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Subcontractor Report

Bird Risk Behaviors and Fatalities at the Altamont Pass Wind Resource Area

Period of Performance: March 1998–December 2000

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EXECUTIVE SUMMARY

It has been documented that wind turbine operations at the Altamont Pass Wind Resource Area kill large numbers of birds of multiple species, including raptors. We initiated a study that integrates research on bird behaviors, raptor prey availability, turbine design, inter-turbine distribution, landscape attributes, and range management practices to explain the variation in avian mortality at two levels of analysis: the turbine and the string of turbines. We found that inter-specific differences in intensities of use of airspace within close proximity did not explain the variation in mortality among species. Some species, however, spent more time flying within 50 m of turbines than expected based on the area within this proximity zone, and they spent less time within 51-100 m or 101-300 m, indicating that these species were drawn into the lands near turbines for some reason(s).

Unique suites of attributes relate to mortality of each species, so species-specific analyses are required to understand the factors that underlie turbine-caused fatalities. We found that golden eagles are killed by turbines located in the canyons and that rock piles produced during preparation of the wind tower laydown areas related positively to eagle mortality, perhaps due to the use of these rock piles as cover by desert cottontails. The degree of clustering of pocket gophers around wind towers related positively to red-tailed hawk mortality, and the degree of clustering of gophers appeared to be greatest on steeper slopes into which laydown areas and access roads were cut, thereby producing increased lateral and vertical edge (which gophers prefer for constructing their burrow systems).

Tubular towers killed more red-tailed hawks and other raptors than would be expected from their numbers within our study area, and this pattern was even stronger for areas in which the tubular towers occurred on ridge tops and other landscape features that produced strong declivity winds. Rotor speed correlated positively with mortality, as did rotor height above the ground and rotor diameter. The windswept area of the turbine string, meaning the cumulative rotor-swept areas of all turbines in the string, correlated positively with mortality of several avian species. Factoring in the windswept area eliminated the effect of turbine position in the string, which some had thought to be an important factor for avian mortality, and which was verified by our data prior to factoring in the windswept area. Raptor fatalities did not correspond well with the distribution of California ground squirrels. Other similar relationships between fatalities and environmental factors are identified and discussed. The tasks remaining to complete the project are summarized.

1.0 INTRODUCTION

Research has consistently documented since about 1989 that wind turbines in the Altamont Pass Wind Resource Area (APWRA) kill a large number of birds, especially raptors (Orloff and Flannery 1992, 1996; Howell 1997; Howell and DiDonato 1991). Early researchers mainly focused on locating kills and quantifying bird fatality rates. Although these researchers hypothesized various causes and mechanisms associated with these fatalities, their research results were too cursory to lend much confidence even to the hypothesis tests that were performed. It soon became evident that if solutions to the problem were to be developed, then it would be necessary to conduct a risk assessment and a risk reduction study (Anderson et al., 1999).

In March 1998, the National Renewable Energy Laboratory (NREL) initiated research to address some complex questions that affect both wind energy development and wildlife conservation. What is the full extent of bird fatalities in the APWRA? What are the underlying causes of the fatalities? Are these events non-random and therefore, predictable? If they are, then what management options might be developed to reduce risk? In an effort to reduce the complexity surrounding these questions, we present the following framework for addressing and interpreting factors related to bird fatalities at the APWRA.

Step 1	Natural behaviors, geographic distributions, and ecological relationships that predispose wildlife to harm due to turbine operations	⇨	Sensitivity
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; proportions of populations killed (risk)	⇨	Impacts
Step 4	Reliable prediction of impacts from indicators of sensitivity and vulnerability	⇨	Solutions

In the above framework, the integration of Steps 1 through 3 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 *sensitivity* and *vulnerability*, terms which are drawn from the ecological indicators framework (Rapport, Reiger, and Hutchinson 1985; Cairns and McCormick 1992; O'Neill et al., 1994; Rotmans et al., 1994; Schultze et al., 1994; USDA 1994; Battaglin and Goolsby 1995; for an example, see Zhang, Geng, and Smallwood 1998) and defined below.

These terms are useful for our purposes because, although we would like to estimate levels of risk for each bird species at the APWRA, we cannot do so because we cannot enumerate each species at and around the APWRA. A true estimate of risk requires that the estimate of mortality be put into context with the total population size. Whereas the risk per species would be the preferred product of our research, solutions to avian mortality at the APWRA can be efficiently derived from the above framework.

1.1 Natural Behaviors and Ecological Relationships: Sensitivity

Birds die when attempting to pass through the rotor plane or when flying into guy wires or perching atop electrical distribution poles that service the wind farm. These attempts to fly through the rotor plane ultimately express natural behaviors, but in an artificial context in which the rotor plane has been introduced along with the other land uses and structures that are characteristic of wind farms. Natural behaviors and ecological relationships of birds contribute to their inherent sensitivity to wind turbines. Since each bird species exhibits unique suites of behaviors, geographic distributions, and ecological relationships, each also possesses unique sensitivities to wind farms. For example, if golden eagles (*Aquila chysaetos*) spend most of their foraging time in canyons, then they may be more sensitive to the placement of wind turbines in canyons. Red-tailed hawks (*Buteo jamaicensis*) may be less sensitive to turbine placement in canyons and perhaps more sensitive to turbines placed on ridgelines, if ridgelines happen to be where they fly most often. Burrowing owls (*Athene cunicularia*) might be most sensitive to turbine placement in areas where they conduct most of their courtship displays or where their foraging takes them into the altitudes of the rotating turbine blades. Thus, sensitivity is estimated by measuring and comparing behaviors that could cause individual species to collide with wind turbines should these behaviors continue unaltered after wind turbines are placed into operation.

Orloff and Flannery (1996) suggested that some birds try to pass through the rotor plane because they simply cannot see rotating turbine blades, or in the case of raptors, because they are fixated on a perch or prey item situated beyond the blades. Raptors may identify a perch or prey item and continuously observe it until they capture or land on it. If the raptor's target is located behind the rotating blades of a turbine, then the raptor may not see the blades or may see them when it is too late to avoid them. The relative effects of retinal 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 indicate that fixed focus on prey items is not the only reason birds attempt to pass through the rotor plane.

Certain flight behaviors might influence a species' sensitivity to wind turbines, such as their long-distance flight behaviors during migration and their use of declivity winds, which are strong winds passing over ridge tops as they are forced upslope. Patterns of perching might connote various levels of sensitivity, if, for example, certain birds are prone to perching on wind towers because these towers simulate trees with which the species is familiar. Certain mating behaviors might distract individuals regardless of whether turbines are operating in the vicinity. Nocturnal predators may be more sensitive than diurnal predators due to differences in sensory perception relied upon by animals during the night versus the day. Lastly, some bird species that occur in relatively high numbers in the study area may only fly at heights well above the current rotor blades, thus indicating low sensitivity to the wind farm. For these and other potential inter-specific differences in sensitivity associated with flight behaviors, future changes in turbine design, operation, and placement might yield different mortalities among bird species at the APWRA.

The best approach for estimating sensitivity is to do so in a study with a before-after control impact (BACI) design with replication of impact and control treatments (Anderson et al., 1999). However, our study could not implement such a design because we were working with wind towers that were developed prior to the initiation of our study. In the absence of the ideal study design, in which we characterize bird behaviors at the APWRA prior to wind turbine operations, we made what inferences we could about sensitivity of bird species to placement and operation of wind turbines (summarized in the Preliminary Results section).

1.2 Exposure to Wind Farm Operations: Vulnerability

The placement and operation of wind turbines can make birds vulnerable to turbine collisions when and where these birds are already sensitive to turbines due to relative abundance, behaviors, and ecological relationships (e.g., predator-prey interactions). Vulnerability is a relative term that requires the measurement of sensitivity and impact across ranges of environmental conditions within the study area. Quantifying vulnerability requires a comparison of both the bird use of the environment near 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 prey species.

Measures of vulnerability can be based on relative abundance near wind turbines and/or on the relative mortality of avian species at turbines with particular attributes. In both cases, a 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 A, and this proportion of flight time is related to the proportion of landscape element A occurring within the study area. Bird mortality can be measured as the proportion of the sample of individuals killed at turbines of a particular type or environmental setting relative to the proportion of those types or settings in which the 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 turbines, n = flight time of a particular species near 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, our study attempts to identify the vulnerability of bird species to strikes with wind turbines based on our weighted measurements of sensitivity and impacts.

1.2.1 Wind Tower Design, Location, and Operation

Orloff and Flannery (1992, 1996) and Hunt (1994) suggested that wind turbines placed near gullies and turbines located at the ends of strings might be more dangerous to birds. The inter-tower spacing and the height of turbine towers and rotor diameters might interact to affect a species' vulnerability to turbine collisions. In addition, the percent of time that wind turbines operate may also be an important factor in bird collisions (Orloff and Flannery 1996).

Orloff and Flannery (1992) suggested that birds perched on certain turbine/tower configurations more often than they did on others, thus increasing the birds' risk at these sites because of the proximity to the turbines' rotating blades. In their comparative analysis of fatality rates among five tower configurations (lattice towers, horizontal cross, vertical axis, guyed pipe, and tubular), Orloff and Flannery (1992) reported significantly higher fatality rates at sites with horizontal lattice towers (i.e., at Kenetech 56-100 units). Certain characteristics of these facilities are believed to have contributed to high bird mortality, including numerous potential raptor perch sites created by the horizontal reinforcing crossbars, a high percentage of time in operation, and a relatively fast "tip speed," which is the rotational velocity of the tip of the rotor blade.

Wind turbines may be especially dangerous during unsettled weather conditions or in periods of poor visibility, such as during fog, rain, darkness, dusk, or dawn (Avery, Springer, and Cassel 1977; Taylor and Kershner 1986; Morrison 1996). Even inoperative turbines may be dangerous. Furthermore, during spring or fall bird migrations, the absolute number of bird fatalities might increase simply in proportion to the larger number of individuals passing through the APWRA, or migrants may be more or less sensitive to turbines than are residents. (Note that migrating raptors often fly at much lower altitudes than migrating passerines.)

The development of wind resource areas can sometimes bring with it numerous additional artificial perching and nesting sites, such as wires that support wind towers, the towers themselves, electrical distribution poles, meteorological towers, and transmission lines. These facilities could attract birds to a wind resource area, thus bringing them closer to turbine blades (Orloff and Flannery 1992). Some of these facilities of the wind resource area pose potential additional hazards to that of rotating turbine blades, such as stationary obstacles encountered during flight and energized elements used for perching.

Some researchers have suggested that modifying the structure or color of the towers or the turbine blades may reduce bird fatalities. For example, modifying towers might reduce perching, and painting disruptive patterns on turbine blades might make them more evident to birds (Kerlinger and Curry 1997). A recently proposed rotor blade painting scheme might enable birds to more clearly see rotating blades at shorter distances than unpainted rotating blades (Hodos et. al, 2001). Reducing golden eagle prey populations in the APWRA through intensive ground squirrel population control programs might modify that species' habitat use and thus might reduce risk of being killed by a turbine (Kerlinger and Curry 1997; G. Hunt, pers. comm.), although the overall risk of death to the eagle might increase as local prey availability declines. These suggestions have not been sufficiently tested to justify their implementation as solutions.

1.2.2 Altered Prey Availability

The development of the APWRA likely affected the distributions, abundance, and availability of prey species (Morrison 1996). Soil disturbance may have increased the numbers of ground squirrels (*Spermophilus beecheyi*), and the reduction of grass height in the presence of cattle grazing may have increased squirrel vulnerability to raptors (Morrison 1996). It may be possible to use habitat alterations to reduce prey vulnerability near turbines, thereby reducing raptor use of these areas as well as fatalities. This suggestion also remains untested.

Raptor mortality at wind turbines has been attributed to the occurrence of prey species near the wind turbines. At the APWRA, the principal prey species of interest to past researchers has been California ground squirrels, based on its status as a major prey item of golden eagles in central California (University of California, 1998). However, pocket gophers (*Thomomys bottae*) are abundant throughout the APWRA, whereas ground squirrels have an uneven, patchy distribution, as we will demonstrate with data in this and future reports. Red-tailed hawks and great horned owls rely heavily on pocket gophers (Fitch, Swenson, and Tillotson 1946; Craighead and Craighead 1956; Orians and Kuhlman 1956), whereas golden eagles rely more heavily on larger prey items, 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. Each raptor species foraging in the APWRA responds uniquely to prey species availability and thus requires independent analysis. (Previous studies have tended to group species into *raptors* and *nonraptors* for analysis.)

1.3 Measuring Effects on Birds: Impacts

Avian mortality studies conducted at wind resource areas have produced a variety of mortality estimates. Howell and DiDonato (1991) sampled the APWRA's turbines in 1988-89 and reported 0.05 deaths per turbine per year (n = 17 fatalities). Orloff and Flannery (1996) conservatively estimated that 39 golden eagles were killed during a 1-year period in the APWRA, and they estimated raptor mortality to range from 0.02-0.05 deaths/turbine/year. During a 1-year period, Howell (1997) confirmed 72 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.

The effects of turbine operations on birds can be interpreted from two perspectives: legal and biological. From a legal perspective, individual fatalities can be considered significant effects and subject to civil or criminal penalties. Federal laws protecting raptors specifically include the Migratory Bird Treaty Act (MBTA), the Bald Eagle 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 "take" to be any injury or fatality of any raptor from a collision with a wind turbine or ancillary facilities in the APWRA, and therefore, a violation of the MBTA (S. Pearson, pers. comm.., Senior Resident Agent, USFWS). Bird fatalities attributable to wind turbines are significant effects, from a legal perspective, because they violate the MBTA.

Comparing the turbine-caused mortality to both the natural mortality and the recruitment rate of each affected species effectively measures the biological importance of turbine-caused fatalities. Doing so yields estimates of the degree to which wind turbines adversely affect a species' population size, stability, and distribution. However, to do so requires extensive information about the distribution and demographic structure of populations occurring at and around the APWRA. Simply counting living birds at the APWRA would be inadequate for this purpose because the numbers of multiple species would change dramatically throughout the year due to migrations. The numerical estimates made at the APWRA would be, in multiple cases, contaminated by individuals that live most or part of their lives elsewhere. The APWRA may directly affect any number of bird species that occur over a broad geographic area. Thus, the geographic scale required for estimating impacts to avian species would be much larger than the APWRA itself. Our scope of study will 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 should be estimated by additional research.

Among the raptor species killed in the APWRA, golden eagles and burrowing owls are probably the species of greatest concern because they are California Species of Special Concern. Although no detailed studies are currently underway to address burrowing owls, a recent study of mortality factors and golden eagle population regulation over a broad geographic region specifically included the APWRA within its overall study area (Hunt 1994, 1997, 2002). In recent years, golden eagle deaths in the area have been attributed to wind turbines. Preliminary research results indicate that the additional effect of the turbine-related fatalities might be contributing to a long-term decline in the region's golden eagle population (Hunt 1994, 1997, 2002). Therefore, although turbines might not cause a species to decline across its entire geographic range, the cumulative effect of human-caused fatalities may extirpate a species over a portion of its range.

Until more rigorous research efforts like the one for golden eagles are conducted at the APWRA for each bird species adversely affected by wind turbines, the full environmental impact of the APWRA will remain unknown. We will not know how the killing of *individual* birds affects their *populations*. In lieu of more rigorous research on population-level impacts, it would be prudent to implement effective management practices that will demonstrably reduce the vulnerability of bird species to the APWRA. In addition, demonstrating a reduction in bird fatalities within the APWRA would likely enable Alameda County (1998) to permit an increase in generating capacity that is available to the wind industry.

1.4 Relating Impacts to Causal Variables: Predictions and Solutions

Holding aside effects of season, weather, and turbine design and operation, if individuals of a bird species were randomly killed at wind turbines among measured environmental elements on the APWRA, then the probability of an individual being killed by a turbine occurring on a particular environmental element would equal the proportion of the 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 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 turbines on southeast-facing slopes. This product of total number killed (N) and the incidence of 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, where the distribution of mortality is random. For example, had 40 red-tailed hawks been killed by 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 cannot be attributed statistically to anything other than turbine numbers. However, when the converse is true, a relationship exists between that environmental element and mortality. If the relationship is less than 1, 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 turbine numbers alone, we are able to identify which environmental factors might have a causal relationship. This approach allows us to assess vulnerability.

At selected wind turbines within the APWRA, we compiled separate data files 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 progress report summarizes the preliminary results of our integration of these data. This attempt at data integration brings us another step closer to developing a predictive model for bird mortality at wind turbines based on turbine location on the landscape, turbine location relative to other turbines, turbine design and operation, the distribution of raptor prey species near turbines, and other potential predictor variables.

We believe that in the future, such an approach will lead to a model that will reliably predict how many birds per species are likely to be killed at individual turbines or at strings of turbines per year. Most important, such a model can be used as a tool to identify zones of vulnerability when siting new wind turbines in the APWRA.

2.0 OBJECTIVES

The primary objectives of this current phase of the research were: (1) to quantify bird use, including characterizing and quantifying perching and flying behaviors exhibited by individual birds around wind turbines; (2) to evaluate the flying behaviors and the environmental and topographic conditions associated with flight behaviors; and (3) to identify possible relationships among bird mortality and bird behaviors, wind tower design and operations, landscape attributes, and prey availability. A fourth objective, to be achieved after the fieldwork is completed, is to develop a predictive, empirical model that identifies areas or conditions that are associated with high vulnerability. Such a model could one day be used in the APWRA to identify locations and conditions of high versus low vulnerability, or to accurately identify those turbines that have demonstrated their ongoing threat to birds.

We began the project by quantifying bird use and bird fatalities associated with that use. Only about 24% of the APWRA's total turbine population was included in the project due to limited access. We quantified bird flight and perching behaviors at the various turbine types and examined whether the frequencies of these behaviors at 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 on wind towers/turbines. 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) turbine/tower design, placement, and operations; and (3) raptor prey availability and distribution in relation to individual turbines and turbine strings.

3.0 STUDY AREA

The APWRA is located 90 km east of San Francisco, within eastern Alameda and southeastern Contra Costa counties in central California (Figure 1). Within the APWRA, which is the largest wind energy facility in the world, some 8,200 turbines were originally approved with as many as 7,200 installed at one time. When the current study began approximately 5,400 turbines were operating (Alameda County 1998). The output capacity of the installed turbines is about 580 megawatts. They are distributed over approximately 150 km^2 (50,000 acres).

The APWRA facility first reached significant levels of energy generation during the mid-1980s, when most of the wind towers now in existence were erected (Hunt 1997). Turbines are generally grouped under common ownership. At least 13 companies manage the energy that is produced in the APWRA, and a variety of different tower/turbine configurations are installed.

The Altamont Pass region exhibits a wide diversity in topographic relief. Hilltop elevations range from 230-470 m above sea level. Valley elevations range from about 78-188 m above sea level (Howell 1997). Livestock grazing and dry farming constitute the primary land use in the area (University of California, 1998).

Steady winds from the southwest blow across Altamont Pass from 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 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 turbines beginning about midafternoon and increasing during the evening hours. During winter, wind speeds average 15-25 km/hr. Dense fog can occur in the Altamont Pass during summer and winter. Severe winter fog conditions often linger for many consecutive days.

The vegetation is predominately non-native 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 frogs (*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).

4.0 METHODS

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).

4.1 Study Plots and Wind Energy Facilities Sampled

We sampled 1,110 individual tower and turbine configurations from March 1998 through December 2000 (Table 1). During the project, we added groups of turbines as they became available to us. In particular, Altamont Infrastructure Company (AIC) wind towers (n = 425) were added to our study much later than the others. By December 2000, we had sampled these turbines only one-third as many times as we did the other turbines in our sample. This differential search effort would confound our analysis if we included all turbines being surveyed as of 31 December 2000. Therefore, we have separated many of the analyses in this report into AIC and non-AIC wind turbines. Unless specifically indicated, the findings presented in this report represent results only for non-AIC turbines/towers (Table 2; n = 685).

