16	16.78	0.95	-4
Turbine congestion (no. in 300 m)				
0 - –12	1	2.64	0.38	-7
13 - –24	13	10.41	1.25	11
25 - –36	6	5.63	1.07	2
37 - –72	3	4.30	0.70	-6
Elevation (m)				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	5	3.43	1.46	7
135 - –185	4	4.85	0.83	-4
185 - –235	4	3.09	1.29	4
235 - –285	1	1.44	0.70	-2
285 - –335	4	3.98	1.00	0
335 - –385	1	2.65	0.38	-7
385 - –535	4	3.56	1.13	2
Slope grade (degrees)				
0	7	9.15	0.77	-9
2 - –5	0	1.81	0.00	-8
6 - –14	5	5.62	0.89	-3
15 - –58	11	6.40	1.72	20
Physical relief				
Peak	0	0.40	0	-2
Plateau	1	1.60	0.63	-3
Ridge crest	8	7.40	1.08	3
Ridgeline	5	4.65	1.07	2
Slope	8	7.76	1.03	1
Saddle	1	1.02	0.98	0
Ravine	0	0.17	0	-1
Canyon				
Not in canyon	21	19.49	1.08	7
In canyon	2	3.51	0.57	-7
Slope aspect				
None (flat)	6	6.65	0.90	-3
North-facing	7	3.34	2.10	16
Northeast	2	1.49	1.34	2
East	2	1.94	1.03	0
Southeast	3	2.61	1.15	2
South	1	1.89	0.53	-4
Southwest	0	0.40	0	-2
West	1	0.85	1.17	1
Northwest	1	3.79	0.26	-12
Slope aspect				
None (flat)	6	6.65	0.90	-3
East-northeast	4	3.43	1.17	2
South-southeast	4	4.51	0.89	-2
West-southwest	1	1.25	0.80	-1
North-northwest	8	7.12	1.12	4
Edge index at tower base				
No edge	0	0.88	0	-4
Some lateral edge	2	2.20	0.91	-1
Lots lateral edge	7	7.20	0.97	-1
Some vertical edge	5	7.34	0.68	-10
Lots vertical edge	9	4.73	1.90	19
Lots vertical and lateral edge	0	0.66	0	-3
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	16	15.89	1.01	1
1	1	1.75	0.57	-4
≥ 2	2	1.37	1.46	3
Rodent control through 2001				
Unknown	0	0.28	0	-1
None	4	5.31	0.75	-6
Control	7	6.15	1.14	4
Intense control	12	11.26	1.07	3
Rodent control through 2002				
Unknown	0	0.28	0	-1
None	3	3.92	0.77	-4
Control	7	6.16	1.14	4
Intense control	13	12.64	1.03	2
Cattle pats 40 m from turbines				
0	1	2.09	0.48	-5
1 - –9	12	10.51	1.14	7
10 - –25	7	7.03	1.00	0
> 25	2	2.37	0.84	-2
Cattle pats at turbines				
0 - –2	1	2.86	0.35	-8
3 - –9	11	7.47	1.47	16
10 - –25	5	7.20	0.69	-10
> 25	5	4.47	1.12	2
Cottontails 40 m from turbines				
No pellets	18	17.11	1.05	4
Some pellets	3	3.87	0.78	-4
Abundant pellets	1	1.02	0.98	0
Cottontails at turbines				
No pellets	20	16.76	1.19	15
Some pellets	1	3.84	0.26	-13
Abundant pellets	1	1.40	0.71	-2
Vegetation height (cm)				
0 - –10	6	3.78	1.59	10
11 - –20	4	7.14	0.56	-14
21 - –35	8	6.69	1.20	6
> 35	4	4.39	0.91	-2
Pocket gopher clusting				
Obs/Exp in 15 m = 0	1	0.68	1.48	3
Obs/Exp in 15 m < 1.5	3	1.12	2.68	19
Obs/Exp in 15 m = 1.5-3.0	4	3.82	1.05	2
Obs/Exp in 15 m > 3	2	4.38	0.46	-24
Ground squirrel clustering				
Obs/Exp in 15 m = 0	5	3.53	1.42	15
Obs/Exp in 15 m ≤ 1.14	2	3.88	0.52	-19
Obs/Exp in 15 m > 1.14	3	2.60	1.15	4
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	3	3.44	0.87	-4

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	2	3.26	0.61	-13
> 3.5/ha	5	3.28	1.52	17
Ground squirrel density ≤ 90 m				
0/ha	3	1.78	1.68	12
0.01 – –5.99/ha	4	5.85	0.68	-19
≥ 6/ha	3	2.37	1.27	6
Clustering of all burrows [t]				
Obs/Exp in 15 m = 0–-1.2	5	2.07	2.41	29
Obs/Exp in 15 m = 1.2–-3.0	3	5.19	0.58	-22
Obs/Exp in 15 m > 3	2	2.74	0.73	-7
Density of all burrow systems				
< 5/ha	3	3.85	0.78	-9
5 – –9/ha	2	2.94	0.68	-9
> 9/ha	5	3.21	1.56	18
Season of the year*				
Spring	4	6.16	0.65	-10
Summer	12	5.49	2.18	30
Fall	3	3.86	0.78	-4
Winter	3	6.48	0.46	-16

Table C9. Chi-square test statistics and derived measures of effect for western meadowlarks.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model **				
Micon	7	6.83	1.02	0
Bonus	38	26.99	1.41	11
Danwin	0	0.49	0	-1
Flowind	8	3.93	2.03	4
Windmatic	2	1.10	1.81	1
Enertech	4	5.00	0.80	-1
KCS-56	28	48.54	0.58	-21
KVS-33	3	1.00	2.99	2
Howden	1	0.43	2.31	1
Nordtank	5	1.58	3.16	4
W.E.G.	0	0.10	0	0
Rated turbine power (kW) **				
40	4	5.00	0.80	-1
65	14	9.51	1.47	5
100	28	48.54	0.58	-21
110	0	0.49	0	-1
120	23	17.85	1.29	5
150	22	12.47	1.76	10
250	1	0.70	1.42	0
330	1	0.43	2.31	1
400	3	1.00	2.99	2
Rotor diameter (m) *				
13.5 – –14.8	6	6.10	0.98	0
16.0	12	8.41	1.43	4
17.2 – –17.8	35	51.87	0.67	-18
19.1 – –19.5	24	18.94	1.27	5
23.4 – –25.2	15	9.24	1.62	6
31.4 – –33.2	4	1.44	2.78	3
Blade tip speed (kph) **				
136.77	2	1.10	1.81	1
143.20	5	1.58	3.16	4
146.42	23	17.85	1.29	5
148.03	4	5.00	0.80	-1
149.64	7	6.83	1.02	0
173.77	15	9.14	1.64	6
180.21	3	1.00	2.99	2
193.08	7	3.83	1.83	3
194.69	1	0.60	1.66	0
212.39	0	0.10	0	0
239.74	1	0.43	2.31	1
246.18	28	48.54	0.58	-21
Blade tip speed (kph) **				
137.77 – –149.64	41	32.36	1.27	9
173.77 – –194.69	26	14.57	1.78	12

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	29	49.07	0.59	-21
Seconds/sweep at blade tip **				
0.272583	28	48.54	0.58	-21
0.343807	4	5.00	0.80	-1
0.374882	0	0.49	0	-1
0.403091	7	6.83	1.02	0
0.407945	2	1.10	1.81	1
0.421219	5	1.58	3.16	4
0.447299	0	0.10	0	0
0.493765	1	0.43	2.31	1
0.502071	23	17.85	1.29	5
0.503748	7	3.33	2.10	4
0.507659	15	9.14	1.64	6
0.554769	1	0.60	1.66	0
0.694529	3	1.00	2.99	2
Seconds/sweep at blade tip **				
0.2726	28	48.54	0.58	-21
0.3438 – –0.4938	19	15.54	1.22	4
0.5021 – –0.6945	49	31.92	1.53	18
Rotor plane (m^2) swept/s **				
1498.8	4	5.00	0.80	-1
1518.1	2	1.10	1.81	1
1660.5	7	3.33	2.10	4
1718.4	5	1.58	3.16	4
1795.7	7	6.83	1.02	0
1859.3	1	0.60	1.66	0
2141.4	23	17.85	1.29	5
2780.4	0	0.49	0	-1
3049.7	15	9.14	1.64	6
3286.5	28	48.54	0.58	-21
4014.2	0	0.10	0	0
4487.2	3	1.00	2.99	2
5645.9	1	0.43	2.31	1
Rotor plane (m^2) swept/s *				
1499 - –1859	26	18.45	1.41	8
2141	23	17.85	1.29	5
2780 - –3287	43	58.17	0.74	-16
4014 - –5646	4	1.54	2.60	3
Tower type **				
Vertical axis	8	3.93	2.03	4
Tubular	51	36.50	1.40	15
Lattice	37	55.57	0.67	-19
Tower height (m) *				
14.0	3	2.51	1.20	1
18.5	22	35.55	0.62	-14
24.0	0	0.49	0	-1
24.6	48	41.99	1.14	6

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	15	9.08	1.65	6
29.5	7	3.33	2.10	4
32.3	1	0.60	1.66	0
36.9	0	0.08	0	0
43.1	0	2.37	0	-2
Tower height (m) *				
14.0	3	2.51	1.20	1
18.5	22	35.55	0.62	-14
24.0 – –25.2	63	51.56	1.22	12
29.5 – –32.3	8	3.93	2.03	4
36.9 – –43.1	0	2.45	0	-3
Rotor orientation to wind **				
Faces wind	64	52.97	1.21	11
Away from wind	24	39.10	0.61	-16
Vertical axis	8	3.93	2.03	4
Blade color scheme				
White	92	93.70	0.98	-2
Black stripes	0	0.39	0	0
Red stripes	0	0.08	0	0
Red tips	3	0.82	3.66	2
Green tips	1	1.00	1.00	0
Perch guard				
None	96	94.96	1.01	1
Wire netting	0	1.04	0	-1
Derelict turbines				
Operating and away from derelict	84	88.54	0.95	-5
Derelict	7	3.34	2.10	4
Next to derelict	5	4.12	1.21	1
Height (m) of low blade reach *				
4.0	8	3.93	2.03	4
5.1	3	2.51	1.20	1
8.0	3	1.00	2.99	2
8.9	1	0.43	2.31	1
9.6	16	29.52	0.54	-14
11.1	2	1.03	1.94	1
11.8	4	5.00	0.80	-1
12.0	0	0.10	0	0
13.5	15	9.08	1.65	6
14.4	0	0.49	0	-1
14.9	23	17.85	1.29	5
15.7	9	14.14	0.64	-5
16.6	12	8.39	1.43	4
17.2	0	0.07	0	0
25.2	0	0.06	0	0
28.9	0	0.02	0	0
34.2	0	2.37	0	-2
Height (m) of low blade reach *				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	11	6.44	1.71	5
8.0 – –9.6	20	30.96	0.65	-11
11.1 – –14.85	44	33.55	1.31	11
15.7 – –17.2	21	22.60	0.93	-2
25.2 – –34.2	0	2.45	0	-3
Height (m) of high blade reach *				
22.9	3	2.51	1.20	1
25.3	4	5.00	0.80	-1
25.9	2	1.03	1.94	1
27.4	16	29.52	0.54	-14
29.5	7	3.33	2.10	4
32.0	0	0.07	0	0
32.3	1	0.60	1.66	0
32.6	12	8.39	1.43	4
33.5	9	14.14	0.64	-5
33.6	0	0.49	0	-1
34.4	23	17.85	1.29	5
36.9	15	9.08	1.65	6
37.2	0	0.10	0	0
40.3	1	0.43	2.31	1
41.2	3	1.00	2.99	2
44.9	0	0.02	0	0
48.6	0	0.06	0	0
52.0	0	2.37	0	-2
Height (m) of high blade reach *				
22.9 – –27.4	25	38.06	0.66	-14
29.5 – –33.6	29	27.03	1.07	2
34.4	23	17.85	1.29	5
36.9 – –52.0	19	13.07	1.45	6
Wind wall *				
Not in wind wall	90	82.54	1.09	8
In wind wall	6	13.46	0.45	-8
Position in string *				
End	32	21.28	1.50	11
Edge of gap	11	8.60	1.28	2
Interior	52	65.73	0.79	-14
Non-operational	1	0.31	3.19	1
Location in wind farm				
Edge of farm	10	12.55	0.80	-3
Edge of local cluster	13	9.95	1.31	3
Interior of wind farm	73	73.21	1.00	0
Turbine congestion (no. in 300 m)				
0 - –12	12	11.01	1.09	1
13 - –24	50	43.44	1.15	7
25 - –36	21	23.50	0.89	-3
37 - –72	13	17.96	0.72	-5
Elevation (m) **				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	15	14.31	1.05	1
135 - –185	25	20.23	1.24	5
185 - –235	26	12.90	2.01	14
235 - –285	5	5.99	0.83	-1
285 - –335	9	16.63	0.54	-8
335 - –385	11	11.05	1.00	0
385 - –535	5	14.84	0.34	-10
Slope grade (degrees) [t]				
0	32	38.18	0.84	-6
2 - –5	5	7.57	0.66	-3
6 - –14	21	23.48	0.89	-3
15 - –58	38	26.71	1.42	12
Physical relief				
Peak	2	1.65	1.21	0
Plateau	10	6.66	1.50	3
Ridge crest	26	30.89	0.84	-5
Ridgeline	21	19.43	1.08	2
Slope	34	32.37	1.05	2
Saddle	1	4.26	0.23	-3
Ravine	2	0.72	2.78	1
Canyon **				
Not in canyon	67	81.36	0.82	-15
In canyon	29	14.64	1.98	15
Slope aspect				
None (flat)	25	27.76	0.90	-3
North-facing	11	13.92	0.79	-3
Northeast	4	6.23	0.64	-2
East	9	8.09	1.11	1
Southeast	11	10.91	1.01	0
South	7	7.91	0.89	-1
Southwest	2	1.68	1.19	0
West	3	3.56	0.84	-1
Northwest	24	15.80	1.52	9
Slope aspect				
None (flat)	25	27.76	0.90	-3
East-northeast	13	14.32	0.91	-1
South-southeast	18	18.81	0.96	-1
West-southwest	5	5.24	0.96	0
North-northwest	35	29.72	1.18	5
Edge index at tower base				
No edge	1	3.67	0.27	-3
Some lateral edge	11	9.17	1.20	2
Lots lateral edge	22	30.04	0.73	-8
Some vertical edge	38	30.64	1.24	8
Lots vertical edge	21	19.72	1.06	1
Lots vertical and lateral edge	3	2.76	1.09	0
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	76	74.42	1.02	2
1	6	8.19	0.73	-2
≥ 2	7	6.40	1.09	1
Rodent control through 2001				
Unknown	0	1.16	0	-1
None	19	22.15	0.86	-3
Control	35	25.69	1.36	10
Intense control	42	47.01	0.89	-5
Rodent control through 2002				
Unknown	0	1.16	0	-1
None	16	16.35	0.98	0
Control	35	25.71	1.36	10
Intense control	45	52.77	0.85	-8
Cattle pats 40 m from turbines				
0	7	7.61	0.92	-1
1 - –9	40	38.21	1.05	2
10 - –25	22	25.57	0.86	-4
> 25	11	8.61	1.28	3
Cattle pats at turbines				
0 - –2	8	10.40	0.77	-3
3 - –9	21	27.18	0.77	-8
10 - –25	31	26.18	1.18	6
> 25	20	16.25	1.23	5
Cottontails 40 m from turbines				
No pellets	65	62.23	1.04	3
Some pellets	11	14.07	0.78	-4
Abundant pellets	4	3.70	1.08	0
Cottontails at turbines **				
No pellets	54	60.95	0.89	-9
Some pellets	26	13.95	1.86	15
Abundant pellets	0	5.10	0	-6
Vegetation height (cm)				
0 - –10	10	13.76	0.73	-5
11 - –20	24	25.95	0.92	-2
21 - –35	24	24.34	0.99	0
> 35	22	15.95	1.38	8
Pocket gopher clusting				
Obs/Exp in 15 m = 0	4	3.04	1.32	2
Obs/Exp in 15 m < 1.5	4	5.04	0.79	-2
Obs/Exp in 15 m = 1.5–-3.0	15	17.19	0.87	-5
Obs/Exp in 15 m > 3	22	19.73	1.12	5
Ground squirrel clustering [t]				
Obs/Exp in 15 m = 0	9	15.86	0.57	-15
Obs/Exp in 15 m ≤ 1.14	21	17.44	1.20	8
Obs/Exp in 15 m > 1.14	15	11.70	1.28	7
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	14	15.49	0.90	-3

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	20	14.66	1.36	12
> 3.5/ha	11	14.78	0.74	-8
Ground squirrel density ≤ 90 m				
0/ha	3	8.01	0.37	-11
0.01 – –5.99/ha	32	26.33	1.22	13
≥ 6/ha	10	10.66	0.94	-1
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	7	9.33	0.75	-5
Obs/Exp in 15 m = 1.2–-3.0	29	23.34	1.24	13
Obs/Exp in 15 m > 3	9	12.33	0.73	-7
Density of all burrow systems				
< 5/ha	13	17.33	0.75	-10
5 – –9/ha	19	13.24	1.43	13
> 9/ha	13	14.43	0.90	-3
Season of the year*				
Spring	16	26.33	0.61	-11
Summer	19	23.47	0.81	-5
Fall	15	16.51	0.91	-2
Winter	44	27.69	1.59	17

Table C10. Chi-square test statistics and derived measures of effect for Mourning doves.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model **				
Micon	11	2.42	4.55	25
Bonus	6	9.56	0.63	-10
Danwin	0	0.18	0	-1
Flowind	0	1.39	0	-4
Windmatic	2	0.39	5.12	5
Enertech	2	1.77	1.13	1
KCS-56	11	17.19	0.64	-18
KVS-33	0	0.36	0	-1
Howden	2	0.15	13.02	5
Nordtank	0	0.56	0	-2
W.E.G.	0	0.04	0	0
Rated turbine power (kW) **				
40	2	1.77	1.13	1
65	13	3.37	3.86	28
100	11	17.19	0.64	-18
110	0	0.18	0	-1
120	5	6.32	0.79	-4
150	1	4.42	0.23	-10
250	0	0.25	0	-1
330	2	0.15	13.02	5
400	0	0.36	0	-1
Rotor diameter (m) **				
13.5 – –14.8	4	2.16	1.85	5
16.0	11	2.98	3.69	24
17.2 – –17.8	11	18.37	0.60	-22
19.1 – –19.5	5	6.71	0.75	-5
23.4 – –25.2	1	3.27	0.31	-7
31.4 – –33.2	2	0.51	3.93	4
Blade tip speed (kph) **				
136.77	2	0.39	5.12	5
143.20	0	0.56	0	-2
146.42	5	6.32	0.79	-4
148.03	2	1.77	1.13	1
149.64	11	2.42	4.55	25
173.77	1	3.24	0.31	-7
180.21	0	0.36	0	-1
193.08	0	1.36	0	-4
194.69	0	0.21	0	-1
212.39	0	0.04	0	0
239.74	2	0.15	13.02	5
246.18	11	17.19	0.64	-18
Blade tip speed (kph) **				
137.77 – –149.64	20	11.46	1.75	25
173.77 – –194.69	1	5.16	0.19	-12

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	13	17.38	0.75	-13
Seconds/sweep at blade tip **				
0.272583	11	17.19	0.64	-18
0.343807	2	1.77	1.13	1
0.374882	0	0.18	0	-1
0.403091	11	2.42	4.55	25
0.407945	2	0.39	5.12	5
0.421219	0	0.56	0	-2
0.447299	0	0.04	0	0
0.493765	2	0.15	13.02	5
0.502071	5	6.32	0.79	-4
0.503748	0	1.18	0	-3
0.507659	1	3.24	0.31	-7
0.554769	0	0.21	0	-1
0.694529	0	0.36	0	-1
Seconds/sweep at blade tip **				
0.2726	11	17.19	0.64	-18
0.3438 – –0.4938	17	5.50	3.09	34
0.5021 – –0.6945	6	11.31	0.53	-16
Rotor plane (m^2) swept/s **				
1498.8	2	1.77	1.13	1
1518.1	2	0.39	5.12	5
1660.5	0	1.18	0	-3
1718.4	0	0.56	0	-2
1795.7	11	2.42	4.55	25
1859.3	0	0.21	0	-1
2141.4	5	6.32	0.79	-4
2780.4	0	0.18	0	-1
3049.7	1	3.24	0.31	-7
3286.5	11	17.19	0.64	-18
4014.2	0	0.04	0	0
4487.2	0	0.36	0	-1
5645.9	2	0.15	13.02	5
Rotor plane (m^2) swept/s **				
1499 - –1859	15	6.53	2.30	25
2141	5	6.32	0.79	-4
2780 - –3287	12	20.60	0.58	-25
4014 - –5646	2	0.55	3.67	4
Tower type [t]				
Vertical axis	0	1.39	0	-4
Tubular	19	12.93	1.47	18
Lattice	15	19.68	0.76	-14
Tower height (m)				
14.0	0	0.89	0	-3
18.5	14	12.59	1.11	4
24.0	0	0.18	0	-1
24.6	19	14.87	1.28	12