4.2 Bird Fatalities

Gauthreaux (1996) suggested that searches for bird fatalities around individual turbines should be circular, with the minimum radius determined by the height of the turbine. Since all wind towers in our study area were arranged in strings, we searched them efficiently by walking strip transects along both sides and around the ends.

Data on each fatality included 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 and turbines where birds were not killed, as well. We used a global positioning system (GPS) device to record these data. The GPS data dictionary used to collect data is included in the Appendix.

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 2). 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, mostly in the area behind the rotor (Orloff and Flannery 1992; Munsters, Noordervliet, and Ter Keurs 1996; Howell 1997). Both searchers walked toward and outward from the string line in a zigzag pattern from wind tower to wind tower until they reached the last one.

On hillsides or steep terrain, the searchers walked parallel to the string line, 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 (i.e., 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.

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 tower 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 found during our searching cycle of from 1 to 60 days. 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 start of this project. The above data, as well as the distance and angle to the wind tower closest to the carcass, were recorded on a standard data sheet. Observers photographed each fatality at the time of discovery.

The ground around each wind tower was searched in 8-10 minutes. Five hours per day were devoted to fatality searches, and two-person crews managed to search 30-40 turbines per day. With two to three people searching 120-150 wind towers per week, all 685 turbines were sampled once every five to six weeks, thus completing approximately eight fatality search cycles in 12 months. Not all 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.

From 26 March 1998 to 29 February 2000, we searched each of 685 wind turbines 16 times. We also present all fatality records through December 2000, but we discontinued collecting flying and perching behaviors after 29 February 2000 due to budget limitations. These additional fatality data are useful for estimating vulnerability for reasons other than behavior.

We analyzed mortality at two levels of resolution. The finest resolution of analysis was at the turbine level, in which we examined the number of fatalities of each species associated with each wind tower. At the turbine level of analysis, we relied on chi-square analysis derived from the model described above. We analyzed turbine-caused mortality among bird species with which we had gathered at least 20 records, except for golden eagles, which had only 12 records but was a principal species of concern in the study due to its rarity, low productivity (University of California, 1998), and special status under environmental laws.

The coarsest resolution of analysis was at the string level. In this case, we examined the number of fatalities of each species associated with entire strings of wind towers. At the string level of analysis, we relied on Pearson correlation and linear, least-square regression analyses. These analyses always started with examination of scatter plots of mortality on the Y-axis and predictor variables on the X-axis in order to identify patterns in the data, and progressed to a systems analysis approach to explaining the variation in fatality rates (Watt 1966, 1992). This systems analysis approach relies on saving unstandardized residuals from linear regression analysis, then systematically plotting these residuals against each of the other predictor variables. Residuals are the vertical, Y-axis distances measured between each data point and the estimated line representing the regression slope. Residuals represent the variation in the dependent variable that is not explained by the predictor variable. The new plots of residuals from one predictor variable plotted against another predictor variable can reveal meaningful patterns in the residual variation of the dependent variable, which can then be explained by both predictor variables in multiple regression analysis (Watt 1966).

The statistics we present in this report are consistent with the objectives 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 when the objective is simply to summarize the degree of correlation. We will report weak and non-significant correlations when doing so meets our objectives.

Because R^2 is based on two independent factors— 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 many of our hypothesis tests.

Although we use analysis of variance (ANOVA) to test some hypotheses in this study, key assumptions of ANOVA cannot be met due to the lack of any sort 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 most efficient for testing many of our hypotheses (Smallwood 1993, 2002).

In all of our hypothesis testing, we relied on an 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 divided by 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.

4.2.1 Scavenging Activities

Orloff and Flannery (1992) reported little evidence of raptor carcass removal by scavengers during their research at Altamont. However, not documenting the full effect of scavenging may cause an underestimation of the number of dead birds found during our searches. We left in the field each bird carcass we found. Having recorded its exact location using GPS and flagging, we then visited each carcass location at least every 3 days or until the proper authorities collected it. During the time the carcass was in the field, we recorded data on the condition of the carcass, amounts of decomposition over time, and any evidence of scavenging at an interval of once per week. Even though the U.S. Fish and Wildlife Service required immediate reporting of carcasses found and endeavored to pick up all of these carcasses from the field soon after reporting, carcasses occasionally remained in the field for up to 1 month before authorized personnel retrieved them. Thus, we conducted a non-systematic scavenging rate evaluation by recording signs of scavenging activity at the time of the finding and occasionally throughout the times that carcasses were left in the field by the U.S. Fish and Wildlife Service.

At our ENRON study site, due to differences in county regulations, carcasses and remains were reported to the supervisor on site but never picked up from the field. This situation presented us with an opportunity to monitor the scavenging and decomposition rates of those carcasses for longer periods than others. Information about change in carcass condition over time and the period carcasses remained in the field helped us assess the effectiveness of fatality searches in discovering fatalities and how long they remain to be discovered. We calibrated our estimates of time since death by comparing the decomposition level of a specific fatality since the known time of death.

4.3 Bird Behaviors

Two biologists spent 303 days in the field collecting bird behavior data within 20 study plots during 26 March 1998 through 30 March 2000. The boundaries of these study plots were determined by including only those wind turbines easily visible to the observers from a fixed observation point. The result of this plot selection process was a mosaic of irregular shaped, non-overlapping polygons, each about 3 km^2 (Table 2).

The plots where we collected behavior data contained 685 turbines, with 25-45 turbines per plot, representing 98% of all turbines accessible to us at that time. We classified each turbine string by slope aspect, average grade, and average elevation. Slope aspect was classified as facing north, northeast, east, southeast, south, southwest, west, northwest, or located in a valley. Average grade was classified as Level 1 = 0%-9% grade, Level 2 = 10%-19%, Level 3 = 20%-29%, and Level 4 = 30%-39%. Average slope elevation was classified into three groups: high elevation, including slopes 250-324 m above sea level; medium elevation slopes (175-249 m); and low elevation slopes (100-174 m).

We also recorded the topography on which turbine strings were situated, such as on ridges, slopes, swales, peaks, or plateaus, and we recorded the direction to which these topographic features face (as described above for individual turbines). Turbine sites refer to the positions of turbines within a string, such as end of the string, second to the end, interior to the string, or separated from other turbines by a gap created by an inoperable turbine or a gully, as examples. Of the turbines sampled, there were 210 end-of-the-row wind towers, 152 second-to-the-end wind towers, 93 third-to-the-end wind towers, and 217 interior wind towers.

We quantified bird behaviors by recording the number of birds detected within specific study plots and categorizing their specific activities while in those plots (Table 3). Within each study plot, a location was selected from which behavioral observations took place. The observation point was a fixed location used for all behavioral data collection and at which the observer had the best view of the wind towers and the surrounding terrain within the study plot. This approach ensured that each bird species was identified and their activities around the turbines documented. Each observer carried maps of the plots in order to identify each turbine by location and number where each bird flew or perched.

Before the behavioral observations commenced, and for the specific purpose of this study, a field data sheet was developed to record many aspects of bird behavior, as well as the environmental conditions at the time of the observation session. Bird behavior was recorded with alphanumeric codes onto a standardized data sheet, along with temperature, wind speed, turbine operations, and cloud cover at the beginning of each 30-min observation session. We measured temperature with a hand-held thermometer. We evaluated wind force by looking at the observable wind characteristics and measured using the Beaufort scale (0-7). The scale numbers were later transformed into km/hr and grouped according to three wind speed levels: low wind speed levels (0-15 km/hr), medium (16-30 km/hr), and high winds (31-50 km/hr). When the wind speed reached > 55 km/hr (near gale winds), the managers of the facilities advised us to leave the premises for safety reasons.

A single observer completed each sampling event with 8x40 binoculars and performing circular visual scans (360^o), also called variable distance circular point observations (Reynolds, Scott, and Nussbaum 1980). Each visual circular-scanning event lasted 30 min and corresponded to one observation session.

Once a bird crossed the boundary into the study plot, we identified it and continuously followed it until it left the plot. For each sighting, we recorded the species, number of birds in a flock, the times when the bird was detected and when last seen, predominant flight behavior, flight direction, distance to the nearest turbine, type of turbine, number of passes by a turbine, and flight height relative to the windswept zone, which is the height above ground from the lowest to the highest reaches of the turbine blades.

We considered two major bird behavior categories—flying and perching—but classified 18 flying activities (Table 3). The focus of the behavioral observations was to determine how close to a turbine each bird flew, and what types of behaviors it exhibited near the "zone of vulnerability." The zone of vulnerability in this study represents the reach of the rotating turbine blades or rotor swept area, within 50 m of the blades (Figure 3).

The estimation of the closest pass to the zone of vulnerability was vital to this study. Therefore, both field assistants practiced calibrations on height and depth measurements of known objects every six months.

A proximity value was assigned to each behavior in terms of how close that behavior was performed in relation to the turbine blades and according to the length of time birds spent doing that behavior near the blades. Proximity Level 1 involved behaviors performed within 1 – 50 m of the 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.

Three hundred meters represented the farthest distance in which many flying birds could be clearly identified to species, their behavior followed, and their distance estimated, so only birds observed within that distance were recorded during the behavioral observations. If the biologists observed the bird perching, they recorded the time and specific perching structure. Perching was recorded on 21 structures within our study site (Table 4).

A bird's "utilization duration" was the amount of time it was observed during a 30-min observation session. We attempted to accurately quantify the amount of time spent flying and perching in order to determine the extent of both activities. After the observation period ended, the observer moved to the next sampling plot to complete another 30-min observation session.

Our biologists sampled all 20 plots at least once every week, stratified by morning and afternoon sessions. The morning session started at 07:00 and continued until 12:00. The afternoon session lasted from 12:01 until dusk. We observed behaviors throughout the year in nearly every weather condition, unless rain or fog reduced observer visibility to <60%, which was too poor to track bird activity accurately. We completed two sessions simultaneously, averaging 6-8 observation sessions per field day. We conducted all simultaneously occurring 30-min sessions on non-adjacent plots to ensure independence among observation sessions.

We calculated the mean minutes of flying and perching behaviors among the 30-min observation sessions for each bird species. Mean minutes of flying and perching behaviors were related to seasons, wind speed levels, topographic features, and wind turbine characteristics to determine whether these variables might affect mean flight time among raptor and non-raptor species. These factors were treated as independent variables in one-way analysis of variance (ANOVA) tests (Zar 1996) on the minutes of flying and perching activities per bird species.

When any of the ANOVA tests rejected the null hypothesis, we used the Tukey test (Zar 1996) to determine where differences existed. The mean minutes of each bird behavior were also considered in one-way ANOVA to identify significant differences for the raptor and non-raptor species among independent variables such as seasons, wind speeds, topographic characteristics, and turbine types.

Statistical tests were performed only for bird species observed in at least 10% of the sessions 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. In cases where subdivision of the data by years reduced the sample size substantially, we grouped data and analyzed them across both years. We performed Student t-tests (Zar 1996) to determine whether significant differences in flying and perching time occurred between years. The species included in our more rigorous analyses reported herein include American kestrel, red-tailed hawk, turkey vulture, golden eagle, burrowing owl, common raven, loggerhead shrike, and several other passerine species. We will provide analyses for the rarer species in the final report.

4.3.1 Observer Bias

To reduce the effects of observer bias in estimating and reporting distances and bird behaviors, paired observations were conducted for 1 month at the beginning of the study. At this time, we calibrated differences between observers in terms of distances, turbine and tower sizes, and depth perception. We also recorded bird behavior to become familiar with the data sheet and to standardize the names for all bird activities, behavior categories, and perching devices. Once the observers were achieving similar records and behavior interpretations, observers began conducting separate 30-min observation sessions. We completed the first calibration period in 18 observation sessions. We repeated these calibration sessions every 6 months in four observation sessions for a period of 1 to 2 days. The observers recorded the behavioral information simultaneously but independently on separate data sheets. At the end of each calibration session, we compared and discussed the information to help ensure consistency of the behavioral interpretations.

4.4 Landscape Features

We used a Trimble Pathfinder Pro-XR GPS to map the location of each wind tower with sub-meter accuracy. At each of these locations, we also recorded attributes of the tower/turbine and the landscape. These attributes were stored in a spatially explicit database (GIS). We recorded the type of turbine, whether it had an anemometer (in order to test whether its availability as a perching structure might relate to fatality rates), whether the turbine faced toward or away from the wind, the turbine's position within the string, the number of turbines in the string, and whether the turbine was part of a windwall, which is composed of turbines at two or more heights above the ground and which together extend the windswept zone. We recorded the physical relief, such as whether the tower/turbine was on a ridgeline, peak, slope, or swale. In addition, we recorded the slope aspect on which the tower/turbine occurs, the elevation in meters above sea level, and various notes about the site.

We mapped the location of each tower by using the offset function of the GPS because we wanted to avoid inaccuracies possibly caused by the electromagnetic field of operating wind turbines. We stood ≥5 m from each tower and input the distance, compass bearing to the tower, and degrees of inclination, if any.

We also mapped the locations of many of the fatalities. This data collection is ongoing and will allow us to complete this task later so that we can detect directional and distance patterns of where fatalities end up on the ground. Recognizing whether the locations of fatalities relate to local topographic and wind patterns might increase the efficiency of future fatality searches.

We mapped the perimeters of stock ponds and natural water bodies to test the effect of proximity to water body on the fatality rates. We mapped the perimeters of rock piles to test for any relationship between raptor fatality rates and proximity to cottontail denning habitat (rock piles). In some cases, pushing together rocks to clear space for the wind tower platforms had artificially created these features. We also mapped the distribution of fossorial rodents. We describe these maps below in more detail.

4.5 Burrowing Rodents

We mapped rodent burrows near 98 wind turbines composing nine turbine strings in the APWRA (see Figures 4 and 5). One string of 38 diagonal lattice turbines operated by ENRON is located on the south side of Altamont Pass Road. EnXco (formerly FORAS) operated eight of the turbine strings (60 tubular tower turbines) on the north side of Altamont Pass Road. These eight strings were selected to provide a wide range of fatality rates while at the same time to span the breadth of our EnXco sampling area. The ENRON string was selected due to its known high fatality rate. Our sampling scheme was intended to establish on a trial basis whether the distribution of rodent burrow systems around wind turbines might relate to fatality rates of raptors. Because of this trial, we have since expanded our sampling effort, but the results are not yet ready to present.

We mapped with GPS the approximate centers of pocket gopher, ground squirrel, and cottontail burrow systems. We located burrow systems based on freshly excavated soil or scats at the burrow entrance, which indicated 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. This pacing method is worked out for pocket gophers, but not for ground squirrels, so the maps made of ground squirrel burrow systems are still preliminary. We mapped burrows used by cottontails and burrowing owls as we encountered them. The presence of scat at each burrow entrance helped identify them.

Our search for burrows began in the string of turbines. A 7.5-m-wide strip transect was walked from 15 m beyond the turbine at one end of the string to 15 m beyond the turbine at the other end. Then perimeter transects were walked at 15 m, 30 m, and 45 m away from the turbine string, thus covering increasingly larger areas around the turbine strings (Figure 4A). 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. 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 turbine string. Also, we estimated the density of burrows within 55 m of each turbine string (Figure 4B) and compared these data to fatality rates of raptor mortality. The distance of 55 m was established by including 10 m of search area beyond the 45-m buffer described above.

We also measured the distance between the turbine and each burrow system, and we counted the burrow systems of each species occurring within 55 m of each turbine (e.g., Figure 4B). We aggregated these counts into zero, 1-2, and ≥ 3 burrow systems in order to facilitate χ^2 tests with adequate cell values. In addition, we classified red-tailed hawk fatalities as either zero or ≥ 1.

Since this preliminary study of animal burrow patterns around wind turbines, we have searched 43 additional turbine strings out to 80 m from each string. We have also begun monitoring the pattern of burrow systems across seasons of the year. The results of these studies are not included in this report.

5.0 PRELIMINARY RESULTS

5.1 Bird Use

We observed at least 36 bird species during the behavioral observations. Sightings averaged 3.2 birds per observation session. We observed no birds in 184 of the 1,958 observation sessions.

Sixty-nine percent of all bird sightings were raptors (n = 3,765), and 31% were non-raptors (n = 2,371). The most frequent raptor species sighted during the behavioral observation sessions was red-tailed hawk (n = 1,820, 48%), followed by turkey vulture (n = 801, 21%), American kestrel (n = 446, 12%), golden eagle (n = 424, 11%), and northern harrier (n = 117, 3%). The most common non-raptor bird species sighted was common raven (n = 837, 35%), gull species (n = 519, 22%), several blackbird species (combined; n = 396, 17%), and rock dove (n = 139, 6%). (These sightings consisted of individuals as well as flocks or small groups, so more birds were actually seen than the n-values reported herein.)

5.2 Bird Behaviors

We recorded 31,317 minutes of bird activity representing 6,146 behavioral sightings. The 13,725 minutes spent flying (44%) were nearly as many as the 17,592 minutes spent perching (56%) (Table 6).

For individual species, the total time spent flying versus perching (Table 7) varied considerably. Therefore, it is likely that there are considerable differences in the sensitivity of each species to turbine operations. For example, American kestrels, burrowing owls, western meadowlarks, and European starlings were usually observed perching, whereas turkey vultures, northern harriers, prairie falcons, mallards, and mourning doves were usually observed flying. One might conclude that the latter group of species would be more sensitive to turbine collisions if it were not for additional factors that influence fatality rates, such as exactly where these birds fly, when they fly there, and how much time they spend flying near turbine blades.

We recorded 6,377 observations of birds in flight, including multiple flights for the same bird. Fly-through behavior was the most common type of flight recorded for all bird species (27%, n = 1,726 sightings), followed by gliding (18%, n = 1,141) and soaring (16%, n = 1008). However, soaring lasted longest on average ($\bar{x}$ = 3.6, SD = 3.5), followed by gliding ($\bar{x}$ = 2.8, SD = 3.3) and fly-through ($\bar{x}$ = 1.22, SD = 0.54).

Raptor species flew more during medium and high wind speeds, with red-tailed hawks spending the greatest amount of time flying during these conditions (Figure 6). In general, larger bird species were seen in the air more often than smaller species. By examining each species' flight time within the species' range of flight times, species-specific use of wind patterns are evident (Figure 7). For example, flight time increases consistently with increasing wind speeds for northern harriers and American kestrels. This relationship plateaus after medium wind speeds for turkey vulture, golden eagle, and prairie falcon, and it drops substantially at medium wind speeds for burrowing owls. There is a noticeable peak for red-tailed hawks. Thus, species appear to differ in their sensitivity to turbine operations due to wind speeds.

Raptors performed 17 of the 19 behaviors observed for all species. Raptors differed significantly by mean flight time per proximity level (ANOVA, F = 105.60, P = 0.001, df = 2, 4,333) (Table 8). Raptors spent significantly more time flying at close proximity to turbine blades ($\bar{x}$ = 4.59 minutes, SD = 5.04) than 51-100 m away ($\bar{x}$ = 3.34, SD = 3.48) or >100 m away ($\bar{x}$ = 2.12, SD = 1.98) (Tukey's test, $P < 0.05$).

Among raptor species, red-tailed hawks performed 66% (n = 748) of the flight behaviors we thought made them most vulnerable to turbine collisions (i.e., flying within the height domain of the rotor plane and within 50 m of the turbines), golden eagles performed 15% (n = 170), and American kestrels performed 10% (n = 112) of them, respectively (Table 9).

American kestrels performed the highest percentage of flights within 50 m of the turbines (45% of 112 flights), followed by northern harriers (39% of 52 flights), and red-tailed hawks (38.6% of 748 flights). Turkey vulture and burrowing owl had the lowest frequency of flights within 50 m of the turbines (Table 10).

American kestrels differed by mean flight time within proximity levels (ANOVA, $F = 7.85$, $P < 0.001$, df = 2, 366), spending significantly less time per flight 101-300 m from the turbine blades compared to 0-50 or 51-100 m (Table 11, Fig. 8). Based on mean values, red-tailed hawks spent significantly more time per flight within proximity level 1 compared to farther away (ANOVA, $F = 57.89$, $P = 0.001$, df = 2, 2,146; Table 11, Fig. 8). Burrowing owls did not differ significantly by mean flying time among proximity levels (ANOVA, $P = 0.15$, $F = 2.07$, df = 2, 23), nor did golden eagles (ANOVA, $P = 0.460$, $F = 0.77$, df = 2, 577), northern harriers (ANOVA, $P = 0.15$, $F = 1.92$, df = 2, 130), and prairie falcons (ANOVA, $P = 0.15$, $F = 1.93$, df = 2, 79) (Table 11, Fig. 8). Turkey vultures did differ significantly by mean flight time within proximity levels (ANOVA, $P = 0.001$, $F = 74.03$, df = 2, 981), spending significantly more time flying per observation within proximity levels 1 and 2 (Table 11, Fig. 8).

Analysis of the mean flight time did not consider the number of times each species flew within proximity levels. Therefore, we examined the total number of minutes each species flew within each proximity level. Figure 8 illustrates the dramatic differences in interpretation when using total flight time rather than the mean flight time. Red-tailed hawks appear to spend the greatest average time per flight within proximity level 1, but considering the total minutes, this species spent more than four times the amount of time in proximity level 1 compared to other species. In proximity level 2, red-tailed hawks averaged no more time than did the other species, but they spent nearly twice as much time there than did turkey vultures and much more time than did the other species.

Total flight time by a species more closely indicates the differences in use of proximity levels than does the mean time per flight. Based on the mean time per flight, red-tailed hawks spent twice the time flying within proximity level 1 compared to proximity level 3, but based on the total time, red-tailed hawks spent more than four times the amount of time flying in proximity level 1 compared to proximity level 3. Factoring in the proportion of the APWRA occupied by these three proximity levels (by applying GIS coverages) will reveal the degree to which each species uses each proximity level relative to chance. This type of analysis will be forthcoming.

We approximated the proportion of the 2,780 ha of our study area composed of proximity levels 1, 2, and 3. Proximity levels 1, 2, and 3 occupy about 15%, 22%, and 63%, respectively, of the total area encompassed by all three proximity levels. Multiplying the total number of minutes of red-tailed hawk flight time by these proportions yields expected flight times of 1,241, 1,821, and 5,214 minutes in proximity Levels 1, 2, and 3, respectively. The observed flight times were 4,069, 3,598, and 609 minutes, respectively. Red-tailed hawks flew within 50 m of the turbine blades about 3.3 times longer than expected by chance, within 51-100 m of the blades 2.0 times longer than expected by chance, and within 101-300 m about 0.1 times the total flight time expected by chance.

Based on this preliminary analysis, it appears that red-tailed hawks are strongly attracted to lands within 50 m of wind turbines in the APWRA, and they seem to avoid lands located farther away from turbines. Analyzing the total number of minutes of flight time reveals that something about wind turbines may attract red-tailed hawks to fly near turbines and at dangerous heights.

Similarly, American kestrels flew in proximity level 1 nearly four times longer than expected by chance, golden eagles two times longer, and northern harriers three times longer. Burrowing owls flew in proximity level 1 only 0.67 times as long and turkey vultures only 0.2 times as long as expected by chance. Figure 9 shows the amount of time each of several raptor species flew within each proximity level relative to the availability (area) of each proximity level. All of these relationships were highly significant, based on the χ^2 test of association ($P < 0.0001$ for all of them).

This type of approach can also reveal important interaction effects, such as between wind levels and the number of passes made within 50 m and farther than 50 m of turbine strings. The proportion of the observation periods during a particular measured wind speed can be multiplied by the proportion of the area composed of proximity levels 1 or 2 to yield the proportion of the time that winds of that particular speed likely blew within that proximity level. This new proportion can then be multiplied by the total number of passes made by a species within each proximity level, and χ^2 analysis can be performed.

For example, Figure 10 illustrates the insight gained by deriving the observed ÷ expected number of passes made by red-tailed hawks during the behavioral observation sessions. Whereas the number of passes peaked during moderate wind levels at the APWRA, and whereas the number of passes was always greater within 50 m as compared to farther than 50 m for each wind speed level (Figure 10, left panel), the disparity in the number of passes between proximity levels is heightened when comparing the observed and expected values or the interaction effect (Figure 10, right panel).

Red-tailed hawks are strongly selecting to pass closely by the wind turbines during moderate wind speeds but are avoiding making passes >50 m from the wind turbines during all wind speeds, based on the availability of the area in proximity level 2 ($\chi^2 = 618$, d.f. = 15, $P < 0.0001$).

This result suggests that our distinction between sensitivity and vulnerability already has been contaminated by the placement of the turbines on the APWRA, meaning that any true observations of sensitivity, *per se*, would need to be made at one or more locations with similar environmental conditions but without the presence of the wind turbines. The placement of wind turbines in the APWRA has fundamentally changed the flight behavior of red-tailed hawks there. Specifically, 18% of the passes made by red-tailed hawks were closer to the turbine strings during winds of 1-34 kph than would be expected by chance based on areas and wind speed as the only factors. We expect that the clustering of prey species around wind turbines is the underlying reason for this altered raptor flight behavior. This same type of analysis remains to be performed for the other species in our study.

5.3 Fatality Searches

We found 439 dead birds and four dead mammals among 31 bird and one mammal species (Table 12). These fatalities included 226 (53%) raptors, 209 (49%) non-raptorial bird species, and 4 (1%) hoary bats. Of these bird carcasses, 372 (87%) were confirmed to be the result of turbine collisions, 11 (3%) we believe resulted from predation by other species, and the cause of death was undetermined for 43 (10%).

We did not find a raptor fatality at most of the turbines we sampled. Of the 1,110 turbine locations sampled from 12-30 months, only 272 (24%) have been recorded to cause one or more fatalities (Table 13). The left-skewed, leptokurtic distributions of mortality among turbines and turbine strings (Figure 11), coupled with the inter-specific correlations at turbines, pose the possibility that mortality among multiple avian species can be reduced by changing turbine and tower design, tower placement, and range management practices. That is, because multiple species are killed by the same subset of turbines, focusing on the factors common to that subset of turbines might benefit multiple species.

5.3.1 Scavenging Effects

Data from the fatality searches indicate that scavenging has little effect on the results, especially for medium to large birds. For example, three dead barn owls monitored for their duration of detectability remained visible in the field for 90, 120, and 150 days. For 17 freshly killed red-tailed hawks monitored for detectability, each remained visible for at least 180 days, with five visible for at least 360 days.

A comprehensive assessment of the role scavenging plays in carcass detection will be provided in the final report; however, at this point we have little reason to suspect that it affects the overall results of our fatality data.

5.4 Seasonal Use Patterns

5.4.1 Flight Time by Season

Mean flight time of raptor species combined varied throughout the seasons and years (Table 15). We found significant differences between years and seasons. These factors also strongly interacted (two-way ANOVA, season: F = 8.374, P = 0.001, df = 3; year: F = 18.789, P = 0.000, df = 1; season by year: F = 6.929, P = 0.001, df = 3, 2793).

The mean flight time of raptors differed by season during 1998-99 (ANOVA, F = 5.724, P = 0.001, df = 3, 865), averaging lowest during summer ($\bar{x}$ = 1.91, SD = 1.47, n = 255) and highest during fall ($\bar{x}$ = 2.75, SD = 3.03, n = 276). Mean flight time of raptors differed between summer and fall (Tukey's, P < 0.05), but not between summer and winter ($\bar{x}$ = 2.56, SD = 2.43, n = 257), nor spring ($\bar{x}$ = 2.63, SD = 3.10, n = 81), fall, and winter (Tukey's P > 0.5).

The highest mean flight time of raptors occurred during winter, 1999-00 ($\bar{x}$ = 4.05, SD = 5.42, n = 381) and lowest in fall ($\bar{x}$ = 2.73, SD = 3.36, n = 624). It differed by season during 1999-00 (ANOVA, F = 12.220, P = 0.001, df = 3, 1928), averaging the highest during winter (Tukey's, P < 0.05), but not differing in spring ($\bar{x}$ = 2.78, SD = 2.52, n = 325), summer ($\bar{x}$ = 2.88, SD = 2.52, n = 602), and fall.

Mean flight time of raptors did not differ significantly during spring (*t*-test, P = 0.644) and fall (*t*-test, P = 0.934), but it did during summer (*t*-test, P = 0.001) and winter (*t*-test, P = 0.001).

5.5 Physical Features

Certain avian species were clearly vulnerable to collisions with turbine rotor blades operating on a variety of tower types. In one instance, we observed a lone rock dove that flew upwind into a rotor and was struck by a rotor blade. We conclude that the majority of the dead birds we found would not have died where we located them had the wind turbines not been located there. Therefore, some aspect or combination of aspects of wind turbine operations resulted in these birds being vulnerable to injury or death.

Operation of these wind turbines also made certain avian species vulnerable to electrocution on electrical distribution poles because we found electrocuted raptors under distribution poles that otherwise would not be located on the APWRA in the absence of the wind turbines. The data presented below focus on various vulnerabilities that may contribute to bird fatalities caused by rotating turbine blades atop wind towers, plus rotations of vertical axis wind turbines.

The fatality rates of some species are correlated. The number of red-tailed hawk fatalities per string correlated with the number of fatalities of American kestrel (r_P = 0.455, P < 0.001), barn owl (r_P = 0.325, P < 0.05), burrowing owl (r_P = 0.210, P < 0.05), golden eagle (rP = 0.270, P < 0.05), and all non-raptor species combined

($r_P = 0.271$, $P < 0.05$). This indicates that patterns related to fatality rates observed for one can sometimes be used to represent the patterns expected of others, however weakly. Because fatality rates are correlated inter-specifically and because it appears that some turbine strings kill more individuals of multiple species, solutions to reduce the fatality rate of one species might be solutions for other species also.

5.5.1 String Size

The number of red-tailed hawk fatalities at a string correlated with the number of wind towers in the string ($r_P = 0.515$, $P < 0.001$), as did the number of fatalities of American kestrel ($r_P = 0.345$, $P < 0.001$), burrowing owl ($r_P = 0.219$, $P < 0.05$), and barn owl ($r_P = 0.353$, $P < 0.001$). These correlations might be significant simply because avian vulnerability to wind turbines increases with the number of wind towers present; that is, a string of 21 wind turbines poses a greater danger to birds than does a string of two wind turbines.

Table 16 includes regression coefficients around which residuals can be calculated and used to uncover relationships between fatality rates and other factors that otherwise may have been masked by the effect of the number of turbines composing a string (i.e., increased probability of fatalities occurring at a string because there are more opportunities for fatalities with more turbines present). If the size of the string is not factored into the analysis, then patterns of fatality rates related to other variables might be hidden and others might be spurious. We made use of these residuals in the analyses that follow.

5.5.2 Windswept Area

The number of fatalities at a turbine string increased with the total windswept area of the string (Table 17), where the windswept area included the sum of all windswept areas of only those wind towers that were operational spanning most of the period during our fatality searches. Windswept area of the string explained more of the variation and tended to be more significant than was the number of turbines in a string. This is evident by comparing the summary statistics provided in Tables 16, 17, and 18. In addition, the average windswept area generally increased with the number of fatalities of each taxonomic group (Figure 12), as well as with individual species (Figure 13).

This relationship indicates that other string-level analyses should also be adjusted by the string's windswept area, which appears to substantially increase vulnerability. We made this adjustment using unstandardized residuals that were calculated from the regression models in Table 17. We made use of these residuals in the analyses that follow.

5.5.3 Tower Type

Avian fatality rates associated non-randomly with tower types (Figure 14; Table 18). Bonus tubular towers killed 1.4 to 2.1 times more red-tailed hawks, golden eagles, burrowing owls, and barn owls than expected by chance. Vertical axis towers killed less than the expected number of red-tailed hawks, golden eagles, and American kestrels, ranging from none to 29% of the expected fatality rates. Diagonal lattice towers killed 1.4 times more American kestrels than expected by chance. Danwin tubular towers killed only one red-tailed hawk. These relationships appear to be closely linked to attributes of the towers, which are described below.

5.5.4 Rotor Diameter

Avian fatality rates associated non-randomly with rotor diameters (Figure 15; Table 18). The two largest diameter rotors killed 1.3 to 2.4 times more red-tailed hawks, golden eagles, burrowing owls, and barn owls than would be expected by chance. The smallest-diameter rotor killed about one-third of all red-tailed hawks but only because there were so many of these small rotors. Rotor diameter appeared not to affect American kestrel fatality rates.

At the string level of analysis, rotor diameter appears to slightly influence red-tailed hawk fatality rates (r^2 = 0.08, regression b = 0.23, df = 1, 107, P < 0.05), but factoring in string size revealed a stronger correlation, but still weak overall (r^2 = 0.17, regression b = 0.28, df = 1, 107, P < 0.001).

5.5.5 Rotor Speeds

Avian fatality rates associated non-randomly with turbine rotor speeds (Figure 16; Table 18). The faster turbines killed 1.2 to 2.1 times more red-tailed hawks, golden eagles, burrowing owls, and barn owls than would be expected by chance, given the frequency distributions of rotor speeds. Turbine rotor speed appears to be unassociated with the fatality rate of American kestrels, however. Interestingly, the average rate of the turbines correlated negatively with the number of turbines in the string (r_P = - 0.38, P < 0.001), indicating that some of the relationships with rotor speed may have been hidden by the strong positive correlations between fatality rates and number of turbines in the string (or windswept area). In addition, average rotor speed correlated positively with rotor diameter (r_P = 0.48, P < 0.01), turbine size (r_P = 0.35, P < 0.01), and tower height (r_P = 0.21, P < 0.05).

5.5.6 Tower Height

Avian fatality rates associated non-randomly with wind tower heights (Figure 17; Table 18). Towers with rotors that were centered 24 m above ground killed 1.1 to 1.3 times more red-tailed hawks, golden eagles, American kestrels, burrowing owls, and barn owls than would be expected by chance, given the frequency of each tower height in the sample. Although most of the wind towers were 24 m tall, these towers killed more than the expected number of each species compared to a random (uniform) distribution of kills. This attribute of wind towers might explain most of the relationship between Bonus tubular towers and their greater-than-chance fatality rates with several of the avian species we studied. Bonus tubular towers are 24 m tall.

However, tower height interacted with landscape features that are related to declivity winds for some species and with other landscape conditions for other species (see below).

5.5.7 Turbine Position in String

Avian fatality rates associated non-randomly with the position of the wind tower in the string (Figure 18; Table 18). Table 19 summarizes the frequency distribution of wind tower positions within the strings that we searched for fatalities in the APWRA.

At the turbine string level of analysis, a majority (68%) of red-tailed hawk fatalities occurred at 56% of the strings. In these strings, the end towers composed only 10%-50% of the string. It would appear, based on examination of the scatter plots (Figure 19), that red-tailed hawk fatalities were more frequent at turbine strings composed of fewer end and gap towers (i.e., edge towers; a gap within a string is defined as 25% greater distance between towers than the average inter-tower distance) and more interior towers. However, end towers composing 10%-50% of the string indicate that these strings were moderate in size because only two towers can be end towers on any given string. The string level of analysis was confounded by the effect of the number of wind towers composing the string and by the windswept area of the string.

Therefore, we calculated the unstandardized residuals from the regression models in Table 16 and then related these residuals to the position of the wind tower in the string (Figure 20). The residuals from the model in Table 16 did not regress significantly on turbine position in the string (Table 20). They increased, however, with increasing numbers of derelict turbines in the string among those strings that had derelict turbines (Figure 21), suggesting that an increasing proportion of derelict turbines in a string might confuse red-tailed hawks flying by them. It is even possible that derelict turbines are more visible because their rotor blades are not moving and so are not causing retinal smear. Red-tailed hawks might fly farther around them and into the rotor blades of adjacent turbines that *are* operating.

Similarly, American kestrels and barn owls appeared to be killed at an increasing rate with a smaller percentage of the string composed of end turbines and with a greater percentage of interior turbines, but these relationships vanished when adjusted by windswept area (Table 20). Golden eagle and burrowing owl fatality rates, however, demonstrated no relationships with turbine position in the string, except that the golden eagle fatality rate adjusted by windswept area increased with a greater percentage of end and gap turbines and with lower percentage of interior turbines (Table 20). However, even this latter relationship might have been influenced by a positive correlation between the percentage of the string composed of end and gap turbines and percentage of the string occurring within canyons ($r_P = 0.25$, $P < 0.01$).

Another inter-variable correlation to consider for future analysis of fatality rates includes the one between percentage of the string composed of end and gap towers and rotor speed ($r_P = 0.35$, $P < 0.01$). Apparently, turbine strings with more gaps and fewer interior turbines maintain higher rotor speeds, which might increase the vulnerability of avian species to turbine strikes. Furthermore, more of these strings also occur within canyons ($r_P = 0.25$, $P < 0.01$). More research is needed to fully understand the contribution of these relationships to fatality rates.

5.5.8 Type of Physical Relief

Avian fatality rates associated non-randomly with types of physical relief (Figure 22), but not significantly (Table 18). Compared to chance, wind towers on ridge tops and swales killed 1.2 and 2.9 times more red-tailed hawks than expected, respectively. Towers situated on slopes killed 1.4 times more golden eagles than expected due to chance. Otherwise, the physical relief appeared to not influence the fatality rates of the species we examined. However, whether the wind towers were located within one of three major canyons within our study area did relate to fatality rates (see Section 6.5.10).

5.5.9 Declivity Winds

Avian fatality rates associated non-randomly with whether the wind towers were placed to take advantage of the declivity winds (Figure 23), but not significantly for golden eagles, barn owls, and burrowing owls (Table 18). Red-tailed hawks were killed 1.3 to 2.1 times more often than expected by chance at 24-m towers placed on swales, ridgelines, and peaks, at 30-m towers on swales, and at 14-m towers on slopes. American kestrels collided with turbines 2.7 to 7.0 times more often than expected by chance at 24-m towers on ridgelines and at 24- and 30-m towers on swales. Thus, it appears that there is an interaction effect between physical relief and tower height for these species. Tall towers on swales or low spots along ridgelines often formed at the junction of two ridges appear to be especially troublesome for red-tailed hawks and American kestrels.

Obviously, the physical relief affects the declivity winds, so ultimately physical relief significantly affects turbine-caused mortality. To recognize the effect of physical relief, the analyst must factor in tower height in this case.

5.5.10 Canyon Effects

Avian fatality rates associated non-randomly with whether turbines were located in or out of canyons (Figure 24; Table 18). Wind towers located in one of the three major canyons in our study area killed 1.8-3.6 times the number of red-tailed hawks, golden eagles, burrowing owls, and barn owls that would be expected by chance given the frequencies of towers in or out of canyons. The rate of American kestrel fatalities did not relate to whether the towers were located in canyons. All the golden eagle fatalities we found occurred within canyons.

The percentage of the string occurring within the three major canyons within our study area also correlated positively with the average turbine-caused mortality ($r_P = 0.40$, $P < 0.001$), average rotor diameter ($r_P = 0.46$, $P < 0.001$), and negatively with average tower height ($r_P = -0.23$, $P < 0.05$). Thus, the relationships between raptor fatality rates and whether turbines occurred in canyons could instead be due to the relationships between fatality rates and these other tower/turbine attributes, or vice versa. More research is needed to isolate the contribution of each of these relationships.

5.5.11 Slope Aspect

Avian fatality rates associated non-randomly with slope aspect (Figure 25; Table 18). Wind turbines located on northwest-facing slopes killed more red-tailed hawks, golden eagles, and barn owls than would be expected by chance, given the proportion of turbines on these slopes. Towers on south-facing slopes killed more red-tailed hawks, American kestrels, and burrowing owls than would be expected by chance. Turbines located on southeast slopes killed more golden eagles than would be expected by chance.