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	1	3.22	0.31	-7
29.5	0	1.18	0	-3
32.3	0	0.21	0	-1
36.9	0	0.03	0	0
43.1	0	0.84	0	-2
Tower height (m)				
14.0	0	0.89	0	-3
18.5	14	12.59	1.11	4
24.0 – –25.2	20	18.26	1.10	5
29.5 – –32.3	0	1.39	0	-4
36.9 – –43.1	0	0.87	0	-3
Rotor orientation to wind				
Faces wind	22	18.76	1.17	10
Away from wind	12	13.85	0.87	-5
Vertical axis	0	1.39	0	-4
Blade color scheme				
White	33	33.19	0.99	-1
Black stripes	0	0.14	0	0
Red stripes	0	0.03	0	0
Red tips	0	0.29	0	-1
Green tips	1	0.36	2.81	2
Perch guard				
None	34	33.63	1.01	1
Wire netting	0	0.37	0	-1
Derelict turbines [t]				
Operating and away from derelict	28	31.36	0.89	-10
Derelict	3	1.18	2.54	5
Next to derelict	3	1.46	2.05	5
Height (m) of low blade reach **				
4.0	0	1.39	0	-4
5.1	0	0.89	0	-3
8.0	0	0.36	0	-1
8.9	2	0.15	13.02	5
9.6	10	10.46	0.96	-1
11.1	2	0.37	5.49	5
11.8	2	1.77	1.13	1
12.0	0	0.04	0	0
13.5	1	3.22	0.31	-7
14.4	0	0.18	0	-1
14.9	5	6.32	0.79	-4
15.7	1	5.01	0.20	-12
16.6	11	2.97	3.70	24
17.2	0	0.03	0	0
25.2	0	0.02	0	0
28.9	0	0.01	0	0
34.2	0	0.84	0	-2
Height (m) of low blade reach				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	0	2.28	0	-7
8.0 – –9.6	12	10.97	1.09	3
11.1 – –14.85	10	11.88	0.84	-6
15.7 – –17.2	12	8.01	1.50	12
25.2 – –34.2	0	0.87	0	-3
Height (m) of high blade reach **				
22.9	0	0.89	0	-3
25.3	2	1.77	1.13	1
25.9	2	0.37	5.49	5
27.4	10	10.46	0.96	-1
29.5	0	1.18	0	-3
32.0	0	0.03	0	0
32.3	0	0.21	0	-1
32.6	11	2.97	3.70	24
33.5	1	5.01	0.20	-12
33.6	0	0.18	0	-1
34.4	5	6.32	0.79	-4
36.9	1	3.22	0.31	-7
37.2	0	0.04	0	0
40.3	2	0.15	13.02	5
41.2	0	0.36	0	-1
44.9	0	0.01	0	0
48.6	0	0.02	0	0
52.0	0	0.84	0	-2
Height (m) of high blade reach				
22.9 – –27.4	14	13.48	1.04	2
29.5 – –33.6	12	9.57	1.25	7
34.4	5	6.32	0.79	-4
36.9 – –52.0	3	4.63	0.65	-5
Wind wall *				
Not in wind wall	34	29.23	1.16	14
In wind wall	0	4.77	0	-14
Position in string *				
End	16	7.54	2.12	25
Edge of gap	1	3.05	0.33	-6
Interior	17	23.28	0.73	-18
Non-operational	0	0.11	0	0
Location in wind farm *				
Edge of farm	10	4.44	2.25	16
Edge of local cluster	4	3.52	1.14	1
Interior of wind farm	20	25.93	0.77	-17
Turbine congestion (no. in 300 m)				
0 - –12	8	3.90	2.05	12
13 - –24	14	15.38	0.91	-4
25 - –36	5	8.32	0.60	-10
37 - –72	7	6.36	1.10	2
Elevation (m) **				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	19	5.07	3.75	41
135 - –185	9	7.16	1.26	5
185 - –235	0	4.57	0	-13
235 - –285	0	2.12	0	-6
285 - –335	2	5.89	0.34	-11
335 - –385	2	3.91	0.51	-6
385 - –535	2	5.26	0.38	-10
Slope grade (degrees) [t]				
0	19	13.52	1.41	16
2 - –5	0	2.68	0.00	-8
6 - –14	4	8.31	0.48	-13
15 - –58	11	9.46	1.16	5
Physical relief *				
Peak	0	0.58	0	-2
Plateau	6	2.36	2.54	11
Ridge crest	5	10.94	0.46	-17
Ridgeline	5	6.88	0.73	-6
Slope	18	11.47	1.57	19
Saddle	0	1.51	0	-4
Ravine	0	0.26	0	-1
Canyon [t]				
Not in canyon	25	28.82	0.87	-11
In canyon	9	5.18	1.74	11
Slope aspect *				
None (flat)	10	9.83	1.02	0
North-facing	7	4.93	1.42	6
Northeast	1	2.21	0.45	-4
East	2	2.87	0.70	-3
Southeast	3	3.86	0.78	-3
South	3	2.80	1.07	1
Southwest	3	0.59	5.06	7
West	4	1.26	3.17	8
Northwest	1	5.60	0.18	-14
Slope aspect **				
None (flat)	10	9.83	1.02	0
East-northeast	3	5.07	0.59	-6
South-southeast	6	6.66	0.90	-2
West-southwest	7	1.85	3.78	15
North-northwest	8	10.53	0.76	-7
Edge index at tower base [t]				
No edge	2	1.30	1.54	2
Some lateral edge	6	3.25	1.85	8
Lots lateral edge	7	10.64	0.66	-11
Some vertical edge	7	10.85	0.64	-11
Lots vertical edge	9	6.99	1.29	6
Lots vertical and lateral edge	3	0.98	3.07	6
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	29	25.92	1.12	10
1	2	2.85	0.70	-3
≥ 2	0	2.23	0	-7
Rodent control through 2001 **				
Unknown	0	0.41	0	-1
None	18	7.84	2.29	30
Control	5	9.10	0.55	-12
Intense control	11	16.65	0.66	-17
Rodent control through 2002 **				
Unknown	0	0.41	0	-1
None	14	5.79	2.42	24
Control	5	9.11	0.55	-12
Intense control	15	18.69	0.80	-11
Cattle pats 40 m from turbines				
0	2	2.76	0.72	-3
1 - –9	15	13.85	1.08	4
10 - –25	7	9.27	0.76	-8
> 25	5	3.12	1.60	6
Cattle pats at turbines				
0 - –2	7	3.77	1.86	11
3 - –9	10	9.85	1.02	1
10 - –25	9	9.49	0.95	-2
> 25	3	5.89	0.51	-10
Cottontails 40 m from turbines				
No pellets	18	22.56	0.80	-16
Some pellets	9	5.10	1.76	13
Abundant pellets	2	1.34	1.49	2
Cottontails at turbines				
No pellets	18	22.09	0.81	-14
Some pellets	9	5.06	1.78	14
Abundant pellets	2	1.85	1.08	1
Vegetation height (cm)				
0 - –10	6	4.99	1.20	3
11 - –20	9	9.41	0.96	-1
21 - –35	6	8.82	0.68	-10
> 35	8	5.78	1.38	8
Pocket gopher clusting **				
Obs/Exp in 15 m = 0	5	0.88	5.70	32
Obs/Exp in 15 m < 1.5	2	1.46	1.37	4
Obs/Exp in 15 m = 1.5-3.0	4	4.97	0.81	-7
Obs/Exp in 15 m > 3	2	5.70	0.35	-28
Ground squirrel clustering **				
Obs/Exp in 15 m = 0	0	4.58	0	-35
Obs/Exp in 15 m ≤ 1.14	5	5.04	0.99	0
Obs/Exp in 15 m > 1.14	8	3.38	2.37	36
Pocket gopher density ≤ 90 m[t]				
0 – –1.4/ha	8	4.47	1.79	27

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	4	4.23	0.94	-2
> 3.5/ha	1	4.27	0.23	-25
Ground squirrel density ≤ 90 m				
0/ha	0	2.32	0	-18
0.01 – –5.99/ha	8	7.61	1.05	3
≥ 6/ha	5	3.08	1.62	15
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	5	2.70	1.86	18
Obs/Exp in 15 m = 1.2–-3.0	7	6.74	1.04	2
Obs/Exp in 15 m > 3	1	3.56	0.28	-20
Density of all burrow systems				
< 5/ha	4	5.01	0.80	-8
5 – –9/ha	5	3.83	1.31	9
> 9/ha	4	4.17	0.96	-1
Season of the year**				
Spring	4	9.52	0.42	-16
Summer	5	8.49	0.59	-10
Fall	0	5.97	0	-18
Winter	25	10.02	2.50	44

Table C11. Chi-square test statistics and derived measures of effect for rock doves.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model **				
Micon	46	13.87	3.32	16
Bonus	35	54.82	0.64	-10
Danwin	0	1.00	0	-1
Flowind	2	7.99	0.25	-3
Windmatic	2	2.24	0.89	0
Enertech	11	10.16	1.08	0
KCS-56	98	98.59	0.99	0
KVS-33	0	2.04	0	-1
Howden	1	0.88	1.13	0
Nordtank	0	3.21	0	-2
W.E.G.	0	0.20	0	0
Rated turbine power (kW) **				
40	11	10.16	1.08	0
65	48	19.32	2.48	15
100	98	98.59	0.99	0
110	0	1.00	0	-1
120	27	36.25	0.74	-5
150	10	25.33	0.39	-8
250	0	1.43	0	-1
330	1	0.88	1.13	0
400	0	2.04	0	-1
Rotor diameter (m) **				
13.5 – –14.8	13	12.40	1.05	0
16.0	46	17.08	2.69	15
17.2 – –17.8	100	105.36	0.95	-3
19.1 – –19.5	27	38.47	0.70	-6
23.4 – –25.2	8	18.77	0.43	-6
31.4 – –33.2	1	2.92	0.34	-1
Blade tip speed (kph) **				
136.77	2	2.24	0.89	0
143.20	0	3.21	0	-2
146.42	27	36.25	0.74	-5
148.03	11	10.16	1.08	0
149.64	46	13.87	3.32	16
173.77	8	18.57	0.43	-5
180.21	0	2.04	0	-1
193.08	2	7.77	0.26	-3
194.69	0	1.22	0	-1
212.39	0	0.20	0	0
239.74	1	0.88	1.13	0
246.18	98	98.59	0.99	0
Blade tip speed (kph) **				
137.77 – –149.64	86	65.73	1.31	10
173.77 – –194.69	10	29.60	0.34	-10

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	99	99.67	0.99	0
Seconds/sweep at blade tip **				
0.272583	98	98.59	0.99	0
0.343807	11	10.16	1.08	0
0.374882	0	1.00	0	-1
0.403091	46	13.87	3.32	16
0.407945	2	2.24	0.89	0
0.421219	0	3.21	0	-2
0.447299	0	0.20	0	0
0.493765	1	0.88	1.13	0
0.502071	27	36.25	0.74	-5
0.503748	2	6.77	0.30	-2
0.507659	8	18.57	0.43	-5
0.554769	0	1.22	0	-1
0.694529	0	2.04	0	-1
Seconds/sweep at blade tip **				
0.2726	98	98.59	0.99	0
0.3438 – –0.4938	60	31.57	1.90	15
0.5021 – –0.6945	37	64.84	0.57	-14
Rotor plane (m^2) swept/s **				
1498.8	11	10.16	1.08	0
1518.1	2	2.24	0.89	0
1660.5	2	6.77	0.30	-2
1718.4	0	3.21	0	-2
1795.7	46	13.87	3.32	16
1859.3	0	1.22	0	-1
2141.4	27	36.25	0.74	-5
2780.4	0	1.00	0	-1
3049.7	8	18.57	0.43	-5
3286.5	98	98.59	0.99	0
4014.2	0	0.20	0	0
4487.2	0	2.04	0	-1
5645.9	1	0.88	1.13	0
Rotor plane (m^2) swept/s **				
1499 - –1859	61	37.47	1.63	12
2141	27	36.25	0.74	-5
2780 - –3287	106	118.16	0.90	-6
4014 - –5646	1	3.12	0.32	-1
Tower type [t]				
Vertical axis	2	7.99	0.25	-3
Tubular	82	74.14	1.11	4
Lattice	111	112.88	0.98	-1
Tower height (m) **				
14.0	8	5.09	1.57	1
18.5	55	72.22	0.76	-9
24.0	0	1.00	0	-1
24.6	121	85.28	1.42	18