5.5.12 Additional Features

At the time of this writing, at least three other related and important topics remain to be analyzed using GIS capabilities: percent slope, elevation, and complexity of relief. Data have been collected on these topics and the analyses will be completed for inclusion in the final project report.

5.6 Burrowing Rodents

As summarized in the introduction, ground squirrels have been thought to be the principal prey species of raptors at the APWRA. However, given the numbers of raptors killed on the south side of Altamont Pass Road, we suspected that ground squirrels might not be the species of principal interest to raptorial birds. Also, previous experience has led us to believe that pocket gophers are important prey of raptorial birds and that gopher burrow systems serve as habitat for various other prey species of raptorial birds. Pocket gophers appear to be abundant in the APWRA on both sides of Altamont Pass Road, whereas ground squirrels appear to be abundant only on the north side. During 2000 and 2001, we found 1,272 ground squirrel burrow systems within the 173.5 ha searched at EnXco for a density of 7.3 burrow systems per ha, which was 30.5 times more dense than the 18 ground squirrel burrow systems we found within the 74.2 ha searched at ENRON for a density of 0.24 burrow systems per ha (these are preliminary results only).

During a previous study we observed that raptorial birds spend a disproportionately large fraction of their flight time directly over pocket gopher burrow systems while capturing pocket gophers, voles, snakes, and black-tailed jackrabbits. Therefore, we decided to map the locations of pocket gopher and ground squirrel burrows in and around selected strings of wind turbines. Our objectives for this activity were to compare the mortality of raptorial birds to the densities and degree of contagion of burrow systems actively used by potential prey species around individual turbines and around turbine strings. Usually, pocket gophers clustered within close proximity to the wind turbines, whereas ground squirrels established colonies farther away from the turbines (Figure 5).

The results presented here are preliminary and therefore not conclusive. Our initial sample sizes were too small to lend much confidence to the results. Continued fieldwork will sufficiently increase the sample sizes of fatalities and turbine strings around which fossorial mammals are mapped, which will add considerable confidence to our results.

5.6.1 Intra-String Comparisons

Red-tailed hawk fatalities *tended* to occur at turbines with one-two gopher burrows more often than expected by chance, and less often at turbines without gopher burrows within 55 m ($\chi^2 = 5.28$, df = 2, P = 0.07). However, red-tailed hawk fatalities did not relate significantly to the occurrence of ground squirrel burrows at turbines ($\chi^2 = 2.88$, df = 2, P = 0.24).

Golden eagle fatalities occurred more often than expected by chance at turbines with ≥ 3 ground squirrel burrows within 55 m ($\chi^2 = 7.72$, df = 2, $P < 0.05$). However, half of the contingency table's expected cell values were less than 5, a condition that requires cautious interpretation of the test result.

Burrowing owl fatalities also occurred more often than expected at turbines with ≥ 3 ground squirrel burrows within 55 m ($\chi^2 = 13.35$, df = 2, $P < 0.001$). Burrowing owl fatalities occurred at the two turbines with the greatest numbers of burrowing owl burrows within 55 m (6 and 7 burrows, respectively; no statistical test performed). Golden eagle and burrowing owl fatalities did not relate significantly with the density of pocket gopher burrow systems around turbine strings. Pocket gophers are not considered a major prey item for either species.

These data suggest that red-tailed hawks and golden eagles, which differ in their foraging behavior and prey selection, were vulnerable to turbine collisions for different reasons. Moreover, the distribution of ground squirrels and pocket gophers near turbines may be used to predict risk for certain raptor species.

5.6.2 Inter-String Comparison

At the inter-string level of analysis, pocket gopher density consistently decreased as larger areas were searched around each turbine string (Figure 26). 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). Steeper regression slopes indicated greater clustering of gopher burrow systems in the immediate vicinity of the turbines. Ground squirrel burrows did not occur within 55 m of four of the nine turbine strings, and ground squirrel burrow density increased as larger areas were searched at another turbine string (Figure 27). At yet another string, the slope value of negative one between log ground squirrel burrow density and study area size was determined by only one burrow, which occurred along the interior transect. Dividing a constant number (one, in this case) by a variable area forces a slope value of negative one.

As was the case for pocket gophers, the density of burrow systems for all species declined as larger areas around the turbine strings were included it the search effort (Figure 28). This multi-species pattern was likely driven by the pocket gopher pattern, as many fossorial species take advantage of the burrows that are abandoned by gophers. Indeed, many gopher burrows were found near the 98 turbines that lacked ground squirrel burrows, but most ground squirrel burrows occurred near turbines that also had gopher burrows. By June 2001, we observed ground squirrels establishing new burrow systems where gopher burrows were previously mapped in the absence of ground squirrel burrows during 1999 and 2000. Pocket gophers are attracted to the vertical and lateral edge created by the access roads and tower laydown areas cut into the steep slopes.

Except for the turbine string at ENRON, which has a distinct assembly of rodent species compared to the EnXco turbine strings and is geographically separated, the number of red-tailed hawk fatalities per turbine string increased with an increasing slope of log gopher burrow density regressed on log study area size (Figure 29):

$$\text{Hawk fatalities} = -3.68-7.01 \times \text{Regression slope coefficient}$$

$r^2 = 0.58$, Root MSE = 0.97, df = 1,7, $P < 0.05$ (not including the ENRON string).

The number of fatalities did not correlate significantly with the intercept of log gopher burrow density regressed on log study area size, nor did it correlate with the overall density of gopher burrows within the areas searched, nor with the maximum density recorded within the interior 7.5-m strip transect.

The turbine string at ENRON, which is south of Altamont Pass Road, had accumulated the largest number of red-tailed hawk fatalities, although it only had one ground squirrel burrow. The larger area of the ENRON operations had very few additional ground squirrel burrows on the premises. Instead, the ENRON turbine strings were home to many cottontails, which live under the tower platforms. The ENRON turbine strings will need to be analyzed separately from the EnXco turbine strings when we search for relationships between raptor fatality rates and prey distributions based on our larger data set.

Of the remaining EnXco tubular turbine strings with ground squirrel burrows, the number of red-tailed hawk fatalities did not relate significantly with the regression slope of log ground squirrel burrow density and log study area size (Figure 30):

Hawk fatalities = 1.510-2.476 Regression slope coefficient

$r^2 = 0.48$, Root MSE = 2.54, df = 1,4, P = 0.20.

We note, however, that our original maps of gopher and ground squirrel burrow systems did not include cottontail burrows, which is a species we have since observed in abundance at this outlier ENRON turbine string and which lives in burrows excavated under the concrete platforms of the turbines. New data are being collected on this aspect of the analysis.

6.0 DISCUSSION

This report describes the progress to date of research designed to identify the factors responsible for avian fatality rates at Altamont Pass Wind Resources Area, and to establish the empirical basis for developing a predictive model. This project is ongoing. Therefore, readers should consider these findings as preliminary and subject to revision. A comprehensive final report is scheduled for completion in late 2003.

Based on 372 carcasses resulting from confirmed collisions with turbines, the combined average annual fatality rate was 0.19 fatalities/turbine/year. Table 14 presents the average annual fatality rates for each of eight individual tower/turbine configurations. These data indicate that collision rates vary considerably when compared based solely on facility configurations. However, other physical features, landscape characteristics, and biological factors may affect the comparative fatality rates.

Our fatality data were derived from only 24% of the turbine population in the APWRA. Nevertheless, assuming our sample is representative of the entire APWRA and applying the fatality rate of 0.19 fatalities/turbine/year to 5,400 active turbines in the APWRA, one may estimate that as many as 1,026 birds are killed per year in the APWRA. Of these, approximately 50% are expected to be raptors.

To date, golden eagles represent 2.4% of the total bird fatalities in our study. This percentage yields an estimated 24 golden eagle deaths per year in the APWRA. Our estimate is fewer than Orloff and Flannery's (1992, 1996) estimate of 39 golden eagle fatalities per year and Hunt’s (2002) estimate of 40 to 60 golden eagle fatalities per year.

Similarly, burrowing owls represent 9% of the fatalities in our study. Extrapolating this percentage across all wind towers in the APWRA yields an estimated 93 fatalities per year. Red-tailed hawks represent 24% of the fatalities in our study, suggesting fatalities number 244 per year in the APWRA. The APWRA has been in operation with more than 4,000 turbines since about 1984. The turbine population peaked in 1987-88 at some 7,000 operating turbines. During the past several years, 5,000-5,400 turbines have consistently remained in operation. These estimates of total annual fatalities for golden eagles, red-tailed hawks, and burrowing owls warrant continued research, monitoring, and management programs designed to reduce these rates.

Despite the higher mortality reported here, it is not possible to conclude that more bird fatalities per turbine occurred between 1998 and 2000 than in previous years. These data probably reveal, however, that historically the full extent of the bird fatality problem has been underestimated. In addition, the fatalities are continuing.

As expected, each species using the APWRA exhibits a somewhat different suite of behaviors. It appears, at least for raptors, that differences in their foraging behaviors and their selection of prey species are closely related to their relative vulnerability to turbines. Our data on gopher burrows indicate that gophers more frequently occur near turbine strings than they do away from turbine strings. Furthermore, the distribution and occurrence of gopher burrows is related to raptor fatalities at turbine strings. From these findings, we conclude that lack of prey availability on the slopes away form turbines encourages red-tailed hawks to hunt near the turbines, thereby increasing the vulnerability of this species to operating turbines.

The number of bird fatalities per turbine string increases in relation to the total rotor swept area of the strings. This factor tended to be more significant than was the relationship between fatality rates and the number of turbines in each string. From these data, it is reasonable to infer that reducing the number of turbines in a particular area will not result in a reduction in bird fatalities unless the total rotor swept area is also reduced. These results contradict the results of Howell (1997), who found that rotor swept area did not explain the difference in fatality rates between two turbine types with different rotor swept areas.

Each of the various turbine/tower configurations has been suspected of causing different bird fatality rates (Howell 1997; Orloff and Flannery 1992, 1996; Anderson et al., 1999). Our data confirm this suspicion, but it appears that these differences may be due to certain turbine attributes or other factors that associate with the distribution of each of these turbine types. It appears that factors other than tower type play more of a role in whether a particular turbine is associated with one or more fatalities, such as prey distribution about the tower's base, physical relief, and presence of declivity winds. Regardless, the number of fatalities at tubular towers was higher than at horizontal lattice towers. This is contrary to previous research results (Orloff and Flannery 1996, Howell and DiDonato 1991). The repowering Environmental Impact Report (EIR) (Alameda County 1998) concluded that replacing horizontal lattice towers with tubular towers to support the new, larger turbines would reduce the number of fatalities post-repowering. The results of the present study do not substantiate the findings of the repowering EIR regarding the likelihood that using tubular towers will significantly reduce bird fatalities.

Past researchers have reported that wind turbines located at the ends of strings kill most of the raptors (Orloff and Flannery 1992, 1996; Hunt 1994). Using a single factor approach, this observation appears correct, but factoring windswept area of the string eliminated the previously apparent effect of turbine position in the string. The exception was the number of derelict turbines in the string, which appeared to increase along with the number of red-tailed hawk fatalities in the string.

Red-tailed hawks fatalities occur more frequently than expected by chance at turbines located on ridgelines than on hillsides. The reverse appears to be true for golden eagles. This finding highlights the need for a species-specific approach to reducing bird fatalities in the APWRA and for a better understanding of the effects of multiple environmental and landscape factors on bird risk.

A relatively large number of burrowing owls were killed at wind turbines in the APWRA, at least in the areas that we have sampled thus far. This species is becoming increasingly rare throughout California. It is possible that the regional impact of turbine fatalities in the APWRA, especially in terms of maintaining a stable population size, will be more significant to this species than is reported for golden eagles nesting in the region. We observed that burrowing owls exhibit unique flight and foraging behaviors, and they nest in relatively large numbers in the immediate area of operating wind turbines. To address this unique circumstance, more research is needed on the effects of turbine kills on this local population of burrowing owls and possible emergency management options that will reduce those impacts.

The recent EIR prepared by Alameda County (Alameda County 1998) assessed the potential impacts of a partial repowering proposal in the APWRA. One of its conclusions was that replacing smaller turbines with larger ones at a 7:1 ratio was likely to result in substantially fewer bird fatalities. The EIR failed to address, however, that converting to fewer turbines would result in a slight net increase in the total rotor swept area. Based on data presented here, it is reasonable to expect that the number of bird fatalities at fewer post-repowering turbines should remain nearly equal to the number of kills reported at the more numerous pre-repowering turbines. This hypothesis remains to be tested as the repowering effort proceeds.

Overall, our results have broadened understanding of bird use, fatality rates, risk behaviors, and the interactions of a variety of landscape elements in relation to risk and fatalities. The results are promising, and we believe that they may eventually lead to a solution to the overall objective of reducing bird kills in the APWRA. For this to occur, however, additional research using comparable methods conducted over a larger percentage of the APWRA's operating turbines is needed.

Eventually we expect patterns to emerge that can be used to identify high risk factors. The distribution of most of these factors is uneven in the region. By quantifying and mapping them, it may be possible to predict where bird fatalities are most likely to occur or where placing new turbines might kill the fewest numbers of birds. Such a model would have wide applicability and might one day help to effectively reduce the number of fatalities well below those that have occurred virtually unabated since the mid-1980s.

6.1 Summary of Key Findings

The following are key findings derived form our results to date. They are provided in no particular order. We intend to discuss their importance in detail in the final report.

- The frequency of sightings of species on the APWRA did not correspond strongly with turbine-caused mortalities among species.

- American kestrels and red-tailed hawks made more flights and spent more time flying within 50 m of the turbines than 51-100 m or 101-300 m away.

- We found 426 dead birds (including 226 dead raptors) and four dead mammals at 685 turbines that were searched 8-16 times each over 12-30 months.

- Fatality rates of raptor species correlated positively with the number of turbines in the string and the windswept area of the string.

- Turbines with larger rotor diameters killed more than the expected number of birds based on turbine numbers alone.

- Turbines with faster rotor-tip speeds killed more than the expected number of birds based on turbine numbers alone.

- Turbines with rotors 24 m above ground killed more than the expected number of birds based on turbine numbers alone, and the majority of these were tubular towers.

- Turbines at the ends and gaps of strings killed more than the expected number of birds based on turbine numbers alone, but factoring in windswept area of the string eliminated this effect.

- Factoring in windswept area, the presence of derelict turbines in the string emerged as a significant associate of red-tailed hawk fatalities.

- Turbines on swales and ridge tops killed more than the expected number of birds based on turbine numbers alone, and tower heights of 24 m and 30 m increased the effect of these landscape features apparently due to the interactions of declivity winds with these tower heights.

- Red-tailed hawk fatalities increased in strings with greater degrees of clustering of pocket gopher burrows.

- Raptor fatalities did not correspond well with the distribution of California ground squirrels.

6.2 Tasks Remaining

We continue to collect data that we believe will eventually contribute a better understanding of avian fatality rates and fatality mechanisms. For example, we are extending the coverage of rodent burrow maps to 80 meters from the turbine string, and we have added maps of burrow systems at about 30-40 turbine strings. In addition, some of our data have yet to be tested analytically because they are still being processed. A good example is the collection of spatial data and our use of GIS to process it. Elevation contours are being estimated using a digital elevation model, against which some of our variables will be compared. We will use landscape complexity measurements from the spatial data we have collected and that we are obtaining from off-site sources. Finally, our results may change as the sample size for total fatalities increases, and as we rule out the contributions of possibly spurious relationships. The statistical power of our analyses will increase with sample size, as will the confidence in our conclusions.

6.3 Management Implications

The need exists for a better, more accurate method of monitoring bird fatalities than the Wildlife Response and Reporting System (WRRS), which is the one on which regulatory agencies currently rely. This is particularly true for the APWRA, where bird fatalities have been chronic and substantial. The WRRS is not a scientifically defensible sampling program. It includes no searches for bird carcasses, no regularity of visitation to turbines, and overall no resemblance to scientific monitoring methods. A partial analysis of data obtained using the WRRS compared to the results of the present study revealed that the WRRS underreports raptor fatalities by at least a factor of eight (Thelander and Smallwood 2002). The level of underreporting is much higher for non-raptors. This assessment is based on a comparison of this study's fatality survey results for May 1998 thru March 2000 (n = 213 non-raptor fatalities found at only 12% of APWRA turbines) to the additional fatalities (n = 166) reported to Alameda County and the USFWS by Green Ridge Services/AIC for the balance of the turbines where reporting is required (i.e., no reporting is required for turbines in adjacent Contra Costa County).

A systematic monitoring protocol, one based on a standardized and systematic sampling methodology with statistical validity, needs to be implemented throughout the APWRA. By doing so, documenting future fatality rates and long-term trends can be monitored with more accuracy than is currently being provided by the WRRS methodology. Also, the results of the various groups collecting fatality data in the APWRA would be comparable.

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9.0 TABLES

Table 1. Number of Individual Wind Turbines/Towers Sampled with Their Output and Physical Characteristics

Tower Type	Output (kW)	Rotor Diameter (m)	Tower Height (m)	No. Sampled	Percent
Vertical Axis	150	17	30	20	2
Vertical Axis	250	19	30	119	11
Tubular	110	19	24	25	2
Tubular	120	19	24	220	20
Tubular	150	23	24	100	9
Horizontal Lattice	100	17	18	367	33
Diagonal Lattice	100	17	43	38	3
Diagonal Lattice	300	33	42	16	1
Diagonal Lattice	100	17	24	169	15
Diagonal Lattice	100	17	24	6	1
Diagonal Lattice	100	17	14	30	3
Total				**1,110**	

Table 2. Plot Number, Plot Size, Tower Type, and Turbine Output Characteristics for 685 Non-AIC Turbines Included in Behavioral Observation Sessions (Turbines on Horizontal Lattice Towers Were Not Included in This Sample)

			TURBINE FREQUENCY						
			Tubular			Vertical Axis		Diagonal Lattice	
Plot No.	Area (Km^2)	Strings in Plot	120 kW	150 kW	110 kW	150 kW	250 kW	100 kW	Total
1	3.5	14	33	0	0	25	0	0	58
2	2.2	5	26	0	0	5	0	0	31
3	3.8	7	0	27	0	9	0	0	36
4	3.2	9	24	0	0	11	0	0	35
5	1.9	3	6	8	0	0	0	0	14
6	3.3	2	0	27	0	0	0	0	27
7	3.6	5	23	14	0	0	0	0	37
8	2.2	5	25	0	0	0	0	0	25
9	3.8	9	29	13	0	0	0	0	42
10	3.5	3	4	11	0	0	0	0	15
11	3.0	6	5	0	0	0	20	0	25
12	4.3	9	16	0	7	22	0	0	45
13	4.0	5	0	0	0	48	0	0	48
14	2.5	6	9	0	8	0	0	0	17
15	2.3	2	14	0	0	0	0	0	14
16	3.0	7	6	0	10	0	0	45	61
17	2.0	4	0	0	0	0	0	52	52
18	2.2	3	0	0	0	0	0	37	37
19	2.6	2	0	0	0	0	0	28	28
20	2.6	3	0	0	0	0	0	38	38
Total	**59.5**	**109**	**220**	**100**	**25**	**120**	**20**	**200**	**685**

Table 3. Flight Behavior Categories Used to Record Observations during 30-Min Observation Sessions in the Study Plots

Flight Behaviors	
1. Fly through	10. Being mobbed
2. Gliding	11. Column soaring
3. Soaring	12. Surfing
4. High soaring	13. Ground hopping
5. Contouring	14. Hawking insects
6. Circling	15. Fleeing
7. Kiting/Hovering	16. Interacting
8. Diving	17. Flocking
9. Mobbing	18. Flushed

Table 4. Possible Perching Structures Used during the 30-Min Observation Sessions

PERCHING STRUCTURES	
1. Tree	11. Vertical axis tower (inner framework)
2. Fence post	12. Vertical axis tower (guy wire)
3. Ground	13. Turbine motor (top)
4. Rock/vegetation	14. Turbine motor (inside)
5. Electrical distribution pole (top)	15. Turbine blade tip/side
6. Electrical distribution pole (wire)	16. Turbine propeller cone
7. Electrical distribution pole (crossarm)	17. Catwalk of wind tower
8. Anemometer tower	18. Side ladder of wind tower
9. Electrical tower	19. Diagonal lattice tower (top)
10. Vertical axis tower (top)	20. Diagonal lattice tower (mid-framework)
	21. Diagonal lattice lower (lower framework)

Table 5. Bird Species Composition and Frequency (*N* = 5,283 Sightings) of Sightings Recorded during the Behavioral Observation Sessions

Common Name	Scientific Name	Count	Common Name	Scientific Name	Count
Great blue heron	*Ardea herodias*	6	Mourning dove	*Zenaida macroura*	10
Mallard	*Anas platyrhynchos*	25	Burrowing owl	*Athene cunicularia*	56
Common goldeneye	*Bucephala clangula*	1	Northern flicker	*Colaptes auratus*	4
Turkey vulture	*Cathartes aura*	740	Say's phoebe	*Sayornis saya*	7
White-tailed kite	*Elanus leucurus*	6	Loggerhead shrike	*Lanius ludovicianus*	100
Northern harrier	*Circus cyaneus*	96	American crow	*Corvus brachyrhynchos*	39
Golden eagle	*Aquila chrysaetos*	381	Common raven	*Corvus corax*	667
Cooper's hawk	*Accipiter cooperii*	1	Horned lark	*Eremophila alpestris*	25
Red-tailed hawk	*Buteo jamaicensis*	1,519	Cliff swallow	*Petrochelidon pyrrhonota*	12
Rough-legged hawk	*Buteo lagopus*	4	Mountain bluebird	*Sialia currucoides*	24
Ferruginous hawk	*Buteo regalis*	10	European starling	*Sturnus vulgaris*	69
American kestrel	*Falco sparverius*	351	American pipit	*Anthus rubescens*	6
Prairie falcon	*Falco mexicanus*	59	Western meadowlark	*Sturnella neglecta*	55
Killdeer	*Charadrius vociferus*	7	Red-winged blackbird	*Agelaius phoeniceus*	81
American avocet	*Recurvirostra americana*	1	Tricolored blackbird	*Agelaius tricolor*	30
Long-billed curlew	*Numenius americanus*	4	Brewers blackbird	*Euphagus cyanocephalus*	40
Ring-billed gull	*Larus delawerensis*	111	House finch	*Carpodacus mexicanus*	19
California gull	*Larus califfornicus*	81	Unidentified Laridae		276
Band-tail pigeon	*Columba fasciata*	1	Unidentified raptor		44
Rock dove	*Columba livia*	134	Unidentified Icterid		85
			Unidentified passerine		28

Table 6. Summary of Time during Which Birds Were Observed Flying Versus Perching. More than One Perch or Flight Behavior May Be Recorded Per Bird Sighting. The Mean Refers to the Minutes of Activity Per Observation Session

	Total Minutes	Mean (Min)	SD
Flight Time	13,725	186.02	2428.45
Perch Time	17,592	11.87	135.86
Total Flying and Perching	31,317	235.53	2515.21

Table 7. Number of Minutes Flying and Perching for Species with 20 or More Sightings. Flying: *n* = 4,585 Sightings, 11,382 Minutes. Perching *n* = 1,520 Sightings, 13,189 Minutes. Total Sightings and Time: *n* = 5,161 Sightings in 24,556 Minutes

	Flying Activity				Perching Activity				Percent Time
Species	*n*	Mean	SD	Sum	*n*	Mean	SD	Sum	in Flight
Red-tailed hawk	1,254	3.47	4.03	4,351	600	11.16	9.07	6,696	39
Turkey vulture	737	2.21	2.48	1,629	15	5.00	6.13	75	96
Corvids	666	1.72	1.46	1,145	174	5.15	5.55	896	56
Gull species	468	2.42	3.89	1,133	0	0.00	0.00	0	100
Golden eagle	355	3.12	2.97	1,108	89	8.53	9.07	759	59
American kestrel	270	1.78	1.93	481	239	7.26	6.97	1,735	22
Generic blackbird	219	1.93	3.21	423	64	7.64	8.19	489	46
Rock dove	131	1.31	2.54	172	12	4.67	8.26	56	75
Generic passerine	101	1.71	2.18	173	74	5.01	5.94	371	32
Northern harrier	95	2.51	2.90	238	11	4.64	7.42	51	82
Prairie falcon	58	1.90	1.57	110	9	7.56	7.23	68	62
Loggerhead shrike	57	1.51	1.04	86	92	5.89	6.45	542	14
Swallow species	46	3.15	5.75	145	0	0.00	0.00	0	100
Western meadowlark	41	1.22	0.82	50	30	8.68	8.43	260	16
European starling	37	1.24	1.04	46	53	11.17	9.71	592	7
Mallard	25	1.04	0.20	26	0	0.00	0.00	0	100
Burrowing owl	24	2.46	4.36	59	54	12.61	9.92	681	8

Table 8. Raptor Flying Time (Minutes) According to Proximity Level. An Asterisk Indicates the Corresponding Mean Differed Statistically from the Others at α = 0.05

Proximity Level	*n*	Mean	SD	Total
0-50 m	1,112	4.59*	5.04	5,104
51-100 m	2,187	3.34	3.48	7,305
101-300 m	686	2.12	1.98	1,454

Table 9. Frequencies of Proximity Level 1 Flights by Raptor Species (AMKE = American Kestrel, BUOW = Burrowing Owl, GOEA = Golden Eagle, NOHA = Northern Harrier, PRFA = Prairie Falcon, RTHA = Red-Tailed Hawk, TUVU = Turkey Vulture). Data Are for Raptor Species with More than 20 Behavior Sightings (*n* = 3,985; March 1998 – March 2000)

	Frequency of Sightings													
	AMKE		BUOW		GOEA		NOHA		PRFA		RTHA		TUVU	
Flight Behavior	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*
Contouring	0.8	2	4.0	1	18.2	105	6.0	8	2.5	2	7	135	0.8	8
Kiting	4.8	12	0.0	0	1.6	9	1.5	2	0.0	0	15.3	296	0.0	0
Hover/Surfing	17.3	43	0.0	0	1.7	10	3.0	4	8.9	7	5.8	107	0.6	6
Diving	11.3	28	8.0	2	2.4	14	3.8	5	10.1	8	5.4	108	0.1	1
Mobbing	9.3	23	0.0	0	2.6	15	1.6	2	7.6	6	2.5	48	0.4	4
Interacting	0.8	2	0.0	0	0.5	3	2.3	3	0.0	0	2.3	44	0.0	0
Flushed	0.8	2	0.0	0	1.9	11	0.0	0	0.0	0	0.6	11	0.0	0
Fleeing	0.0	0	0.0	0	0.5	3	0.0	0	0.0	0	0.1	2	0.0	0
Gliding	9.7	24	16.0	4	23.1	133	12.8	17	17.7	14	17.8	345	33.3	328
Soaring	6.5	16	4.0	1	22.0	127	12.0	16	7.6	6	19.7	383	27.9	225
Circling	9.3	23	0.0	0	9.7	56	9.0	12	16.5	13	10.8	209	13.5	133
Hawking Insects	1.6	4	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
Flocking	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
Flying Through	25.8	64	48.0	12	6.3	36	20.3	27	22.8	18	7.7	150	15.0	148
High Soaring	0.8	2	0.0	0	9.2	53	6.0	8	5.1	4	5.4	104	8.0	79
Ground Hopping	1.2	3	20.0	5	0.2	1	0.8	1	0.0	0	0.1	1	0.2	2
Soaring in Column	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0
TOTAL		**248**		**25**		**576**		**133**		**79**		**1,940**		**984**

Table 10. Frequencies of Proximity Level Flights by Raptor Species for March 1998 – March 2000

	Frequency of Sightings in Proximity Levels to Turbines					
	≤50 m		51-100 m		101-300 m	
Species	**%**	***n***	**%**	***n***	**%**	***n***
American kestrel	45	112	30.0	67	25.0	5
Burrowing owl	12.0	3	20.0	5	68.0	17
Golden eagle	29.5	170	54.9	316	15.6	90
Northern harrier	39.1	52	33.8	45	27.1	36
Prairie falcon	29.1	23	41.8	33	29.1	23
Red-tailed hawk	38.6	748	48.3	937	13.1	255
Turkey vulture	1.9	19	74.8	736	23.3	229
Total	**28.3**	**1,127**	**53.7**	**2,139**	**18.0**	**719**

Table 11. Mean Flying Time for Raptors by Proximity Level for March 1998 – March 2000.

Asterisk Indicates a Statistically Significant Difference between Means

	Flight Time (Minutes) per Observed Flight						
		≤50 m		51-100 m		101-300 m	
Species	*N*	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
American kestrel	369	2.11	1.88	2.55	3.22	1.39*	1.04
Burrowing owl	26	1.67	1.15	4.83	7.96	1.24	0.44
Golden eagle	580	3.75	3.89	3.67	3.19	3.23	2.82
Northern harrier	133	3.29	3.66	2.96	2.49	2.08	1.79
Prairie falcon	82	2.35	1.70	2.21	1.95	2.54	0.76
Red-tailed hawk	2,149	5.44*	5.61	3.84	3.95	2.39	2.15
Turkey vulture	984	3.74*	3.59	2.65*	2.74	1.83	1.64

Table 12. Summary of 439 Fatalities Divided between Raptors and Non-Raptors

Species/Group	Raptor Fatalities	Non-Raptor Fatalities
Red-tailed hawk	103	
Burrowing owl	51	
Barn owl	26	
American kestrel	24	
Golden eagle	11	
Great horned owl	6	
Northern harrier	2	
Prairie falcon	1	
White-tailed kite	1	
Buteo sp.	1	
Rock dove (pigeons)		60
Western meadowlark		49
European starling		19
Mallard		16
House finch		15
Horned lark		10
Passeridae sp. (sparrows)		8
Mourning doves		8
Icterinae sp. (blackbirds)		7
Laridae sp. (gulls)		5
Cliff swallow		4
Hoary bat		4
Black-crowned night herons		2
Common raven		2
Loggerhead shrike		2
Northern flicker		1
Wild turkey		1
Total	**226**	**213**

Table 13. Summary of Individual Tower/Turbine Configurations Involved in Bird Collisions

Type	Rotor Diameter (m)	Height (m)	Towers Sampled	Years Sampled	Towers with Collisions
Vertical Axis 150 kW	17	30	20	2.5	4
Vertical Axis 250 kW	19	30	119	2.5	27
Tubular 150 kW Bonus	23	24	100	2.7	43
Tubular 120 kW Bonus	19	24	220	2.7	78
Tubular 120 kW	19	24	25	2.5	1
Diagonal Lattice 100 kW	17	43	38	1.0	1
Diagonal Lattice 300 kW	33	42	16	1.0	5
Diagonal Lattice 100 kV	17	24	6	1.0	0
Diagonal Lattice 100 kW	17	24	169	2.5	52
Diagonal Lattice 100 kW	17	14	30	2.5	5
Horizontal Lattice 100 kW	17	18	367	1.0	6
			1,110		**272 (24%)**

Table 14. Summary of Bird Collisions Per Turbine Per Year by Tower and Turbine Type

Tower/Turbine/Output	No. Towers	No. Bird Collisions	Collisions/Tower/Year
Tubular Bonus 150	100	75	0.27
Tubular Bonus 120	220	109	0.18
Tubular Danwin 110	25	1	0.02
Vertical Axis 150	20	4	0.08
Vertical Axis 250	119	28	0.09
Diagonal Lattice 100	243	88	0.17
Diagonal Lattice KVS-33	16	5	0.31
Horizontal Lattice 56-100s	367	59	0.16

Table 15. Mean Flying Time (in Minutes) for Raptors by Season.

Asterisk Indicates a Statistically Significant Difference between Means

	1998-1999				1999-2000			
SEASON	***N***	***Mean***	***SD***	***Total***	***N***	***Mean***	***SD***	***Total***
Spring	81	2.63	3.10	213	325	2.78	2.52	904
Summer	255	1.91	1.47	487	602	2.88	2.94	1734
Fall	276	2.75	3.03	759	624	2.73	3.36	1704
Winter	257	2.56	2.43	658	381	4.05	5.42 *	1543

Table 16. Statistics Summarizing Fatality Rate Regressed on Number of Turbines in a String

Dependent Variable	a	b	r^2	RMSE	P
Red-tailed hawk	-0.0746	1.4100	0.27	1.23	0.001
Golden eagle	-0.0740	0.0059	0.01	0.34	0.36
American kestrel	-0.0058	0.0258	0.12	0.37	0.001
Burrowing owl	0.1070	0.0300	0.05	0.70	0.023
Barn owl	-0.0200	0.0339	0.13	0.47	0.001

Table 17. Raptor Fatalities per Turbine String Regressed on Windswept Area of Turbine String

Dependent Variable	a	b	r^2	RMSE	P
Red-tailed hawk	-0.27	0.00062	0.41	1.10	0.001
Golden eagle	0.015	0.00006	0.06	0.34	0.015
American kestrel	-0.006	0.00009	0.12	0.37	0.001
Burrowing owl	0.031	0.00015	0.10	0.68	0.001
Barn owl	-0.052	0.00014	0.17	0.46	0.001

Table 18. Chi-Square (χ^2) Test Results between Fatalities of Five Raptor Species and Attributes of the Wind Tower/Turbine

VARIABLE RELATED TO FATALITIES	χ^2 value	d.f.	P-value
Turbine/Tower Type (Fig. 14)			
Red-tailed hawk	22.0	3	$P < 0.01$
Golden eagle	13.6	3	$P < 0.01$
American kestrel	3.4	3	ns
Burrowing owl	15.3	3	$P < 0.01$
Barn owl	5.6	3	ns
Turbine Rate/Speed (Fig. 16)			
Red-tailed hawk	16.1	2	$P < 0.01$
Golden eagle	13.7	2	$P < 0.01$
American kestrel	2.3	2	ns
Burrowing owl	15.3	2	$P < 0.01$
Barn owl	5.4	2	ns
Turbine Orientation Relative to Wind			
Red-tailed hawk	17.9	1	$P < 0.01$
Golden eagle	3.0	1	ns
American kestrel	2.3	1	ns
Burrowing owl	0.1	1	ns
Barn owl	0.5	1	ns
Rotor Diameter (Fig. 15)			
Red-tailed hawk	29.3	4	$P < 0.01$
Golden eagle	13.8	4	$P < 0.01$
American kestrel	1.3	4	ns
Burrowing owl	13.9	4	$P < 0.01$
Barn owl	6.6	4	ns
Turbine Size (kW/h)			
Red-tailed hawk	3.4	4	ns
Golden eagle	8.6	4	ns
American kestrel	1.6	4	ns
Burrowing owl	15.8	4	$P < 0.01$
Barn owl	4.5	4	ns
Anemometer			
Red-tailed hawk		1	
Golden eagle		1	
American kestrel		1	
Burrowing owl		1	
Barn owl		1	

Tower Height (Fig. 17)			
Red-tailed hawk	18.2	2	$P < 0.01$
Golden eagle	4.0	2	ns
American kestrel	3.5	2	ns
Burrowing owl	1.7	2	ns
Barn owl	1.3	2	ns
Whether Part of a Windwall			
Red-tailed hawk		1	
Golden eagle		1	
American kestrel		1	
Burrowing owl		1	
Barn owl		1	
Position in String (Fig. 18)			
Red-tailed hawk	0.5	3	ns
Golden eagle	6.2	3	ns
American kestrel	3.1	3	ns
Burrowing owl	19.0	3	$P < 0.01$
Barn owl	1.4	3	ns
Whether in Canyon (Fig. 24)			
Red-tailed hawk	15.9	1	$P < 0.01$
Golden eagle	21.3	1	$P < 0.01$
American kestrel	0.1	1	ns
Burrowing owl	7.2	1	$P < 0.01$
Barn owl	20.5	1	$P < 0.01$
Slope Aspect (Fig. 25)			
Red-tailed hawk	11.8	8	ns
Golden eagle	9.5	8	ns
American kestrel	4.7	8	ns
Burrowing owl	10.0	8	ns
Barn owl	15.8	8	$P < 0.05$
Physical Relief (Fig. 22)			
Red-tailed hawk	4.2	4	ns
Golden eagle	2.5	4	ns
American kestrel	5.2	4	ns
Burrowing owl	1.5	4	ns
Barn owl	1.2	4	ns
Declivity (Fig. 23)			
Red-tailed hawk	24.6	14	
Golden eagle	6.9	14	ns
American kestrel	50.9	14	
Burrowing owl	3.8	14	ns
Barn owl	5.2	14	ns

Table 19. Frequency of Tower/Turbine Position within Strings of Turbines, where 2nd and 3rd Refer to Their Relative Locations from the End Turbines. These Frequencies Were Factored into the Chi-Square Tests as the Available Positions within the String, whereas the Frequencies in the Bottom Table Compose the Use, where Use Was Indicated by Fatalities

Position in String	Frequency	Percentage
End	183	26.8
2nd	129	18.9
3rd	82	12
Middle	176	25.8
Gap	97	14.2
Total	667	100

Simplified from Above:

Position in String	Frequency	Percentage
End	183	26.8
Gap	97	14.2
2nd	129	18.9
Middle	387	37.8
Total	667	100

Number of Fatalities:

Species	Total	End	Gap	2nd	3rd	Middle
Red-tailed hawk	88	24	15	16	9	24
American kestrel	17	4	4	1	3	5
Golden eagle	12	6	3	2	1	0
Burrowing owl	32	18	7	1	1	5
Barn owl	21	8	3	3	0	7

Table 20. Raptor Fatalities per Turbine String Regressed on the Percentage of Turbines Located at Particular Positions in the String. The Number of Raptor Fatalities Adjusted by Windswept Area Regressed on the Percentage of Turbines at Particular Positions in the String

	Dependent Variable: Fatalities per Turbine String					Fatalities per Turbine String Adjusted by Windswept Area of the String				
Predictor Variable: Percent of String	**a**	**b**	**r^2**	**RMSE**	**P**	**a**	**b**	**r^2**	**RMSE**	**P**
Red-tailed hawk										
End towers	1.332	-0.012	0.07	1.38	0.005	-0.057	0.0014	0.00	1.23	0.72
Gap towers	0.807	0.0005	0.00	1.43	0.920	-0.013	0.0009	0.00	1.23	0.84
Ends and gaps	1.654	-0.015	0.09	1.37	0.002	-0.225	0.004	0.01	1.10	0.29
Middle towers	0.152	0.016	0.11	1.36	0.001	0.017	-0.0004	0.00	1.23	0.92
Golden eagle										
End towers	0.143	-0.0008	0.01	0.34	0.475	-0.027	0.0007	0.00	0.34	0.527
Gap towers	0.079	0.0022	0.03	0.34	0.085	-0.030	0.0021	0.03	0.33	0.093
Ends and gaps	0.058	0.0009	0.01	0.34	0.429	-0.147	0.0026	0.05	0.33	0.023
Middle towers	0.134	-0.0006	0.00	0.35	0.629	0.092	-0.0022	0.04	0.33	0.045
American kestrel										
End towers	0.266	-0.0026	0.04	0.38	0.031	0.007	-0.0002	0.000	0.37	0.882
Gap towers	0.158	-0.00003	0.00	0.39	0.984	0.003	-0.0002	0.000	0.37	0.872
Ends and gaps	0.340	-0.0033	0.06	0.38	0.015	0.023	-0.0004	0.000	0.37	0.752
Middle towers	0.012	0.0035	0.07	0.38	0.006	-0.027	0.0007	0.000	0.37	0.589
Burrowing owl										
End towers	0.400	-0.0025	0.01	0.71	0.262	-0.061	0.0015	0.00	0.68	0.490
Gap towers	0.255	0.0028	0.01	0.71	0.289	-0.036	0.0025	0.01	0.68	0.320
Ends and gaps	0.333	-0.0007	0.00	0.72	0.792	-0.223	0.0004	0.03	0.67	0.089
Middle towers	0.260	0.0009	0.00	0.72	0.713	0.155	-0.0038	0.03	0.67	0.098
Barn owl										
End towers	0.366	-0.0041	0.07	0.49	0.008	0.018	-0.0004	0.00	0.46	0.756
Gap towers	0.169	0.0017	0.01	0.50	0.357	-0.021	0.0014	0.01	0.46	0.400
Ends and gaps	0.397	-0.0036	0.04	0.49	0.036	-0.039	0.0007	0.00	0.46	0.664
Middle towers	0.077	0.0029	0.03	0.50	0.089	0.060	-0.0015	0.01	0.46	0.342