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	8	18.45	0.43	-5
29.5	2	6.77	0.30	-2
32.3	0	1.22	0	-1
36.9	0	0.15	0	0
43.1	1	4.82	0.21	-2
Tower height (m) **				
14.0	8	5.09	1.57	1
18.5	55	72.22	0.76	-9
24.0 – –25.2	129	104.74	1.23	12
29.5 – –32.3	2	7.99	0.25	-3
36.9 – –43.1	1	4.97	0.20	-2
Rotor orientation to wind **				
Faces wind	137	107.59	1.27	15
Away from wind	56	79.42	0.71	-12
Vertical axis	2	7.99	0.25	-3
Blade color scheme				
White	195	190.33	1.02	2
Black stripes	0	0.80	0	0
Red stripes	0	0.16	0	0
Red tips	0	1.67	0	-1
Green tips	0	2.04	0	-1
Perch guard **				
None	187	192.88	0.97	-3
Wire netting	8	2.12	3.77	3
Derelict turbines				
Operating and away from derelict	186	179.85	1.03	3
Derelict	2	6.78	0.30	-2
Next to derelict	7	8.37	0.84	-1
Height (m) of low blade reach **				
4.0	2	7.99	0.25	-3
5.1	8	5.09	1.57	1
8.0	0	2.04	0	-1
8.9	1	0.88	1.13	0
9.6	42	59.97	0.70	-9
11.1	2	2.09	0.96	0
11.8	11	10.16	1.08	0
12.0	0	0.20	0	0
13.5	8	18.45	0.43	-5
14.4	0	1.00	0	-1
14.9	27	36.25	0.74	-5
15.7	47	28.71	1.64	9
16.6	46	17.05	2.70	15
17.2	0	0.15	0	0
25.2	0	0.12	0	0
28.9	0	0.04	0	0
34.2	1	4.82	0.21	-2
Height (m) of low blade reach **				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	10	13.08	0.76	-2
8.0 – –9.6	43	62.89	0.68	-10
11.1 – –14.85	48	68.15	0.70	-10
15.7 – –17.2	93	45.91	2.03	24
25.2 – –34.2	1	4.97	0.20	-2
Height (m) of high blade reach **				
22.9	8	5.09	1.57	1
25.3	11	10.16	1.08	0
25.9	2	2.09	0.96	0
27.4	42	59.97	0.70	-9
29.5	2	6.77	0.30	-2
32.0	0	0.15	0	0
32.3	0	1.22	0	-1
32.6	46	17.05	2.70	15
33.5	47	28.71	1.64	9
33.6	0	1.00	0	-1
34.4	27	36.25	0.74	-5
36.9	8	18.45	0.43	-5
37.2	0	0.20	0	0
40.3	1	0.88	1.13	0
41.2	0	2.04	0	-1
44.9	0	0.04	0	0
48.6	0	0.12	0	0
52.0	1	4.82	0.21	-2
Height (m) of high blade reach **				
22.9 – –27.4	63	77.31	0.81	-7
29.5 – –33.6	95	54.90	1.73	21
34.4	27	36.25	0.74	-5
36.9 – –52.0	10	26.54	0.38	-8
Wind wall *				
Not in wind wall	157	167.65	0.94	-5
In wind wall	38	27.35	1.39	5
Position in string				
End	41	43.23	0.95	-1
Edge of gap	11	17.47	0.63	-3
Interior	143	133.51	1.07	5
Non-operational	0	0.64	0	0
Location in wind farm **				
Edge of farm	35	25.48	1.37	5
Edge of local cluster	36	20.21	1.78	8
Interior of wind farm	124	148.70	0.83	-13
Turbine congestion (no. in 300 m) **				
0 - –12	9	22.25	0.40	-7
13 - –24	70	87.78	0.80	-9
25 - –36	64	47.49	1.35	9
37 - –72	51	36.30	1.40	8
Elevation (m) **				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	64	29.06	2.20	18
135 - –185	44	41.09	1.07	1
185 - –235	14	26.21	0.53	-6
235 - –285	11	12.17	0.90	-1
285 - –335	46	33.77	1.36	6
335 - –385	13	22.45	0.58	-5
385 - –535	3	30.14	0.10	-14
Slope grade (degrees) *				
0	98	77.54	1.26	10
2 - –5	17	15.38	1.10	1
6 - –14	37	47.69	0.78	-5
15 - –58	43	54.26	0.79	-6
Physical relief **				
Peak	2	3.35	0.60	-1
Plateau	33	13.53	2.44	10
Ridge crest	43	62.74	0.69	-10
Ridgeline	22	39.46	0.56	-9
Slope	70	65.76	1.06	2
Saddle	22	8.65	2.54	7
Ravine	3	1.46	2.05	1
Canyon				
Not in canyon	171	165.27	1.03	3
In canyon	24	29.73	0.81	-3
Slope aspect **				
None (flat)	65	56.38	1.15	4
North-facing	18	28.27	0.64	-5
Northeast	11	12.65	0.87	-1
East	15	16.44	0.91	-1
Southeast	18	22.15	0.81	-2
South	13	16.06	0.81	-2
Southwest	5	3.40	1.47	1
West	20	7.23	2.77	7
Northwest	30	32.10	0.93	-1
Slope aspect **				
None (flat)	65	56.38	1.15	4
East-northeast	26	29.08	0.89	-2
South-southeast	31	38.21	0.81	-4
West-southwest	25	10.63	2.35	7
North-northwest	48	60.37	0.80	-6
Edge index at tower base *				
No edge	8	7.45	1.07	0
Some lateral edge	30	18.63	1.61	6
Lots lateral edge	69	61.02	1.13	4
Some vertical edge	54	62.25	0.87	-4
Lots vertical edge	32	40.06	0.80	-4
Lots vertical and lateral edge	2	5.61	0.36	-2
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	151	157.19	0.96	-3
1	24	17.29	1.39	4
≥ 2	13	13.51	0.96	0
Rodent control through 2001 *				
Unknown	1	2.36	0.42	-1
None	65	44.98	1.44	10
Control	41	52.18	0.79	-6
Intense control	88	95.48	0.92	-4
Rodent control through 2002 *				
Unknown	1	2.36	0.42	-1
None	50	33.22	1.51	9
Control	41	52.23	0.79	-6
Intense control	103	107.19	0.96	-2
Cattle pats 40 m from turbines *				
0	24	16.65	1.44	4
1 - –9	82	83.58	0.98	-1
10 - –25	62	55.94	1.11	3
> 25	7	18.83	0.37	-7
Cattle pats at turbines **				
0 - –2	32	22.74	1.41	5
3 - –9	74	59.45	1.24	8
10 - –25	51	57.27	0.89	-4
> 25	18	35.54	0.51	-10
Cottontails 40 m from turbines **				
No pellets	122	136.12	0.90	-8
Some pellets	36	30.79	1.17	3
Abundant pellets	17	8.10	2.10	5
Cottontails at turbines **				
No pellets	109	133.33	0.82	-14
Some pellets	44	30.51	1.44	8
Abundant pellets	22	11.17	1.97	6
Vegetation height (cm) **				
0 - –10	15	30.10	0.50	-9
11 - –20	60	56.77	1.06	2
21 - –35	76	53.25	1.43	13
> 35	24	34.89	0.69	-6
Pocket gopher clusting **				
Obs/Exp in 15 m = 0	15	7.29	2.06	7
Obs/Exp in 15 m < 1.5	16	12.10	1.32	4
Obs/Exp in 15 m = 1.5–-3.0	23	41.26	0.56	-17
Obs/Exp in 15 m > 3	54	47.35	1.14	6
Ground squirrel clustering **				
Obs/Exp in 15 m = 0	26	38.07	0.68	-11
Obs/Exp in 15 m ≤ 1.14	23	41.86	0.55	-17
Obs/Exp in 15 m > 1.14	59	28.07	2.10	29
Pocket gopher density ≤ 90 m **				
0 – –1.4/ha	83	36.14	2.30	45

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	8	34.20	0.23	-25
> 3.5/ha	14	34.48	0.41	-19
Ground squirrel density ≤ 90 m				
0/ha	16	19.23	0.83	-3
0.01 – –5.99/ha	72	63.19	1.14	8
≥ 6/ha	20	25.58	0.78	-5
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	25	22.39	1.12	2
Obs/Exp in 15 m = 1.2–-3.0	60	56.03	1.07	4
Obs/Exp in 15 m > 3	23	29.59	0.78	-6
Density of all burrow systems **				
< 5/ha	55	41.60	1.32	12
5 – –9/ha	36	31.78	1.13	4
> 9/ha	17	34.62	0.49	-16
Season of the year**				
Spring	41	51.26	0.80	-6
Summer	85	45.70	1.86	21
Fall	20	32.13	0.62	-7
Winter	37	53.91	0.69	-9

Table C12. Chi-square test statistics and derived measures of effect for European starlings.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model *				
Micon	11	4.77	2.31	9
Bonus	11	18.83	0.58	-12
Danwin	0	0.35	0	-1
Flowind	4	2.75	1.46	2
Windmatic	1	0.77	1.30	0
Enertech	4	3.49	1.15	1
KCS-56	31	33.87	0.92	-4
KVS-33	0	0.70	0	-1
Howden	1	0.30	3.30	1
Nordtank	4	1.10	3.63	4
W.E.G.	0	0.07	0	0
Rated turbine power (kW) *				
40	4	3.49	1.15	1
65	16	6.64	2.41	14
100	31	33.87	0.92	-4
110	0	0.35	0	-1
120	8	12.46	0.64	-7
150	6	8.70	0.69	-4
250	1	0.49	2.04	1
330	1	0.30	3.30	1
400	0	0.70	0	-1
Rotor diameter (m) **				
13.5 – –14.8	5	4.26	1.17	1
16.0	15	5.87	2.56	14
17.2 – –17.8	34	36.20	0.94	-3
19.1 – –19.5	9	13.22	0.68	-6
23.4 – –25.2	3	6.45	0.47	-5
31.4 – –33.2	1	1.00	1.00	0
Blade tip speed (kph) *				
136.77	1	0.77	1.30	0
143.20	4	1.10	3.63	4
146.42	8	12.46	0.64	-7
148.03	4	3.49	1.15	1
149.64	11	4.77	2.31	9
173.77	3	6.38	0.47	-5
180.21	0	0.70	0	-1
193.08	3	2.67	1.12	0
194.69	1	0.42	2.38	1
212.39	0	0.07	0	0
239.74	1	0.30	3.30	1
246.18	31	33.87	0.92	-4
Blade tip speed (kph)				
137.77 – –149.64	28	22.58	1.24	8
173.77 – –194.69	7	10.17	0.69	-5

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	32	34.25	0.93	-3
Seconds/sweep at blade tip *				
0.272583	31	33.87	0.92	-4
0.343807	4	3.49	1.15	1
0.374882	0	0.35	0	-1
0.403091	11	4.77	2.31	9
0.407945	1	0.77	1.30	0
0.421219	4	1.10	3.63	4
0.447299	0	0.07	0	0
0.493765	1	0.30	3.30	1
0.502071	8	12.46	0.64	-7
0.503748	3	2.33	1.29	1
0.507659	3	6.38	0.47	-5
0.554769	1	0.42	2.38	1
0.694529	0	0.70	0	-1
Seconds/sweep at blade tip **				
0.2726	31	33.87	0.92	-4
0.3438 – –0.4938	21	10.85	1.94	15
0.5021 – –0.6945	15	22.28	0.67	-11
Rotor plane (m^2) swept/s *				
1498.8	4	3.49	1.15	1
1518.1	1	0.77	1.30	0
1660.5	3	2.33	1.29	1
1718.4	4	1.10	3.63	4
1795.7	11	4.77	2.31	9
1859.3	1	0.42	2.38	1
2141.4	8	12.46	0.64	-7
2780.4	0	0.35	0	-1
3049.7	3	6.38	0.47	-5
3286.5	31	33.87	0.92	-4
4014.2	0	0.07	0	0
4487.2	0	0.70	0	-1
5645.9	1	0.30	3.30	1
Rotor plane (m^2) swept/s [t]				
1499 - –1859	24	12.87	1.86	17
2141	8	12.46	0.64	-7
2780 - –3287	34	40.60	0.84	-10
4014 - –5646	1	1.07	0.93	0
Tower type				
Vertical axis	4	2.75	1.46	2
Tubular	27	25.47	1.06	2
Lattice	36	38.78	0.93	-4
Tower height (m)				
14.0	1	1.75	0.57	-1
18.5	31	24.81	1.25	9
24.0	0	0.35	0	-1
24.6	28	29.30	0.96	-2