10.0 FIGURES

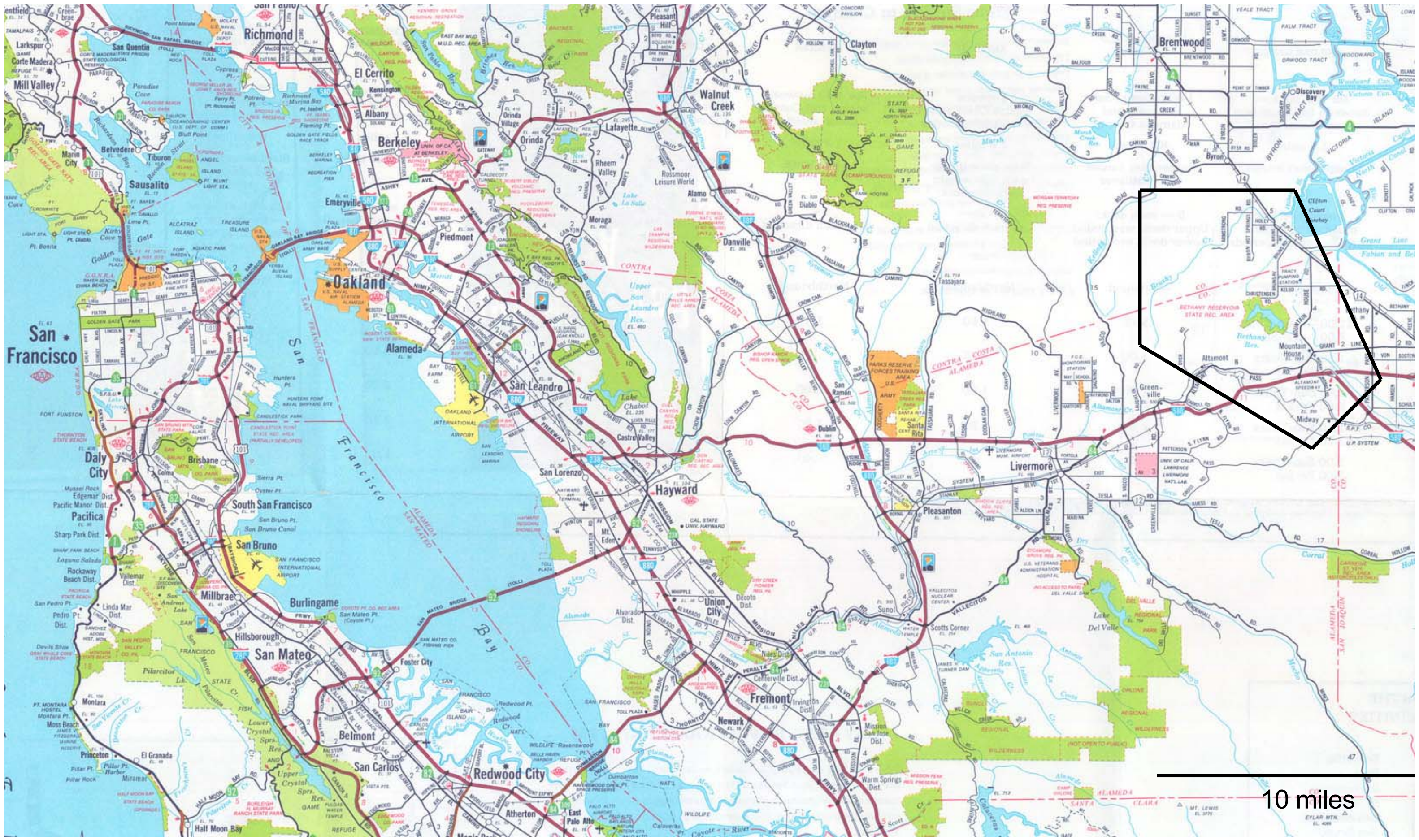

Figure 1. Approximate boundaries (outlined polygon) of the Altamont Wind Resource Area, located in Alameda and Contra Costa counties east of San Francisco, California.

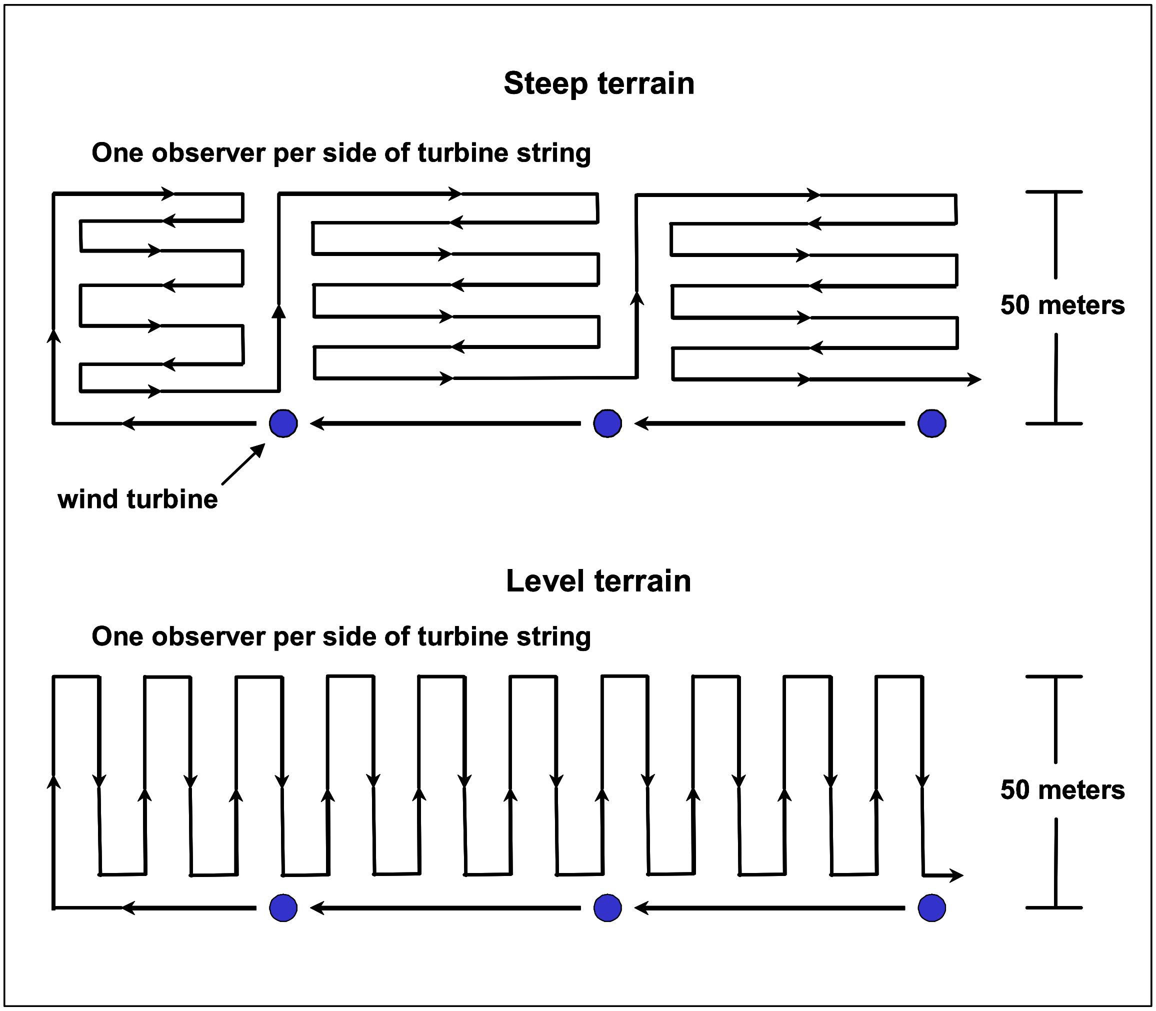

Figure 2. Searching pattern for the location of bird fatalities around wind turbines (search pattern is depicted for only one side of turbine string).

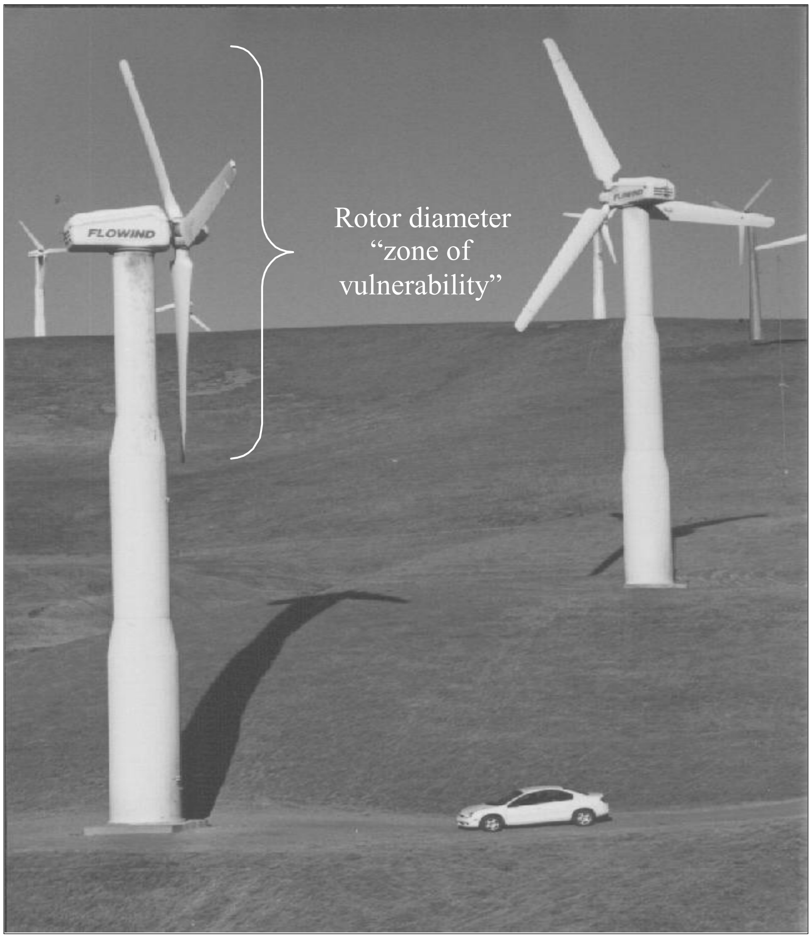

Figure 3. Wind turbine rotor diameter area or "zone of vulnerability."

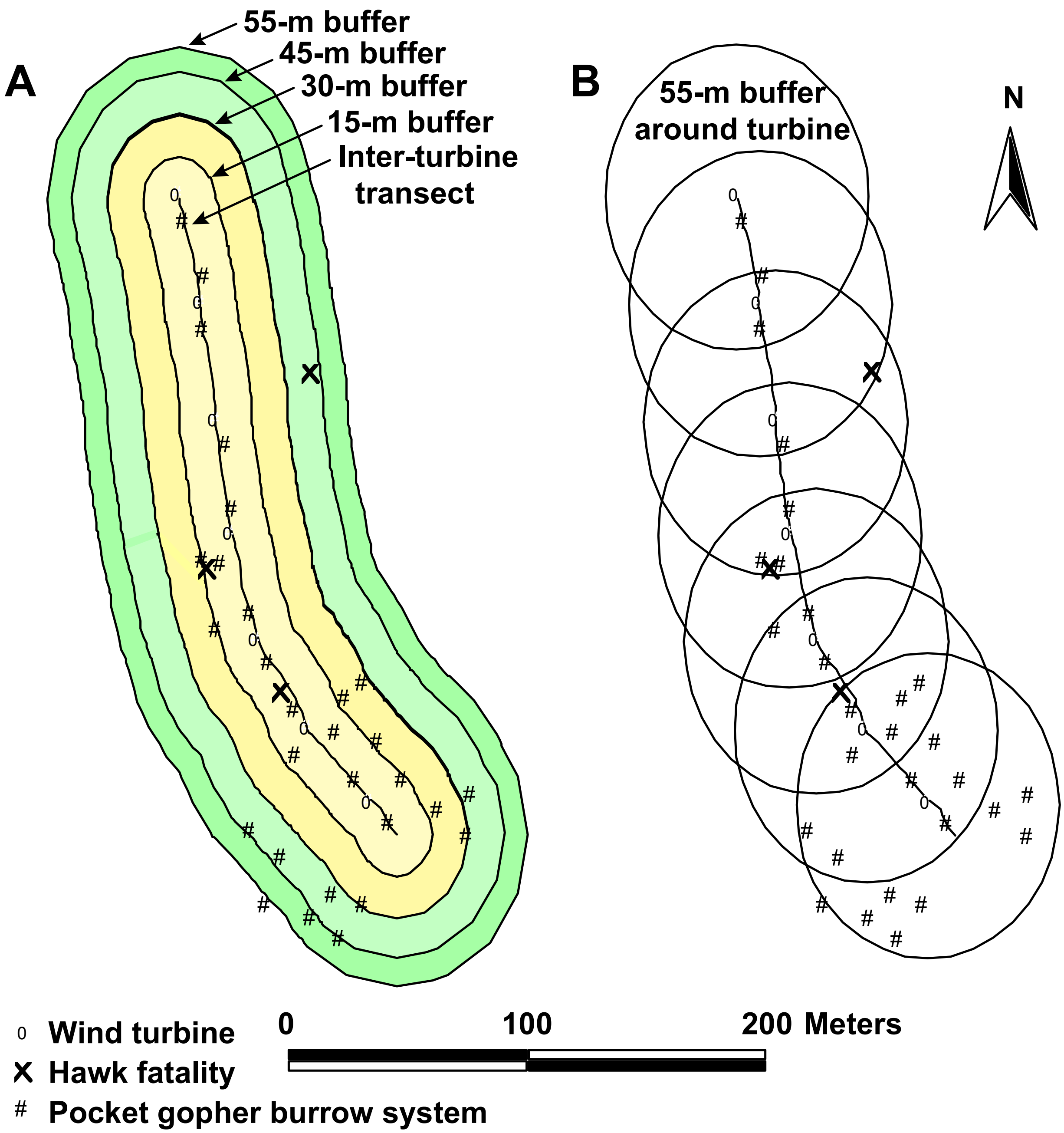

Figure 4. The density of pocket gopher burrow systems at Turbine String 9 (shown above) was calculated within each search area identified by the boundaries expanding away from the inter-turbine transect (A) and within 55 m of each turbine (B). Note that the gopher burrow systems are most strongly clustered near the wind turbines, and there is an additional cluster extending to the southwest of the turbine string.

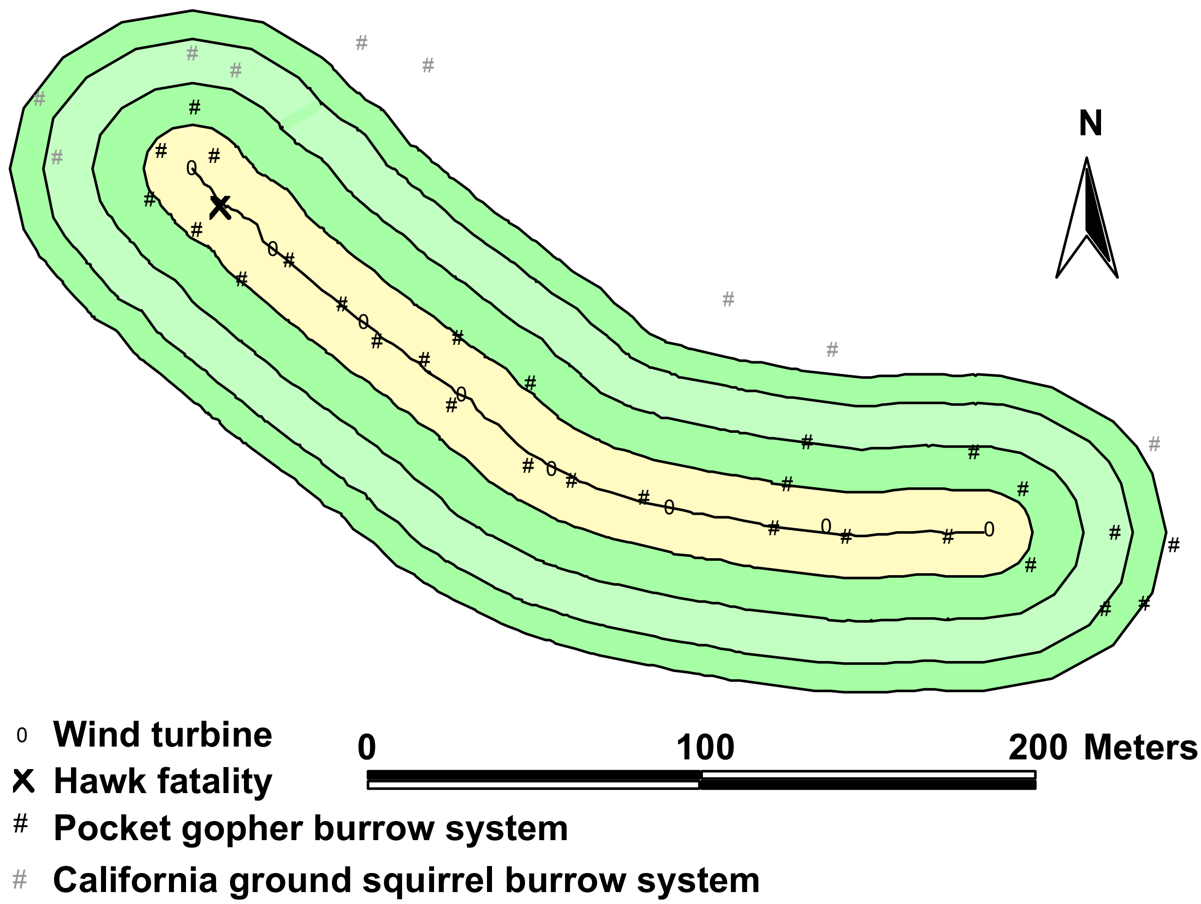

Figure 5. Gopher burrow systems are clustered within Turbine String 3 (shown here), whereas ground squirrel burrow systems are farther away. The largest portion of the ground squirrel colony is located north of this map beyond the search area.