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	3	6.34	0.47	-5
29.5	3	2.33	1.29	1
32.3	1	0.42	2.38	1
36.9	0	0.05	0	0
43.1	0	1.66	0	-2
Tower height (m)				
14.0	1	1.75	0.57	-1
18.5	31	24.81	1.25	9
24.0 – –25.2	31	35.99	0.86	-7
29.5 – –32.3	4	2.75	1.46	2
36.9 – –43.1	0	1.71	0	-3
Rotor orientation to wind				
Faces wind	32	36.97	0.87	-7
Away from wind	31	27.29	1.14	6
Vertical axis	4	2.75	1.46	2
Blade color scheme [t]				
White	63	65.40	0.96	-4
Black stripes	0	0.28	0	0
Red stripes	0	0.06	0	0
Red tips	1	0.57	1.75	1
Green tips	3	0.70	4.28	3
Perch guard				
None	67	66.27	1.01	1
Wire netting	0	0.73	0	-1
Derelict turbines				
Operating and away from derelict	62	61.79	1.00	0
Derelict	2	2.33	0.86	0
Next to derelict	3	2.88	1.04	0
Height (m) of low blade reach *				
4.0	4	2.75	1.46	2
5.1	1	1.75	0.57	-1
8.0	0	0.70	0	-1
8.9	1	0.30	3.30	1
9.6	26	20.61	1.26	8
11.1	1	0.72	1.39	0
11.8	4	3.49	1.15	1
12.0	0	0.07	0	0
13.5	3	6.34	0.47	-5
14.4	0	0.35	0	-1
14.9	8	12.46	0.64	-7
15.7	4	9.87	0.41	-9
16.6	15	5.86	2.56	14
17.2	0	0.05	0	0
25.2	0	0.04	0	0
28.9	0	0.01	0	0
34.2	0	1.66	0	-2
Height (m) of low blade reach				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	5	4.49	1.11	1
8.0 – –9.6	27	21.61	1.25	8
11.1 – –14.85	16	23.42	0.68	-11
15.7 – –17.2	19	15.78	1.20	5
25.2 – –34.2	0	1.71	0	-3
Height (m) of high blade reach *				
22.9	1	1.75	0.57	-1
25.3	4	3.49	1.15	1
25.9	1	0.72	1.39	0
27.4	26	20.61	1.26	8
29.5	3	2.33	1.29	1
32.0	0	0.05	0	0
32.3	1	0.42	2.38	1
32.6	15	5.86	2.56	14
33.5	4	9.87	0.41	-9
33.6	0	0.35	0	-1
34.4	8	12.46	0.64	-7
36.9	3	6.34	0.47	-5
37.2	0	0.07	0	0
40.3	1	0.30	3.30	1
41.2	0	0.70	0	-1
44.9	0	0.01	0	0
48.6	0	0.04	0	0
52.0	0	1.66	0	-2
Height (m) of high blade reach [t]				
22.9 – –27.4	32	26.56	1.20	8
29.5 – –33.6	23	18.86	1.22	6
34.4	8	12.46	0.64	-7
36.9 – –52.0	4	9.12	0.44	-8
Wind wall [t]				
Not in wind wall	63	57.60	1.09	8
In wind wall	4	9.40	0.43	-8
Position in string				
End	14	14.85	0.94	-1
Edge of gap	6	6.00	1.00	0
Interior	47	45.87	1.02	2
Non-operational	0	0.22	0	0
Location in wind farm				
Edge of farm	8	8.76	0.91	-1
Edge of local cluster	9	6.95	1.30	3
Interior of wind farm	50	51.09	0.98	-2
Turbine congestion (no. in 300 m)				
0 - –12	6	7.69	0.78	-3
13 - –24	26	30.31	0.86	-6
25 - –36	20	16.40	1.22	5
37 - –72	15	12.54	1.20	4
Elevation (m) *				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	19	9.84	1.93	14
135 - –185	13	13.91	0.93	-1
185 - –235	8	8.87	0.90	-1
235 - –285	5	4.12	1.21	1
285 - –335	11	11.43	0.96	-1
335 - –385	6	7.60	0.79	-2
385 - –535	4	10.20	0.39	-9
Slope grade (degrees)				
0	27	26.64	1.01	1
2 - –5	5	5.29	0.95	0
6 - –14	21	16.38	1.28	7
15 - –58	14	18.64	0.75	-7
Physical relief				
Peak	0	1.15	0	-2
Plateau	9	4.65	1.94	6
Ridge crest	13	21.56	0.60	-13
Ridgeline	15	13.56	1.11	2
Slope	26	22.60	1.15	5
Saddle	4	2.97	1.35	2
Ravine	0	0.50	0	-1
Canyon				
Not in canyon	58	56.78	1.02	2
In canyon	9	10.22	0.88	-2
Slope aspect				
None (flat)	17	19.37	0.88	-4
North-facing	14	9.71	1.44	6
Northeast	3	4.35	0.69	-2
East	9	5.65	1.59	5
Southeast	6	7.61	0.79	-2
South	6	5.52	1.09	1
Southwest	1	1.17	0.86	0
West	2	2.48	0.80	-1
Northwest	9	11.03	0.82	-3
Slope aspect				
None (flat)	17	19.37	0.88	-4
East-northeast	12	9.99	1.20	3
South-southeast	12	13.13	0.91	-2
West-southwest	3	3.65	0.82	-1
North-northwest	23	20.74	1.11	3
Edge index at tower base				
No edge	4	2.56	1.56	2
Some lateral edge	7	6.40	1.09	1
Lots lateral edge	19	20.96	0.91	-3
Some vertical edge	20	21.39	0.94	-2
Lots vertical edge	13	13.76	0.94	-1
Lots vertical and lateral edge	4	1.93	2.08	3
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	48	51.00	0.94	-5
1	8	5.61	1.43	4
≥ 2	5	4.39	1.14	1
Rodent control through 2001 [t]				
Unknown	2	0.81	2.47	2
None	25	15.46	1.62	14
Control	10	17.93	0.56	-12
Intense control	30	32.81	0.91	-4
Rodent control through 2002 *				
Unknown	2	0.81	2.47	2
None	17	11.41	1.49	8
Control	10	17.95	0.56	-12
Intense control	38	36.83	1.03	2
Cattle pats 40 m from turbines				
0	3	4.47	0.67	-3
1 - –9	26	22.45	1.16	8
10 - –25	15	15.03	1.00	0
> 25	3	5.06	0.59	-4
Cattle pats at turbines				
0 - –2	5	6.11	0.82	-2
3 - –9	20	15.97	1.25	9
10 - –25	16	15.38	1.04	1
> 25	6	9.55	0.63	-8
Cottontails 40 m from turbines				
No pellets	33	36.56	0.90	-8
Some pellets	10	8.27	1.21	4
Abundant pellets	4	2.17	1.84	4
Cottontails at turbines *				
No pellets	28	35.81	0.78	-17
Some pellets	12	8.19	1.46	8
Abundant pellets	7	3.00	2.33	9
Vegetation height (cm)				
0 - –10	6	8.08	0.74	-4
11 - –20	15	15.25	0.98	-1
21 - –35	19	14.30	1.33	10
> 35	7	9.37	0.75	-5
Pocket gopher clusting *				
Obs/Exp in 15 m = 0	2	1.35	1.48	3
Obs/Exp in 15 m < 1.5	6	2.24	2.68	19
Obs/Exp in 15 m = 1.5–-3.0	5	7.64	0.65	-13
Obs/Exp in 15 m > 3	7	8.77	0.80	-9
Ground squirrel clustering **				
Obs/Exp in 15 m = 0	0	7.05	0	-35
Obs/Exp in 15 m ≤ 1.14	11	7.75	1.42	16
Obs/Exp in 15 m > 1.14	9	5.20	1.73	19
Pocket gopher density ≤ 90 m *				
0 – –1.4/ha	10	5.85	1.71	24

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	6	5.54	1.08	3
> 3.5/ha	1	5.58	0.18	-27
Ground squirrel density ≤ 90 m[t]				
0/ha	0	3.56	0	-18
0.01 – –5.99/ha	13	11.70	1.11	6
≥ 6/ha	7	4.74	1.48	11
Clustering of all burrows *				
Obs/Exp in 15 m = 0–-1.2	7	4.15	1.69	14
Obs/Exp in 15 m = 1.2–-3.0	13	10.38	1.25	13
Obs/Exp in 15 m > 3	0	5.48	0	-27
Density of all burrow systems				
< 5/ha	8	7.70	1.04	1
5 – –9/ha	6	5.89	1.02	1
> 9/ha	6	6.41	0.94	-2
Season of the year				
Spring	14	16.53	0.85	-4
Summer	15	14.73	1.02	0
Fall	13	10.36	1.25	4
Winter	17	17.38	0.98	-1

APPENDIX D

CHI-SQUARE TEST STATISTICS AND DERIVED MEASURES OF EFFECT FOR HAWKS, RAPTORS, AND ALL BIRDS

APPENDIX D

CHI-SQUARE TEST STATISTICS AND DERIVED MEASURES OF EFFECT FOR HAWKS, RAPTORS, AND ALL BIRDS

Table D1. Chi-square test statistics and derived measures of effect for all hawks.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model *				
Micon	14	17.29	0.81	-1
Bonus	83	68.31	1.22	6
Danwin	1	1.25	0.80	0
Flowind	4	9.96	0.40	-2
Windmatic	2	2.79	0.72	0
Enertech	4	12.66	0.32	-4
KCS-56	120	122.86	0.98	-1
KVS-33	3	2.54	1.18	0
Howden	3	1.10	2.73	1
Nordtank	9	4.00	2.25	2
W.E.G.	0	0.25	0	0
Rated turbine power (kW) *				
40	4	12.66	0.32	-4
65	25	24.08	1.04	0
100	120	122.86	0.98	-1
110	1	1.25	0.80	0
120	41	45.17	0.91	-2
150	45	31.57	1.43	6
250	1	1.78	0.56	0
330	3	1.10	2.73	1
400	3	2.54	1.18	0
Rotor diameter (m) **				
13.5 – –14.8	6	15.45	0.39	-4
16.0	23	21.29	1.08	1
17.2 – –17.8	123	131.29	0.94	-3
19.1 – –19.5	43	47.95	0.90	-2
23.4 – –25.2	42	23.39	1.80	8
31.4 – –33.2	6	3.64	1.65	1
Blade tip speed (kph) **				
136.77	2	2.79	0.72	0
143.20	9	4.00	2.25	2
146.42	41	45.17	0.91	-2
148.03	4	12.66	0.32	-4
149.64	14	17.29	0.81	-1
173.77	42	23.14	1.82	8
180.21	3	2.54	1.18	0
193.08	4	9.68	0.41	-2
194.69	1	1.53	0.66	0

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39	0	0.25	0	0
239.74	3	1.10	2.73	1
246.18	120	122.86	0.98	-1
Blade tip speed (kph) *				
137.77 – –149.64	70	81.91	0.85	-5
173.77 – –194.69	50	36.88	1.36	5
212.39 – –246.18	123	124.21	0.99	0
Seconds/sweep at blade tip **				
0.272583	120	122.86	0.98	-1
0.343807	4	12.66	0.32	-4
0.374882	1	1.25	0.80	0
0.403091	14	17.29	0.81	-1
0.407945	2	2.79	0.72	0
0.421219	9	4.00	2.25	2
0.447299	0	0.25	0	0
0.493765	3	1.10	2.73	1
0.502071	41	45.17	0.91	-2
0.503748	3	8.43	0.36	-2
0.507659	42	23.14	1.82	8
0.554769	1	1.53	0.66	0
0.694529	3	2.54	1.18	0
Seconds/sweep at blade tip				
0.2726	120	122.86	0.98	-1
0.3438 – –0.4938	33	39.34	0.84	-3
0.5021 – –0.6945	90	80.81	1.11	4
Rotor plane (m^2) swept/s **				
1498.8	4	12.66	0.32	-4
1518.1	2	2.79	0.72	0
1660.5	3	8.43	0.36	-2
1718.4	9	4.00	2.25	2
1795.7	14	17.29	0.81	-1
1859.3	1	1.53	0.66	0
2141.4	41	45.17	0.91	-2
2780.4	1	1.25	0.80	0
3049.7	42	23.14	1.82	8
3286.5	120	122.86	0.98	-1
4014.2	0	0.25	0	0
4487.2	3	2.54	1.18	0
5645.9	3	1.10	2.73	1
Rotor plane (m^2) swept/s [t]				
1499 - –1859	33	46.69	0.71	-6
2141	41	45.17	0.91	-2
2780 - –3287	163	147.24	1.11	6
4014 - –5646	6	3.89	1.54	1
Tower type *				
Vertical axis	4	9.96	0.40	-2
Tubular	110	92.38	1.19	7