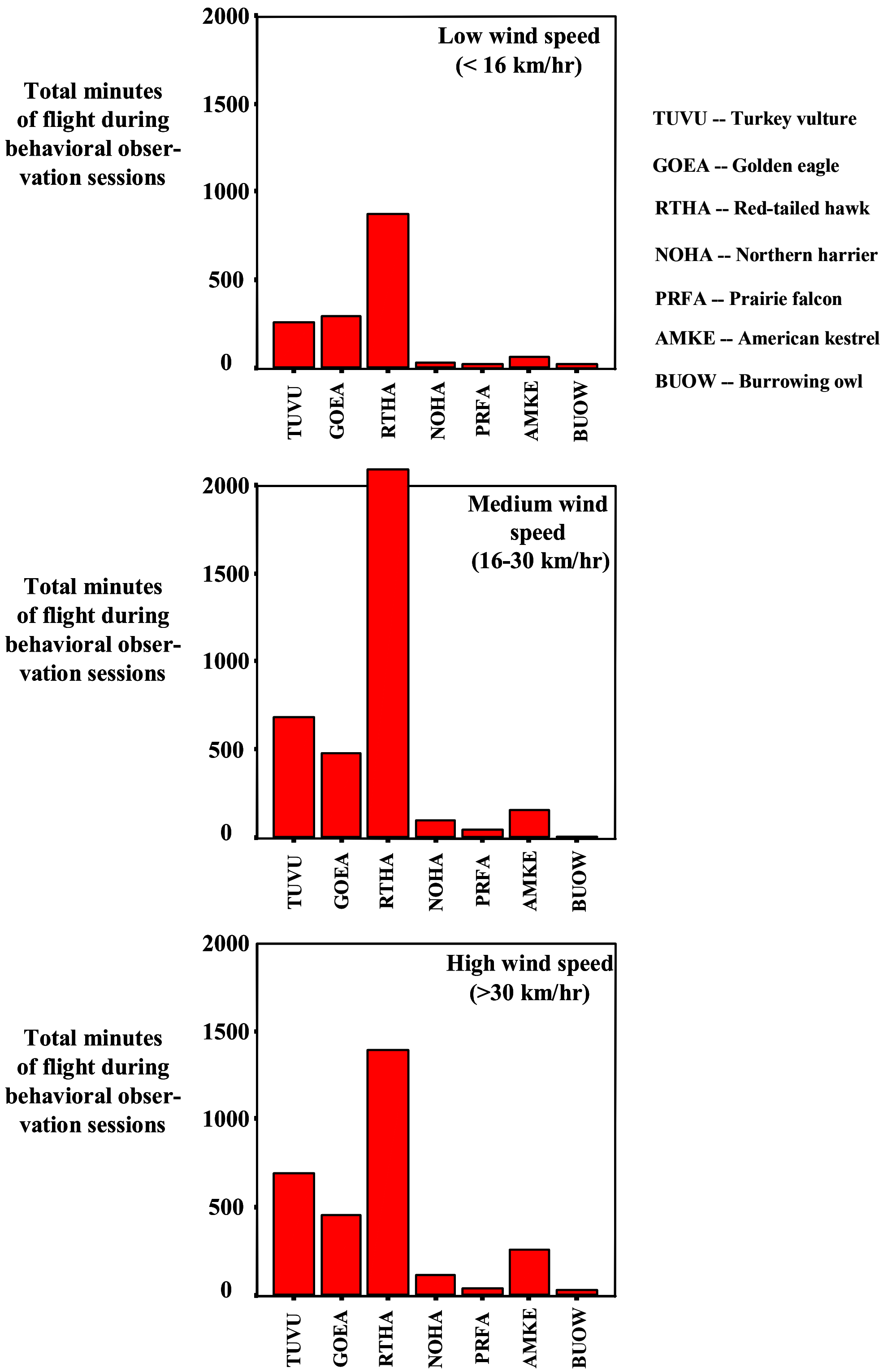

Figure 6. Comparisons of total flying time among raptor species during low (< 15 km/hr), medium (16-30 km/hr), and high (>31 km/hr) winds.

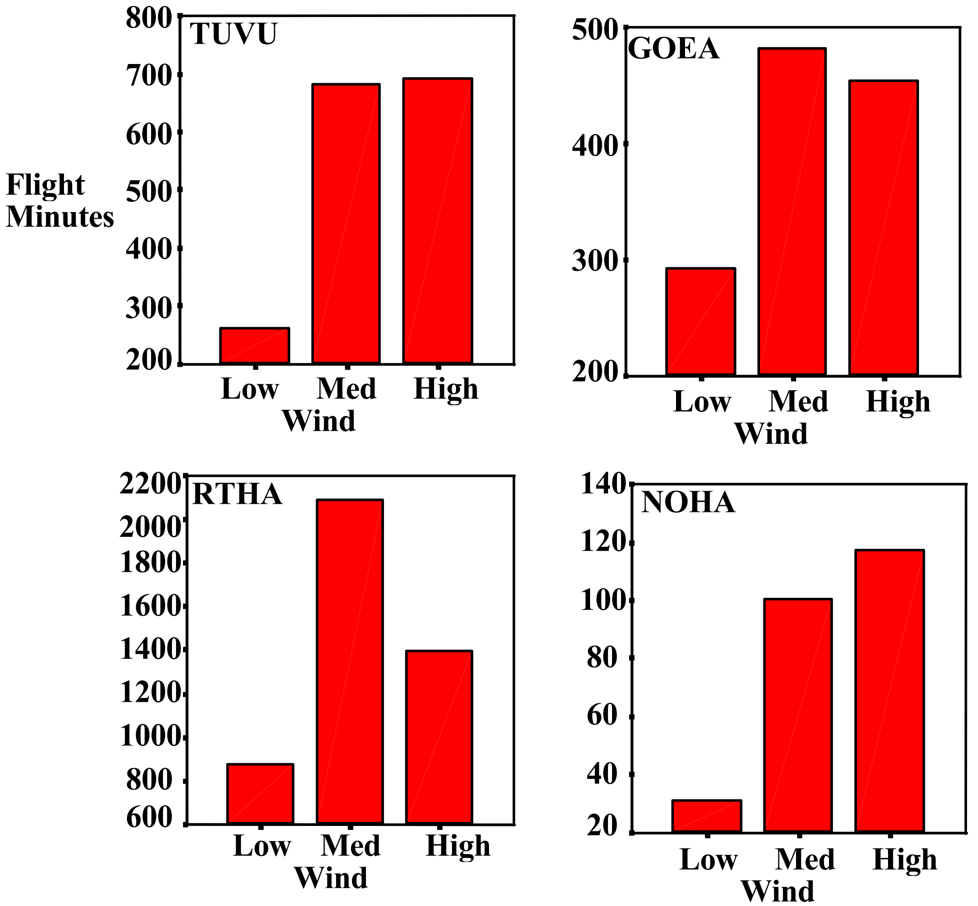

Figure 7. Total number of minutes flying in low, medium, and high winds for raptor species. TUVU = turkey vulture, GOEA = golden eagle, RTHA = red-tailed hawk, NOHA = northern harrier.

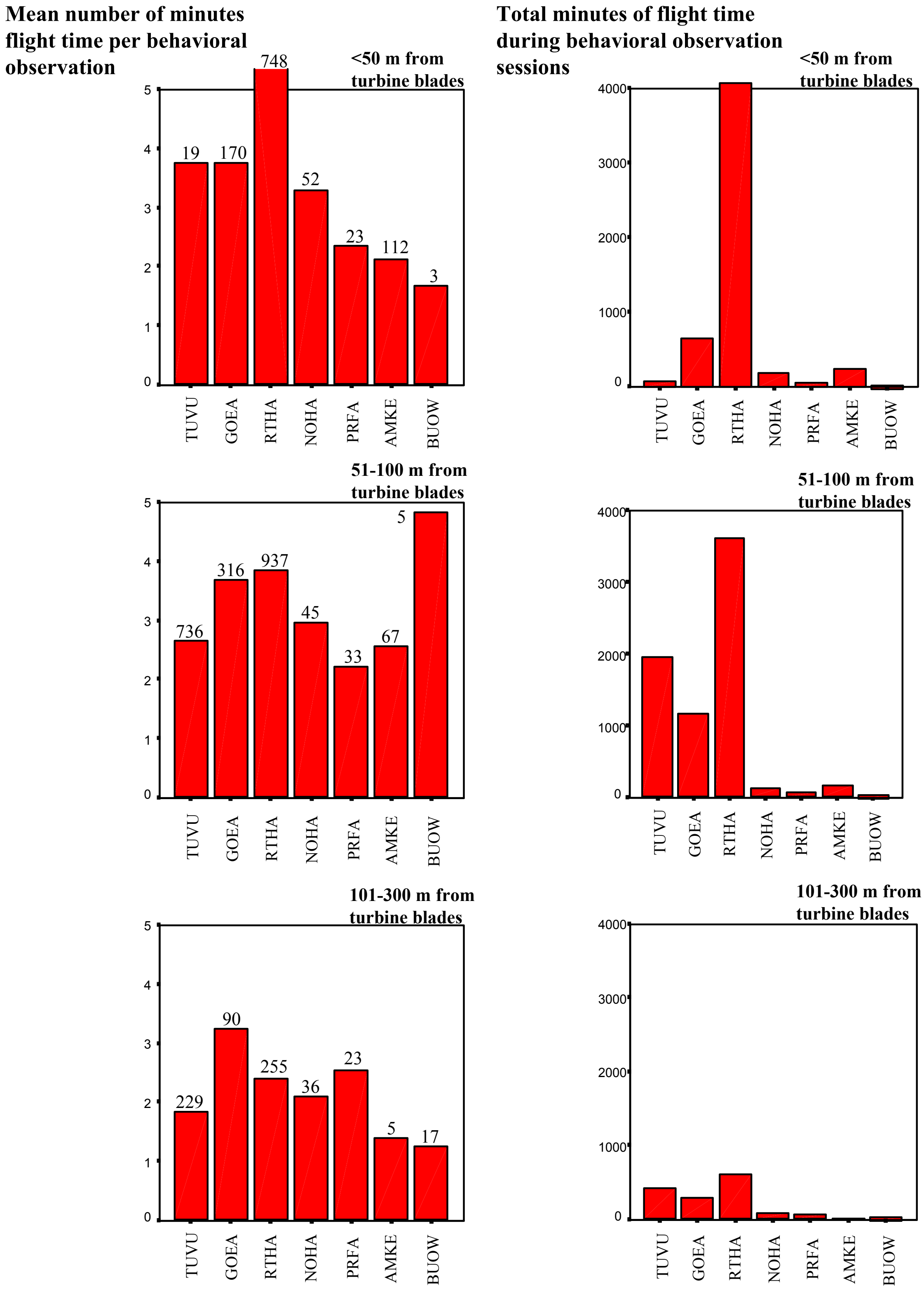

Figure 8. Differences between mean and total flight time of raptor species within proximity Level 1 (<50 m), Level 2 (51-100 m), and Level 3 (100-300 m). The species designations on the X-axis are American Ornithologist's Union acronyms: TUVU = turkey vulture, GOEA = golden eagle, RTHA = red-tailed hawk, NOHA = northern harrier, PRFA = prairie falcon, AMKE = American kestrel, and BUOW = burrowing owl.

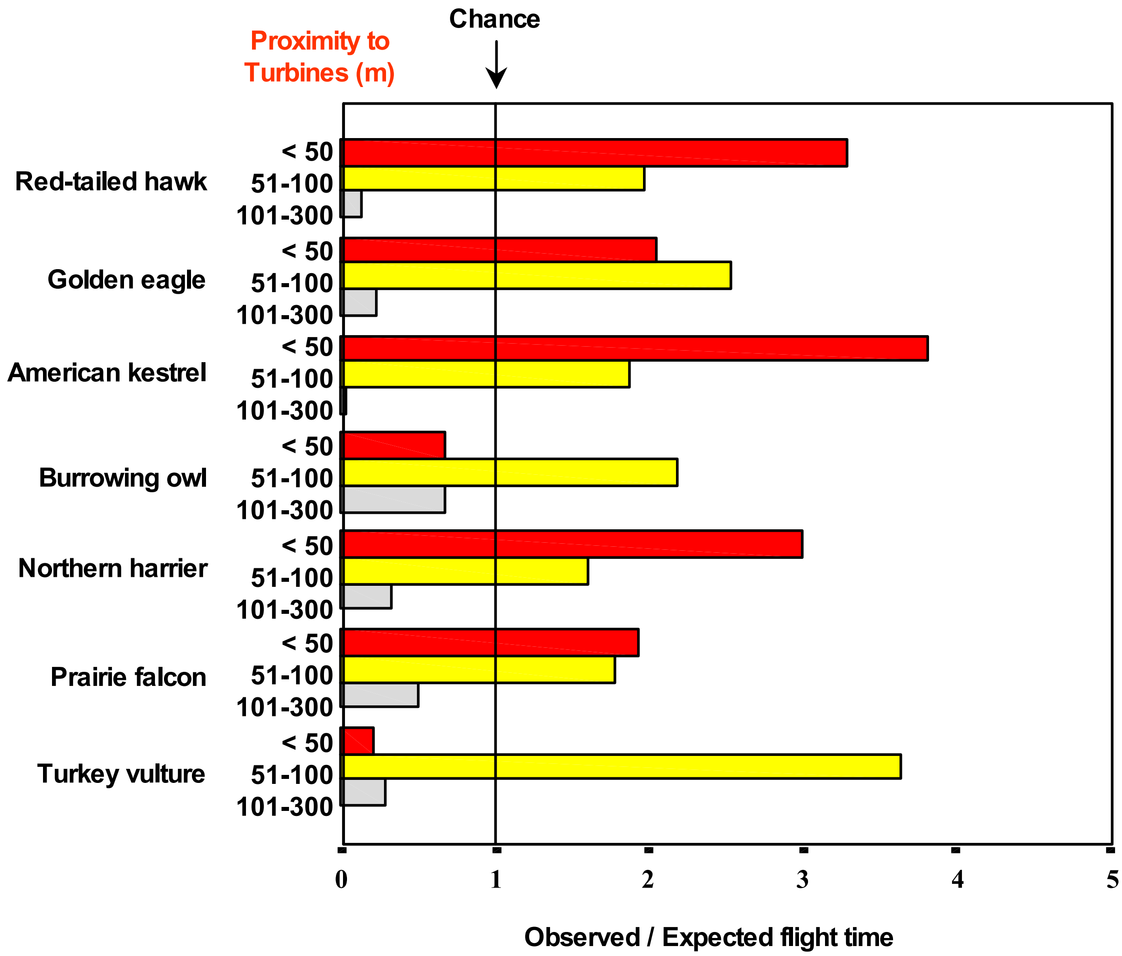

Figure 9. Associations between flight time and proximity to turbines among raptor species, where the total minutes of flying time within each proximity level was compared to the availability of the proximity level based on its approximate geographic area. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

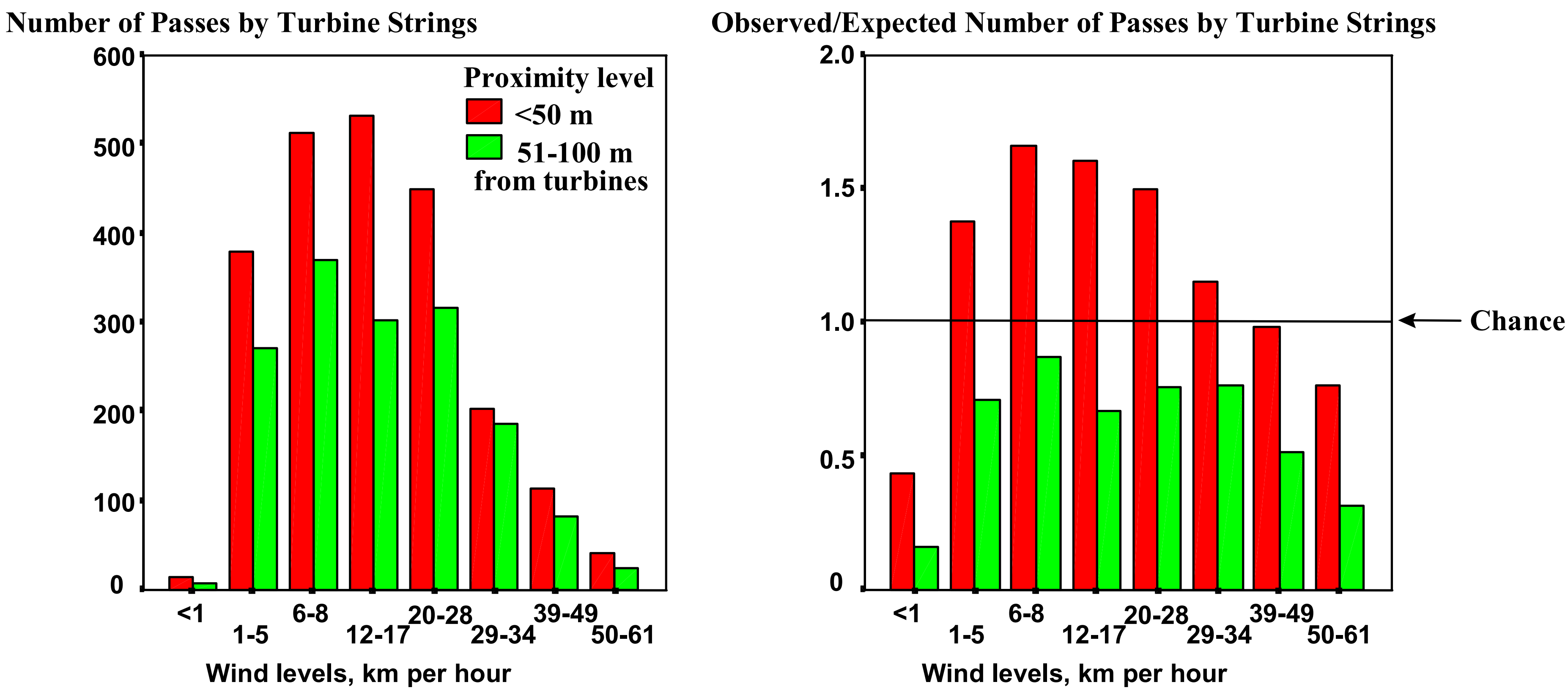

Figure 10. Left panel: Comparison of the number of passes by red-tailed hawk by turbine strings within and farther away than 50 m and at eight levels of wind speed. Right panel: A comparison of the observed and expected number of passes under these conditions, factoring in the proportion of observation sessions having a particular wind speed and the proportion of the area composed of proximity levels 1 and 2.

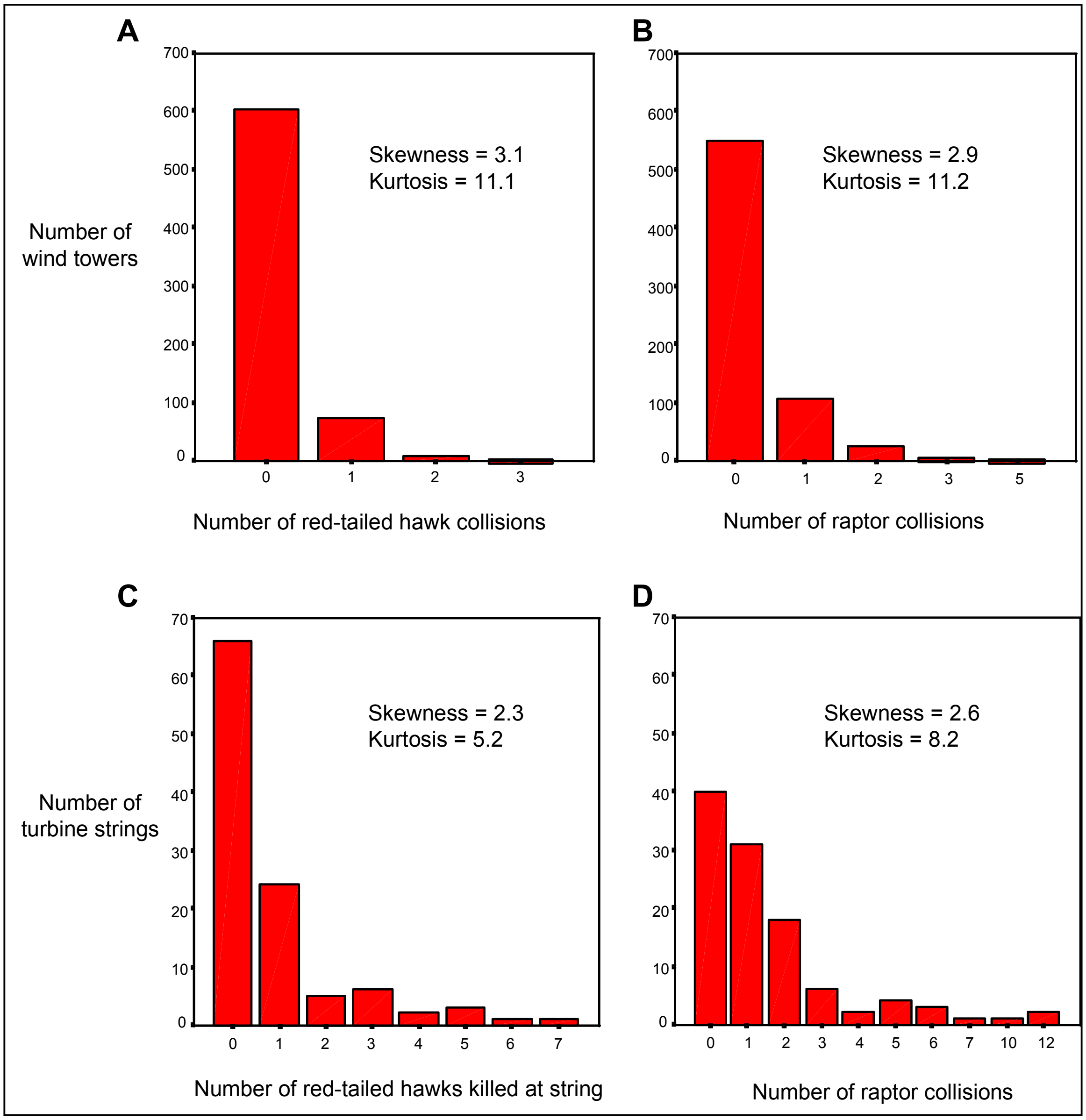

Figure 11. Frequency distributions of red-tailed hawk and all raptor fatalities among all wind towers (Graphs A and B, respectively) and among turbine strings (Graphs C and D, respectively).