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Lattice	129	140.66	0.92	-5
Tower height (m) **				
14.0	4	6.34	0.63	-1
18.5	76	90.00	0.84	-6
24.0	1	1.25	0.80	0
24.6	112	106.28	1.05	2
25.2	42	22.99	1.83	8
29.5	3	8.43	0.36	-2
32.3	1	1.53	0.66	0
36.9	0	0.19	0	0
43.1	4	6.00	0.67	-1
Tower height (m) *				
14.0	4	6.34	0.63	-1
18.5	76	90.00	0.84	-6
24.0 – –25.2	155	130.52	1.19	10
29.5 – –32.3	4	9.96	0.40	-2
36.9 – –43.1	4	6.19	0.65	-1
Rotor orientation to wind *				
Faces wind	155	134.08	1.16	9
Away from wind	84	98.97	0.85	-6
Vertical axis	4	9.96	0.40	-2
Blade color scheme **				
White	232	237.18	0.98	-2
Black stripes	1	1.00	1.00	0
Red stripes	2	0.20	9.90	1
Red tips	6	2.08	2.89	2
Green tips	2	2.54	0.79	0
Perch guard **				
None	235	240.36	0.98	-2
Wire netting	8	2.64	3.03	2
Derelict turbines				
Operating and away from derelict	233	224.12	1.04	4
Derelict	4	8.45	0.47	-2
Next to derelict	6	10.43	0.58	-2
Height (m) of low blade reach *				
4.0	4	9.96	0.40	-2
5.1	4	6.34	0.63	-1
8.0	3	2.54	1.18	0
8.9	3	1.10	2.73	1
9.6	70	74.73	0.94	-2
11.1	2	2.61	0.77	0
11.8	4	12.66	0.32	-4
12.0	0	0.25	0	0
13.5	42	22.99	1.83	8
14.4	1	1.25	0.80	0
14.9	41	45.17	0.91	-2
15.7	42	35.78	1.17	3

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
16.6	23	21.25	1.08	1
17.2	0	0.19	0	0
25.2	0	0.15	0	0
28.9	0	0.04	0	0
34.2	4	6.00	0.67	-1
Height (m) of low blade reach				
4.0 – –5.1	8	16.30	0.49	-3
8.0 – –9.6	76	78.37	0.97	-1
11.1 – –14.85	90	84.93	1.06	2
15.7 – –17.2	65	57.21	1.14	3
25.2 – –34.2	4	6.19	0.65	-1
Height (m) of high blade reach *				
22.9	4	6.34	0.63	-1
25.3	4	12.66	0.32	-4
25.9	2	2.61	0.77	0
27.4	70	74.73	0.94	-2
29.5	3	8.43	0.36	-2
32.0	0	0.19	0	0
32.3	1	1.53	0.66	0
32.6	23	21.25	1.08	1
33.5	42	35.78	1.17	3
33.6	1	1.25	0.80	0
34.4	41	45.17	0.91	-2
36.9	42	22.99	1.83	8
37.2	0	0.25	0	0
40.3	3	1.10	2.73	1
41.2	3	2.54	1.18	0
44.9	0	0.04	0	0
48.6	0	0.15	0	0
52.0	4	6.00	0.67	-1
Height (m) of high blade reach **				
22.9 – –27.4	80	96.34	0.83	-7
29.5 – –33.6	70	68.42	1.02	1
34.4	41	45.17	0.91	-2
36.9 – –52.0	52	33.08	1.57	8
Wind wall				
Not in wind wall	211	208.92	1.01	1
In wind wall	32	34.08	0.94	-1
Position in string **				
End	82	53.88	1.52	12
Edge of gap	23	21.77	1.06	1
Interior	138	166.38	0.83	-12
Non-operational	0	0.79	0	0
Location in wind farm **				
Edge of farm	31	31.50	0.98	0
Edge of local cluster	42	24.98	1.68	7
Interior of wind farm	168	183.78	0.91	-7

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine congestion (no. in 300 m) **				
0 - –12	44	27.87	1.58	7
13 - –24	102	109.95	0.93	-3
25 - –36	65	59.48	1.09	2
37 - –72	32	45.47	0.70	-6
Elevation (m) [t]				
85 - –135	41	36.22	1.13	2
135 - –185	49	51.20	0.96	-1
185 - –235	37	32.66	1.13	2
235 - –285	18	15.16	1.19	1
285 - –335	51	42.08	1.21	4
335 - –385	27	27.98	0.97	0
385 - –535	20	37.56	0.53	-7
Slope grade (degrees) [t]				
0	76	96.63	0.79	-8
2 - –5	23	19.17	1.20	2
6 - –14	69	59.42	1.16	4
15 - –58	75	67.62	1.11	3
Physical relief				
Peak	2	4.17	0.48	-1
Plateau	10	16.86	0.59	-3
Ridge crest	78	78.19	1.00	0
Ridgeline	56	49.17	1.14	3
Slope	79	81.95	0.96	-1
Saddle	17	10.77	1.58	3
Ravine	1	1.82	0.55	0
Canyon **				
Not in canyon	174	205.95	0.84	-13
In canyon	69	37.05	1.86	13
Slope aspect *				
None (flat)	50	70.26	0.71	-8
North-facing	27	35.23	0.77	-3
Northeast	17	15.76	1.08	1
East	18	20.48	0.88	-1
Southeast	30	27.60	1.09	1
South	27	20.01	1.35	3
Southwest	7	4.24	1.65	1
West	10	9.01	1.11	0
Northwest	57	40.00	1.43	7
Slope aspect *				
None (flat)	50	70.26	0.71	-8
East-northeast	35	36.24	0.97	-1
South-southeast	57	47.61	1.20	4
West-southwest	17	13.25	1.28	2
North-northwest	84	75.23	1.12	4
Edge index at tower base **				
No edge	6	9.28	0.65	-1

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Some lateral edge	22	23.21	0.95	0
Lots lateral edge	52	76.03	0.68	-10
Some vertical edge	83	77.57	1.07	2
Lots vertical edge	63	49.92	1.26	5
Lots vertical and lateral edge	17	6.99	2.43	4
Rockpiles ≤ 50 m away				
None	181	185.62	0.98	-2
1	27	20.42	1.32	3
≥ 2	14	15.96	0.88	-1
Rodent control through 2001 [t]				
Unknown	1	2.94	0.34	-1
None	50	56.06	0.89	-2
Control	83	65.02	1.28	7
Intense control	109	118.98	0.92	-4
Rodent control through 2002 *				
Unknown	1	2.94	0.34	-1
None	44	41.40	1.06	1
Control	83	65.08	1.28	7
Intense control	115	133.58	0.86	-8
Cattle pats 40 m from turbines *				
0	31	17.60	1.76	7
1 - –9	83	88.35	0.94	-3
10 - –25	52	59.14	0.88	-4
> 25	19	19.91	0.95	0
Cattle pats at turbines				
0 - –2	25	24.04	1.04	1
3 - –9	53	62.84	0.84	-5
10 - –25	69	60.54	1.14	5
> 25	38	37.57	1.01	0
Cottontails 40 m from turbines *				
No pellets	157	143.90	1.09	7
Some pellets	19	32.54	0.58	-7
Abundant pellets	9	8.56	1.05	0
Cottontails at turbines [t]				
No pellets	154	140.94	1.09	7
Some pellets	22	32.25	0.68	-6
Abundant pellets	9	11.80	0.76	-2
Vegetation height (cm)				
0 - –10	20	31.82	0.63	-6
11 - –20	66	60.01	1.10	3
21 - –35	57	56.29	1.01	0
> 35	42	36.89	1.14	3
Pocket gopher clusting				
Obs/Exp in 15 m = 0	8	7.22	1.11	1
Obs/Exp in 15 m < 1.5	10	11.99	0.83	-2
Obs/Exp in 15 m = 1.5–-3.0	35	40.88	0.86	-5
Obs/Exp in 15 m > 3	54	46.91	1.15	7

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Ground squirrel clustering				
Obs/Exp in 15 m = 0	39	37.71	1.03	1
Obs/Exp in 15 m ≤ 1.14	39	41.48	0.94	-2
Obs/Exp in 15 m > 1.14	29	27.81	1.04	1
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	45	36.83	1.22	8
1.41 – –3.5/ha	35	34.85	1.00	0
> 3.5/ha	26	35.13	0.74	-9
Ground squirrel density ≤ 90 m				
0/ha	19	19.06	1.00	0
0.01 – –5.99/ha	71	62.60	1.13	8
≥ 6/ha	17	25.34	0.67	-8
Clustering of all burrows				
Obs/Exp in 15 m = 0–-1.2	21	22.18	0.95	-1
Obs/Exp in 15 m = 1.2–-3.0	50	55.51	0.90	-5
Obs/Exp in 15 m > 3	36	29.31	1.23	6
Density of all burrow systems *				
< 5/ha	54	41.22	1.31	12
5 – –9/ha	27	31.49	0.86	-4
> 9/ha	26	34.30	0.76	-8
Season of the year**				
Spring	13	43.70	0.30	-20
Summer	45	38.95	1.16	4
Fall	37	27.39	1.35	6
Winter	61	45.95	1.33	10

Table D2. Chi-square test statistics and derived measures of effect for all raptors.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model **				
Micon	33	36.78	0.90	-1
Bonus	171	145.33	1.18	5
Danwin	1	2.66	0.38	0
Flowind	18	21.18	0.85	-1
Windmatic	4	5.94	0.67	0
Enertech	12	26.93	0.45	-3
KCS-56	244	261.39	0.93	-3
KVS-33	11	5.41	2.03	1
Howden	8	2.34	3.42	1
Nordtank	15	8.52	1.76	1
W.E.G.	0	0.54	0	0
Rated turbine power (kW) **				
40	12	26.93	0.45	-3
65	52	51.23	1.01	0
100	244	261.39	0.93	-3
110	1	2.66	0.38	0
120	95	96.10	0.99	0
150	91	67.16	1.35	5
250	3	3.78	0.79	0
330	8	2.34	3.42	1
400	11	5.41	2.03	1
Rotor diameter (m) **				
13.5 – –14.8	16	32.87	0.49	-3
16.0	48	45.29	1.06	1
17.2 – –17.8	259	279.33	0.93	-4
19.1 – –19.5	99	102.01	0.97	-1
23.4 – –25.2	76	49.76	1.53	5
31.4 – –33.2	19	7.74	2.45	2
Blade tip speed (kph) **				
136.77	4	5.94	0.67	0
143.20	15	8.52	1.76	1
146.42	95	96.10	0.99	0
148.03	12	26.93	0.45	-3
149.64	33	36.78	0.90	-1
173.77	76	49.23	1.54	5
180.21	11	5.41	2.03	1
193.08	16	20.60	0.78	-1
194.69	3	3.24	0.92	0
212.39	0	0.54	0	0
239.74	8	2.34	3.42	1
246.18	244	261.39	0.93	-3
Blade tip speed (kph) **				
137.77 – –149.64	159	174.26	0.91	-3
173.77 – –194.69	106	78.47	1.35	5

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
212.39 – –246.18	252	264.26	0.95	-2
Seconds/sweep at blade tip **				
0.272583	244	261.39	0.93	-3
0.343807	12	26.93	0.45	-3
0.374882	1	2.66	0.38	0
0.403091	33	36.78	0.90	-1
0.407945	4	5.94	0.67	0
0.421219	15	8.52	1.76	1
0.447299	0	0.54	0	0
0.493765	8	2.34	3.42	1
0.502071	95	96.10	0.99	0
0.503748	15	17.94	0.84	-1
0.507659	76	49.23	1.54	5
0.554769	3	3.24	0.92	0
0.694529	11	5.41	2.03	1
Seconds/sweep at blade tip *				
0.2726	244	261.39	0.93	-3
0.3438 – –0.4938	73	83.69	0.87	-2
0.5021 – –0.6945	200	171.92	1.16	5
Rotor plane (m^2) swept/s **				
1498.8	12	26.93	0.45	-3
1518.1	4	5.94	0.67	0
1660.5	15	17.94	0.84	-1
1718.4	15	8.52	1.76	1
1795.7	33	36.78	0.90	-1
1859.3	3	3.24	0.92	0
2141.4	95	96.10	0.99	0
2780.4	1	2.66	0.38	0
3049.7	76	49.23	1.54	5
3286.5	244	261.39	0.93	-3
4014.2	0	0.54	0	0
4487.2	11	5.41	2.03	1
5645.9	8	2.34	3.42	1
Rotor plane (m^2) swept/s **				
1499 - –1859	82	99.34	0.83	-3
2141	95	96.10	0.99	0
2780 - –3287	321	313.27	1.02	1
4014 - –5646	19	8.28	2.29	2
Tower type *				
Vertical axis	18	21.18	0.85	-1
Tubular	228	196.55	1.16	6
Lattice	271	299.26	0.91	-5
Tower height (m) **				
14.0	7	13.49	0.52	-1
18.5	177	191.47	0.92	-3
24.0	1	2.66	0.38	0
24.6	232	226.11	1.03	1

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
25.2	75	48.91	1.53	5
29.5	15	17.94	0.84	-1
32.3	3	3.24	0.92	0
36.9	1	0.41	2.46	0
43.1	6	12.77	0.47	-1
Tower height (m) *				
14.0	7	13.49	0.52	-1
18.5	177	191.47	0.92	-3
24.0 – –25.2	308	277.68	1.11	6
29.5 – –32.3	18	21.18	0.85	-1
36.9 – –43.1	7	13.18	0.53	-1
Rotor orientation to wind				
Faces wind	298	285.26	1.04	2
Away from wind	201	210.56	0.95	-2
Vertical axis	18	21.18	0.85	-1
Blade color scheme **				
White	489	504.62	0.97	-3
Black stripes	4	2.12	1.88	0
Red stripes	3	0.43	6.98	0
Red tips	12	4.42	2.72	1
Green tips	9	5.41	1.66	1
Perch guard[t]				
None	505	511.38	0.99	-1
Wire netting	12	5.62	2.14	1
Derelict turbines				
Operating and away from derelict	480	476.83	1.01	1
Derelict	16	17.97	0.89	0
Next to derelict	21	22.20	0.95	0
Height (m) of low blade reach **				
4.0	18	21.18	0.85	-1
5.1	7	13.49	0.52	-1
8.0	11	5.41	2.03	1
8.9	8	2.34	3.42	1
9.6	161	159.00	1.01	0
11.1	4	5.54	0.72	0
11.8	12	26.93	0.45	-3
12.0	0	0.54	0	0
13.5	75	48.91	1.53	5
14.4	1	2.66	0.38	0
14.9	95	96.10	0.99	0
15.7	70	76.13	0.92	-1
16.6	48	45.20	1.06	1
17.2	0	0.40	0	0
25.2	1	0.31	3.19	0
28.9	0	0.09	0	0
34.2	6	12.77	0.47	-1
Height (m) of low blade reach				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
4.0 – –5.1	25	34.67	0.72	-2
8.0 – –9.6	180	166.74	1.08	3
11.1 – –14.85	187	180.68	1.03	1
15.7 – –17.2	118	121.72	0.97	-1
25.2 – –34.2	7	13.18	0.53	-1
Height (m) of high blade reach **				
22.9	7	13.49	0.52	-1
25.3	12	26.93	0.45	-3
25.9	4	5.54	0.72	0
27.4	161	159.00	1.01	0
29.5	15	17.94	0.84	-1
32.0	0	0.40	0	0
32.3	3	3.24	0.92	0
32.6	48	45.20	1.06	1
33.5	70	76.13	0.92	-1
33.6	1	2.66	0.38	0
34.4	95	96.10	0.99	0
36.9	75	48.91	1.53	5
37.2	0	0.54	0	0
40.3	8	2.34	3.42	1
41.2	11	5.41	2.03	1
44.9	0	0.09	0	0
48.6	1	0.31	3.19	0
52.0	6	12.77	0.47	-1
Height (m) of high blade reach **				
22.9 – –27.4	184	204.96	0.90	-4
29.5 – –33.6	137	145.57	0.94	-2
34.4	95	96.10	0.99	0
36.9 – –52.0	101	70.37	1.44	6
Wind wall *				
Not in wind wall	464	444.49	1.04	4
In wind wall	53	72.51	0.73	-4
Position in string **				
End	180	114.62	1.57	13
Edge of gap	53	46.32	1.14	1
Interior	282	353.98	0.80	-14
Non-operational	2	1.69	1.18	0
Location in wind farm **				
Edge of farm	65	67.30	0.97	0
Edge of local cluster	87	53.38	1.63	7
Interior of wind farm	363	392.72	0.92	-6
Turbine congestion (no. in 300 m) **				
0 - –12	86	59.30	1.45	5
13 - –24	251	233.92	1.07	3
25 - –36	115	126.55	0.91	-2
37 - –72	65	96.74	0.67	-6
Elevation (m) *				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
85 - –135	88	77.05	1.14	2
135 - –185	109	108.94	1.00	0
185 - –235	88	69.49	1.27	4
235 - –285	36	32.25	1.12	1
285 - –335	79	89.53	0.88	-2
335 - –385	60	59.52	1.01	0
385 - –535	57	79.92	0.71	-4
Slope grade (degrees) **				
0	159	205.59	0.77	-9
2 - –5	56	40.79	1.37	3
6 - –14	137	126.43	1.08	2
15 - –58	165	143.86	1.15	4
Physical relief **				
Peak	3	8.88	0.34	-1
Plateau	28	35.87	0.78	-2
Ridge crest	153	166.35	0.92	-3
Ridgeline	136	104.62	1.30	6
Slope	161	174.35	0.92	-3
Saddle	29	22.92	1.27	1
Ravine	6	3.87	1.55	0
Canyon **				
Not in canyon	382	438.17	0.87	-11
In canyon	135	78.83	1.71	11
Slope aspect **				
None (flat)	119	149.48	0.80	-6
North-facing	59	74.96	0.79	-3
Northeast	30	33.53	0.89	-1
East	39	43.58	0.89	-1
Southeast	62	58.73	1.06	1
South	56	42.57	1.32	3
Southwest	14	9.02	1.55	1
West	26	19.17	1.36	1
Northwest	112	85.10	1.32	5
Slope aspect **				
None (flat)	119	149.48	0.80	-6
East-northeast	69	77.10	0.89	-2
South-southeast	118	101.30	1.16	3
West-southwest	40	28.19	1.42	2
North-northwest	171	160.06	1.07	2
Edge index at tower base **				
No edge	17	19.75	0.86	-1
Some lateral edge	46	49.39	0.93	-1
Lots lateral edge	115	161.77	0.71	-9
Some vertical edge	174	165.03	1.05	2
Lots vertical edge	131	106.21	1.23	5
Lots vertical and lateral edge	34	14.86	2.29	4
Rockpiles ≤ 50 m away				

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
None	375	387.13	0.97	-3
1	55	42.59	1.29	3
≥ 2	33	33.28	0.99	0
Rodent control through 2001 **				
Unknown	6	6.25	0.96	0
None	116	119.27	0.97	-1
Control	174	138.34	1.26	7
Intense control	221	253.15	0.87	-6
Rodent control through 2002 **				
Unknown	6	6.25	0.96	0
None	97	88.07	1.10	2
Control	174	138.47	1.26	7
Intense control	240	284.20	0.84	-9
Cattle pats 40 m from turbines				
0	39	35.96	1.08	1
1 - –9	184	180.53	1.02	1
10 - –25	105	120.84	0.87	-4
> 25	50	40.68	1.23	2
Cattle pats at turbines				
0 - –2	43	49.12	0.88	-2
3 - –9	112	128.41	0.87	-4
10 - –25	134	123.71	1.08	3
> 25	89	76.77	1.16	3
Cottontails 40 m from turbines				
No pellets	308	294.02	1.05	4
Some pellets	53	66.50	0.80	-4
Abundant pellets	17	17.49	0.97	0
Cottontails at turbines				
No pellets	301	287.98	1.05	3
Some pellets	57	65.90	0.86	-2
Abundant pellets	20	24.12	0.83	-1
Vegetation height (cm) *				
0 - –10	52	65.01	0.80	-3
11 - –20	128	122.62	1.04	1
21 - –35	105	115.01	0.91	-3
> 35	93	75.37	1.23	5
Pocket gopher clusting				
Obs/Exp in 15 m = 0	14	13.50	1.04	0
Obs/Exp in 15 m < 1.5	25	22.41	1.12	1
Obs/Exp in 15 m = 1.5-3.0	64	76.41	0.84	-6
Obs/Exp in 15 m > 3	97	87.69	1.11	5
Ground squirrel clustering				
Obs/Exp in 15 m = 0	64	70.49	0.91	-3
Obs/Exp in 15 m ≤ 1.14	72	77.52	0.93	-3
Obs/Exp in 15 m > 1.14	64	51.99	1.23	6
Pocket gopher density ≤ 90 m				
0 – –1.4/ha	78	68.15	1.14	5

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
1.41 – –3.5/ha	63	64.49	0.98	-1
> 3.5/ha	57	65.01	0.88	-4
Ground squirrel density ≤ 90 m[t]				
0/ha	28	35.62	0.79	-4
0.01 – –5.99/ha	133	117.02	1.14	8
≥ 6/ha	39	47.36	0.82	-4
Clustering of all burrows				
Obs/Exp in 15 m = 0-1.2	40	41.46	0.96	-1
Obs/Exp in 15 m = 1.2–-3.0	105	103.75	1.01	1
Obs/Exp in 15 m > 3	55	54.79	1.00	0
Density of all burrow systems				
< 5/ha	84	77.04	1.09	3
5 – –9/ha	61	58.85	1.04	1
> 9/ha	55	64.11	0.86	-5
Season of the year**				
Spring	44	101.69	0.43	-16
Summer	119	90.64	1.31	8
Fall	64	63.74	1.00	0
Winter	136	106.93	1.27	8

Table D3. Chi-square test statistics and derived measures of effect for all birds.

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Turbine model **				
Micon	136	82.24	1.65	5
Bonus	344	324.95	1.06	2
Danwin	1	5.95	0.17	0
Flowind	43	47.36	0.91	0
Windmatic	17	13.28	1.28	0
Enertech	42	60.21	0.70	-2
KCS-56	520	584.46	0.89	-6
KVS-33	14	12.09	1.16	0
Howden	13	5.22	2.49	1
Nordtank	26	19.04	1.37	1
W.E.G.	0	1.21	0	0
Rated turbine power (kW) **				
40	42	60.21	0.70	-2
65	179	114.56	1.56	6
100	520	584.46	0.89	-6
110	1	5.95	0.17	0
120	218	214.89	1.01	0
150	163	150.18	1.09	1
250	6	8.46	0.71	0
330	13	5.22	2.49	1
400	14	12.09	1.16	0
Rotor diameter (m) **				
13.5 – –14.8	59	73.49	0.80	-1
16.0	162	101.28	1.60	5
17.2 – –17.8	557	624.57	0.89	-6
19.1 – –19.5	225	228.09	0.99	0
23.4 – –25.2	126	111.27	1.13	1
31.4 – –33.2	27	17.31	1.56	1
Blade tip speed (kph) **				
136.77	17	13.28	1.28	0
143.20	26	19.04	1.37	1
146.42	218	214.89	1.01	0
148.03	42	60.21	0.70	-2
149.64	136	82.24	1.65	5
173.77	126	110.07	1.14	1
180.21	14	12.09	1.16	0
193.08	38	46.06	0.83	-1
194.69	6	7.25	0.83	0
212.39	0	1.21	0	0
239.74	13	5.22	2.49	1
246.18	520	584.46	0.89	-6
Blade tip speed (kph) **				
137.77 – –149.64	439	389.65	1.13	4

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
173.77 – –194.69	184	175.47	1.05	1
212.39 – –246.18	533	590.89	0.90	-5
Seconds/sweep at blade tip **				
0.272583	520	584.46	0.89	-6
0.343807	42	60.21	0.70	-2
0.374882	1	5.95	0.17	0
0.403091	136	82.24	1.65	5
0.407945	17	13.28	1.28	0
0.421219	26	19.04	1.37	1
0.447299	0	1.21	0	0
0.493765	13	5.22	2.49	1
0.502071	218	214.89	1.01	0
0.503748	37	40.11	0.92	0
0.507659	126	110.07	1.14	1
0.554769	6	7.25	0.83	0
0.694529	14	12.09	1.16	0
Seconds/sweep at blade tip **				
0.2726	520	584.46	0.89	-6
0.3438 – –0.4938	235	187.14	1.26	4
0.5021 – –0.6945	401	384.41	1.04	1
Rotor plane (m^2) swept/s **				
1498.8	42	60.21	0.70	-2
1518.1	17	13.28	1.28	0
1660.5	37	40.11	0.92	0
1718.4	26	19.04	1.37	1
1795.7	136	82.24	1.65	5
1859.3	6	7.25	0.83	0
2141.4	218	214.89	1.01	0
2780.4	1	5.95	0.17	0
3049.7	126	110.07	1.14	1
3286.5	520	584.46	0.89	-6
4014.2	0	1.21	0	0
4487.2	14	12.09	1.16	0
5645.9	13	5.22	2.49	1
Rotor plane (m^2) swept/s **				
1499 - –1859	264	222.13	1.19	4
2141	218	214.89	1.01	0
2780 - –3287	647	700.47	0.92	-5
4014 - –5646	27	18.52	1.46	1
Tower type **				
Vertical axis	43	47.36	0.91	0
Tubular	520	439.49	1.18	7
Lattice	593	669.15	0.89	-7
Tower height (m) **				
14.0	20	30.16	0.66	-1
18.5	403	428.12	0.94	-2

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
24.0	1	5.95	0.17	0
24.6	551	505.58	1.09	4
25.2	125	109.37	1.14	1
29.5	37	40.11	0.92	0
32.3	6	7.25	0.83	0
36.9	1	0.91	1.10	0
43.1	12	28.55	0.42	-1
Tower height (m) **				
14.0	20	30.16	0.66	-1
18.5	403	428.12	0.94	-2
24.0 – –25.2	677	620.89	1.09	5
29.5 – –32.3	43	47.36	0.91	0
36.9 – –43.1	13	29.46	0.44	-1
Rotor orientation to wind *				
Faces wind	682	637.84	1.07	4
Away from wind	431	470.80	0.92	-3
Vertical axis	43	47.36	0.91	0
Blade color scheme **				
White	1111	1128.31	0.98	-1
Black stripes	4	4.75	0.84	0
Red stripes	4	0.96	4.16	0
Red tips	17	9.88	1.72	1
Green tips	20	12.10	1.65	1
Perch guard				
None	1131	1143.44	0.99	-1
Wire netting	25	12.56	1.99	1
Derelict turbines				
Operating and away from derelict	1059	1066.18	0.99	-1
Derelict	39	40.18	0.97	0
Next to derelict	58	49.64	1.17	1
Height (m) of low blade reach **				
4.0	43	47.36	0.91	0
5.1	20	30.16	0.66	-1
8.0	14	12.09	1.16	0
8.9	13	5.22	2.49	1
9.6	344	355.52	0.97	-1
11.1	17	12.39	1.37	0
11.8	42	60.21	0.70	-2
12.0	0	1.21	0	0
13.5	125	109.37	1.14	1
14.4	1	5.95	0.17	0
14.9	218	214.89	1.01	0
15.7	144	170.22	0.85	-2
16.6	162	101.07	1.60	5
17.2	0	0.89	0	0
25.2	1	0.70	1.43	0

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
28.9	0	0.21	0	0
34.2	12	28.55	0.42	-1
Height (m) of low blade reach **				
4.0 – –5.1	63	77.53	0.81	-1
8.0 – –9.6	371	372.83	1.00	0
11.1 – –14.85	403	404.00	1.00	0
15.7 – –17.2	306	272.17	1.12	3
25.2 – –34.2	13	29.46	0.44	-1
Height (m) of high blade reach **				
22.9	20	30.16	0.66	-1
25.3	42	60.21	0.70	-2
25.9	17	12.39	1.37	0
27.4	344	355.52	0.97	-1
29.5	37	40.11	0.92	0
32.0	0	0.89	0	0
32.3	6	7.25	0.83	0
32.6	162	101.07	1.60	5
33.5	144	170.22	0.85	-2
33.6	1	5.95	0.17	0
34.4	218	214.89	1.01	0
36.9	125	109.37	1.14	1
37.2	0	1.21	0	0
40.3	13	5.22	2.49	1
41.2	14	12.09	1.16	0
44.9	0	0.21	0	0
48.6	1	0.70	1.43	0
52.0	12	28.55	0.42	-1
Height (m) of high blade reach				
22.9 – –27.4	423	458.29	0.92	-3
29.5 – –33.6	350	325.48	1.08	2
34.4	218	214.89	1.01	0
36.9 – –52.0	165	157.35	1.05	1
Wind wall **				
Not in wind wall	1040	993.87	1.05	4
In wind wall	116	162.13	0.72	-4
Position in string **				
End	373	256.29	1.46	10
Edge of gap	116	103.56	1.12	1
Interior	664	791.49	0.84	-11
Non-operational	3	3.78	0.79	0
Location in wind farm **				
Edge of farm	166	150.68	1.10	1
Edge of local cluster	176	119.51	1.47	5
Interior of wind farm	811	879.23	0.92	-6
Turbine congestion (no. in 300 m)				
0 - –12	149	132.48	1.12	1

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
13 - –24	536	522.58	1.03	1
25 - –36	278	282.71	0.98	0
37 - –72	192	216.12	0.89	-2
Elevation (m) **				
85 - –135	276	172.14	1.60	9
135 - –185	269	243.37	1.11	2
185 - –235	165	155.25	1.06	1
235 - –285	70	72.06	0.97	0
285 - –335	169	200.01	0.84	-3
335 - –385	113	132.97	0.85	-2
385 - –535	93	178.54	0.52	-7
Slope grade (degrees) *				
0	412	459.70	0.90	-4
2 - –5	107	91.21	1.17	1
6 - –14	283	282.69	1.00	0
15 - –58	354	321.67	1.10	3
Physical relief **				
Peak	8	19.86	0.40	-1
Plateau	115	80.19	1.43	3
Ridge crest	303	371.95	0.81	-6
Ridgeline	241	233.92	1.03	1
Slope	411	389.84	1.05	2
Saddle	65	51.25	1.27	1
Ravine	12	8.66	1.39	0
Canyon **				
Not in canyon	901	979.73	0.92	-7
In canyon	255	176.27	1.45	7
Slope aspect **				
None (flat)	304	334.23	0.91	-3
North-facing	142	167.61	0.85	-2
Northeast	67	74.97	0.89	-1
East	90	97.43	0.92	-1
Southeast	141	131.31	1.07	1
South	103	95.19	1.08	1
Southwest	29	20.17	1.44	1
West	64	42.87	1.49	2
Northwest	216	190.28	1.14	2
Slope aspect **				
None (flat)	304	334.23	0.91	-3
East-northeast	157	172.40	0.91	-1
South-southeast	244	226.50	1.08	2
West-southwest	93	63.03	1.48	3
North-northwest	358	357.89	1.00	0
Edge index at tower base **				
No edge	36	44.15	0.82	-1
Some lateral edge	124	110.43	1.12	1

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Lots lateral edge	298	361.71	0.82	-6
Some vertical edge	369	369.00	1.00	0
Lots vertical edge	277	237.48	1.17	3
Lots vertical and lateral edge	52	33.23	1.56	2
Rockpiles ≤ 50 m away [t]				
None	856	882.12	0.97	-2
1	115	97.05	1.18	2
≥ 2	84	75.84	1.11	1
Rodent control through 2001 **				
Unknown	10	13.99	0.72	0
None	301	266.68	1.13	3
Control	351	309.31	1.13	4
Intense control	494	566.03	0.87	-6
Rodent control through 2002 **				
Unknown	10	13.99	0.72	0
None	231	196.93	1.17	3
Control	352	309.62	1.14	4
Intense control	563	635.47	0.89	-6
Cattle pats 40 m from turbines				
0	88	86.00	1.02	0
1 - –9	450	431.74	1.04	2
10 - –25	275	288.99	0.95	-2
> 25	91	97.28	0.94	-1
Cattle pats at turbines				
0 - –2	119	117.47	1.01	0
3 - –9	287	307.09	0.93	-2
10 - –25	323	295.85	1.09	3
> 25	175	183.60	0.95	-1
Cottontails 40 m from turbines *				
No pellets	689	703.15	0.98	-2
Some pellets	157	159.03	0.99	0
Abundant pellets	58	41.82	1.39	2
Cottontails at turbines *				
No pellets	653	688.72	0.95	-4
Some pellets	178	157.61	1.13	2
Abundant pellets	73	57.68	1.27	2
Vegetation height (cm) [t]				
0 - –10	118	155.46	0.76	-4
11 - –20	299	293.24	1.02	1
21 - –35	297	275.05	1.08	2
> 35	190	180.25	1.05	1
Pocket gopher clusting **				
Obs/Exp in 15 m = 0	52	32.74	1.59	4
Obs/Exp in 15 m < 1.5	75	54.34	1.38	4
Obs/Exp in 15 m = 1.5–-3.0	151	185.29	0.81	-7
Obs/Exp in 15 m > 3	207	212.64	0.97	-1

Variable and Attribute	Observed	Expected	Obs ÷ Exp	Accountable percent
Ground squirrel clustering **				
Obs/Exp in 15 m = 0	129	170.95	0.75	-9
Obs/Exp in 15 m ≤ 1.14	174	187.99	0.93	-3
Obs/Exp in 15 m > 1.14	182	126.06	1.44	12
Pocket gopher density ≤ 90 m **				
0 – –1.4/ha	228	162.45	1.40	14
1.41 – –3.5/ha	135	153.73	0.88	-4
> 3.5/ha	109	154.97	0.70	-10
Ground squirrel density ≤ 90 m **				
0/ha	55	86.38	0.64	-6
0.01 – –5.99/ha	315	283.77	1.11	6
≥ 6/ha	115	114.86	1.00	0
Clustering of all burrows **				
Obs/Exp in 15 m = 0-1.2	128	100.53	1.27	6
Obs/Exp in 15 m = 1.2-3.0	259	251.60	1.03	2
Obs/Exp in 15 m > 3	98	132.86	0.74	-7
Density of all burrow systems [t]				
< 5/ha	191	186.81	1.02	1
5 – –9/ha	160	142.72	1.12	4
> 9/ha	134	155.47	0.86	-4
Season of the year**				
Spring	171	258.28	0.66	-9
Summer	305	230.22	1.32	8
Fall	133	161.89	0.82	-3
Winter	313	271.60	1.15	4