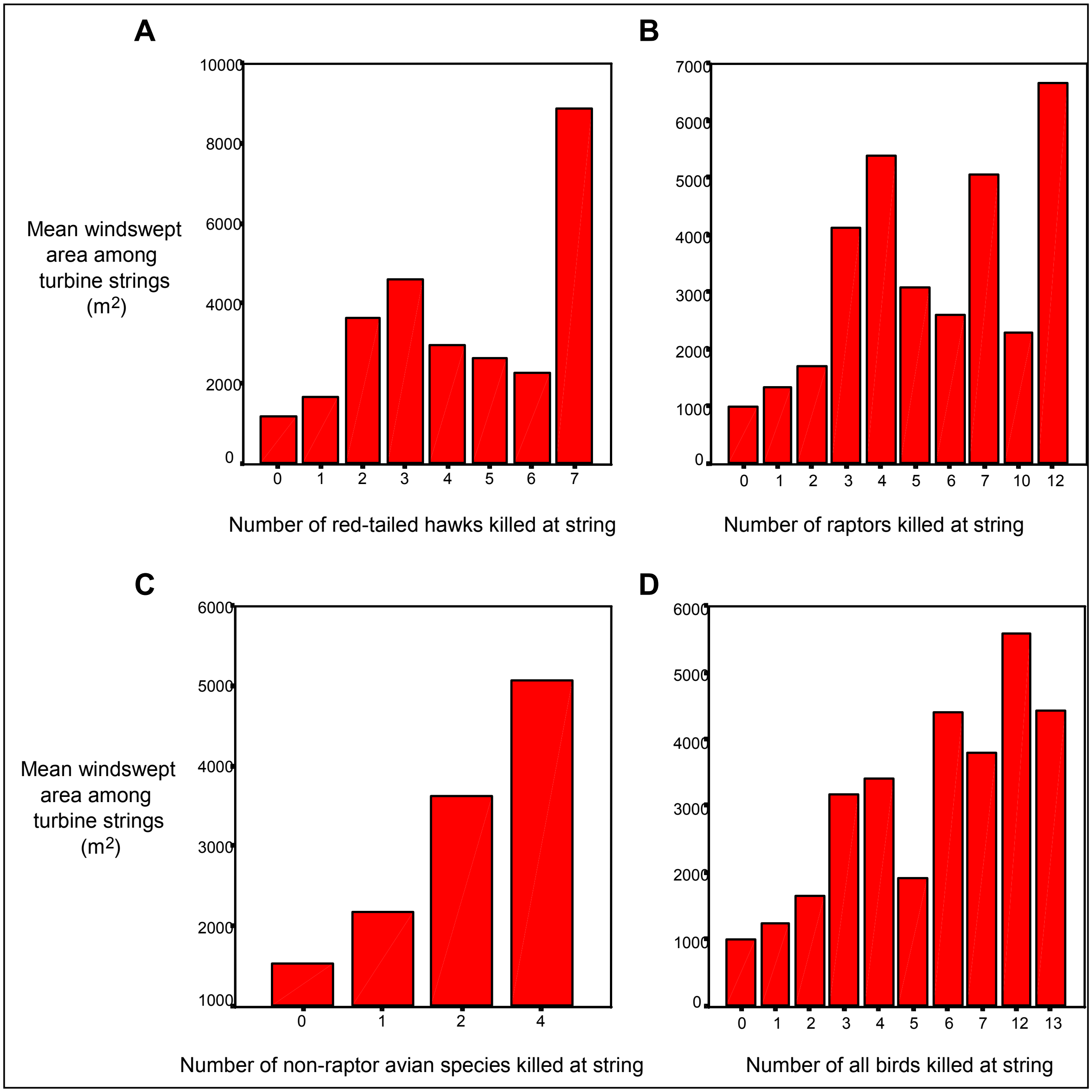

Figure 12. Mean windswept area per turbine strings associated with increasing numbers of fatalities of (A) red-tailed hawks, (B) all raptors, (C) non-raptor species, (D) all bird species.

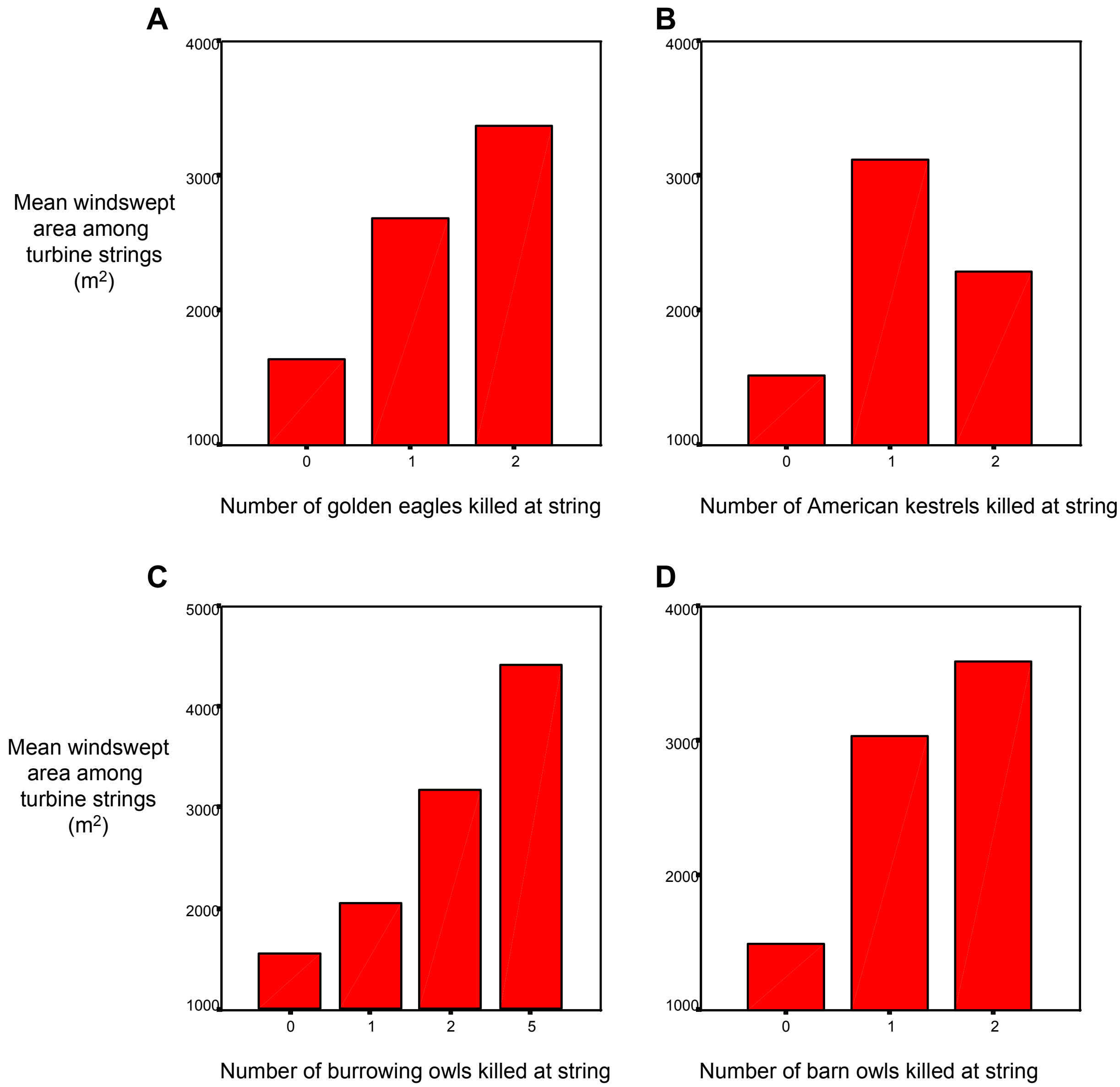

Figure 13. Mean windswept area per turbine strings associated with increasing numbers of fatalities for (A) golden eagles, (B) American kestrels, (C) burrowing owls, and (D) barn owls.

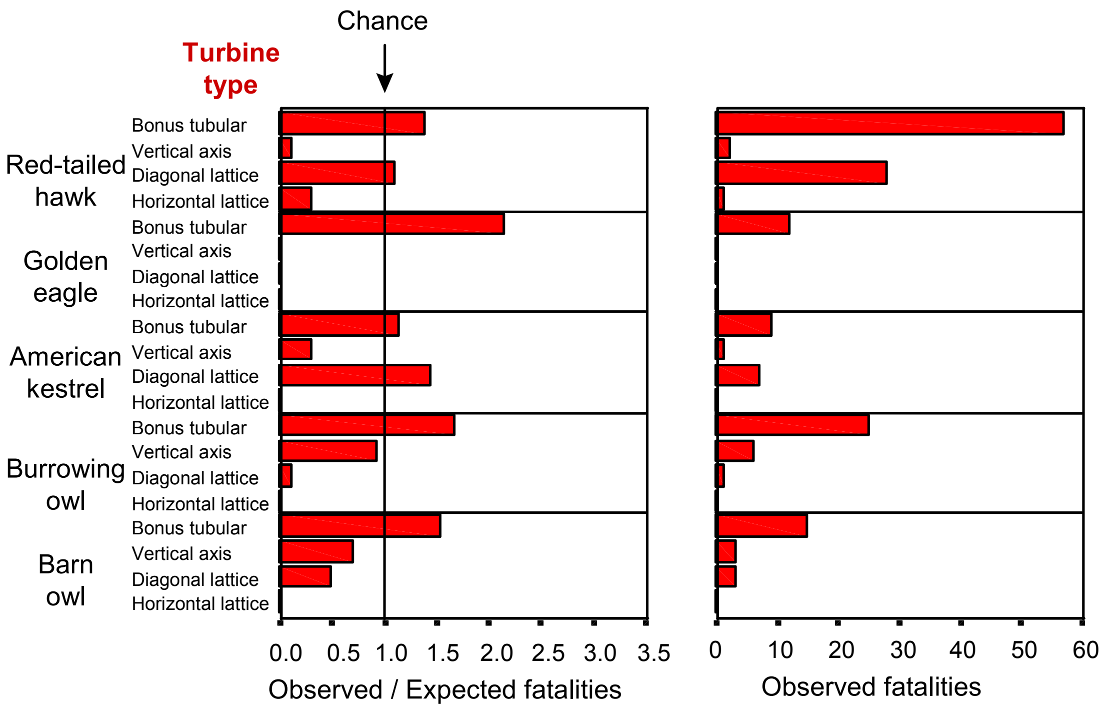

Figure 14. Associations between fatalities and tower/turbine type among raptor species. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

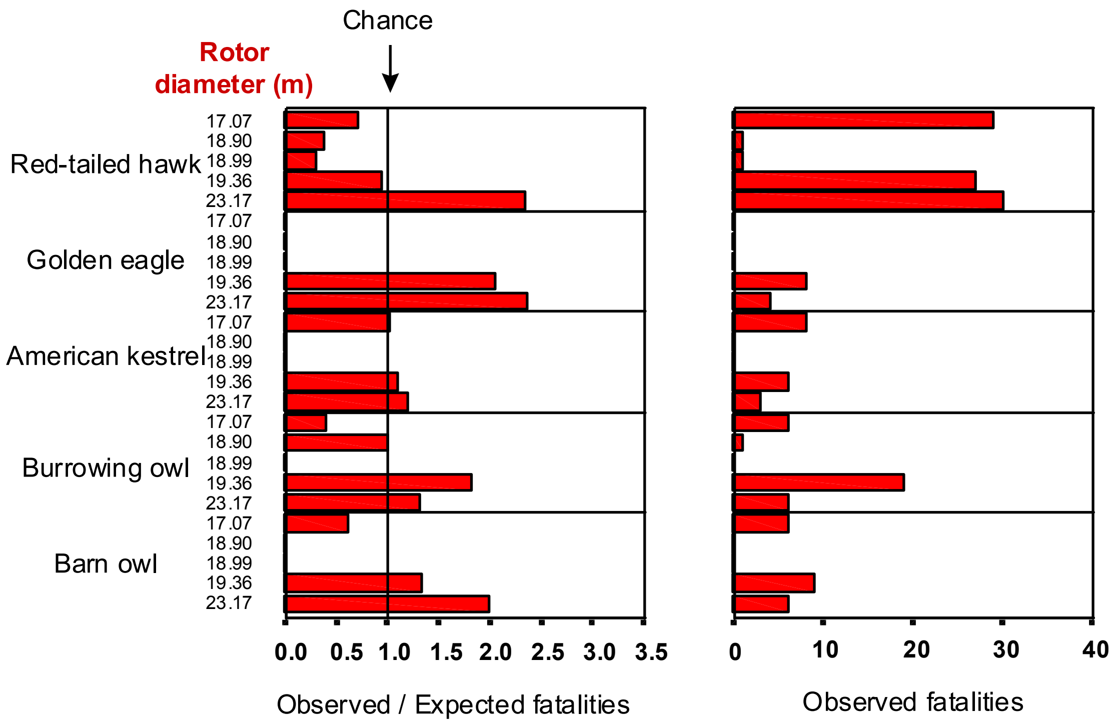

Figure 15. Associations between fatalities and rotor diameter among raptor species. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

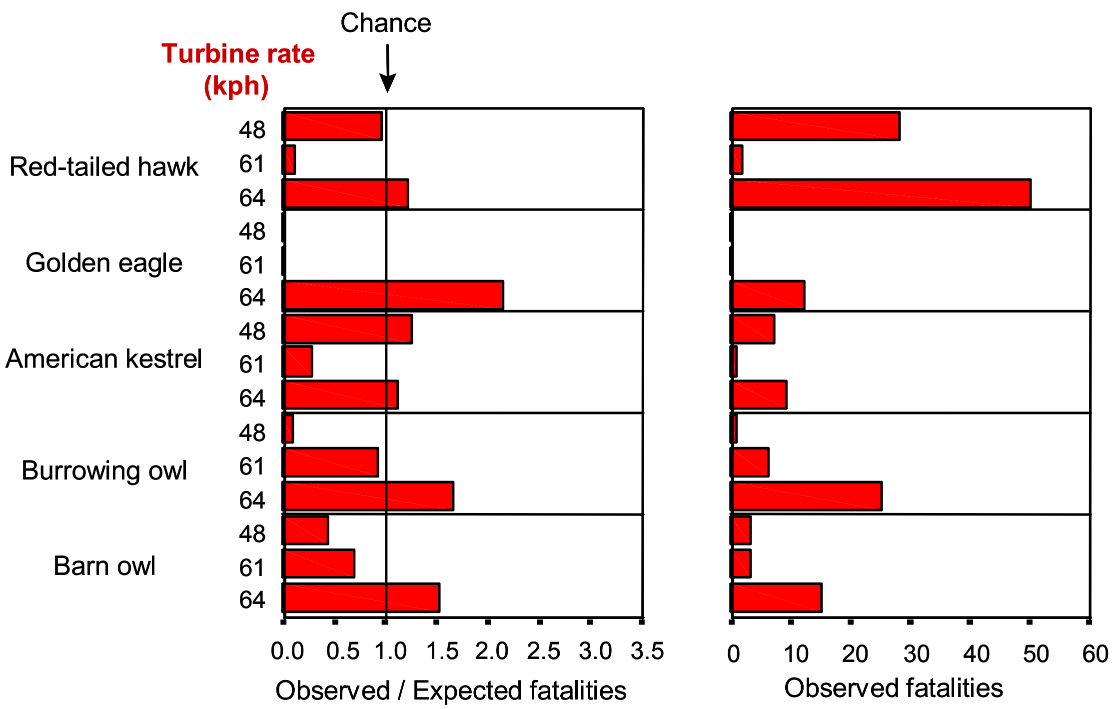

Figure 16. Associations between fatalities and rotor speed (kilometers per hour) among raptor species. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

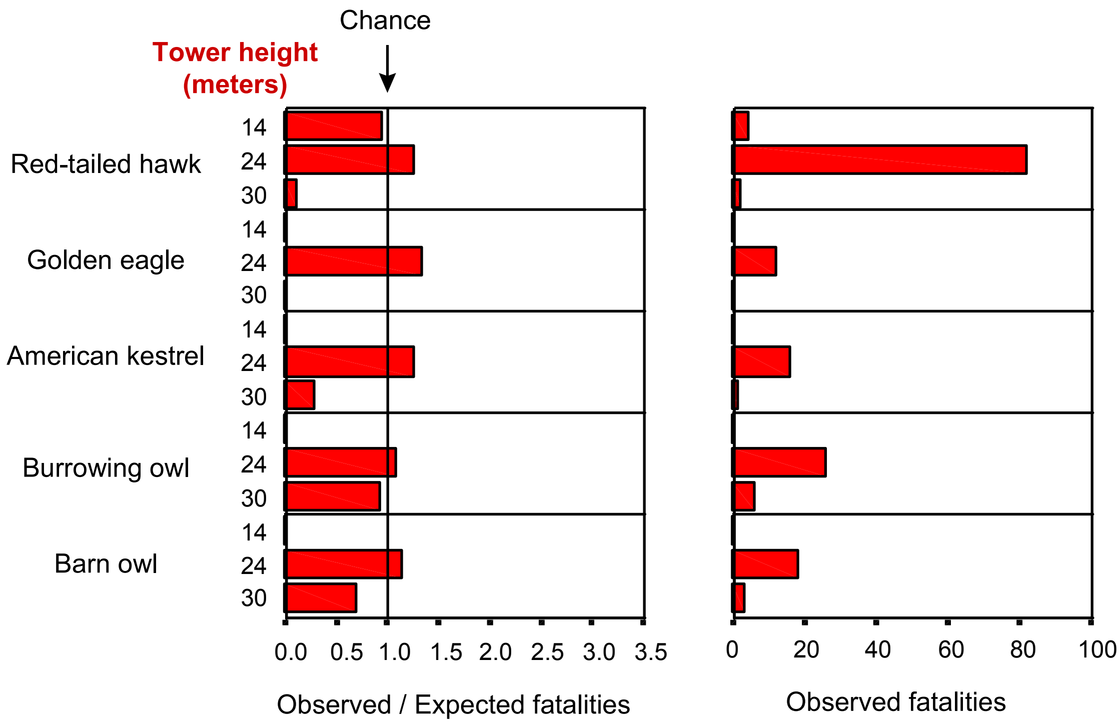

Figure 17. Associations between fatalities and tower height among raptor species. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

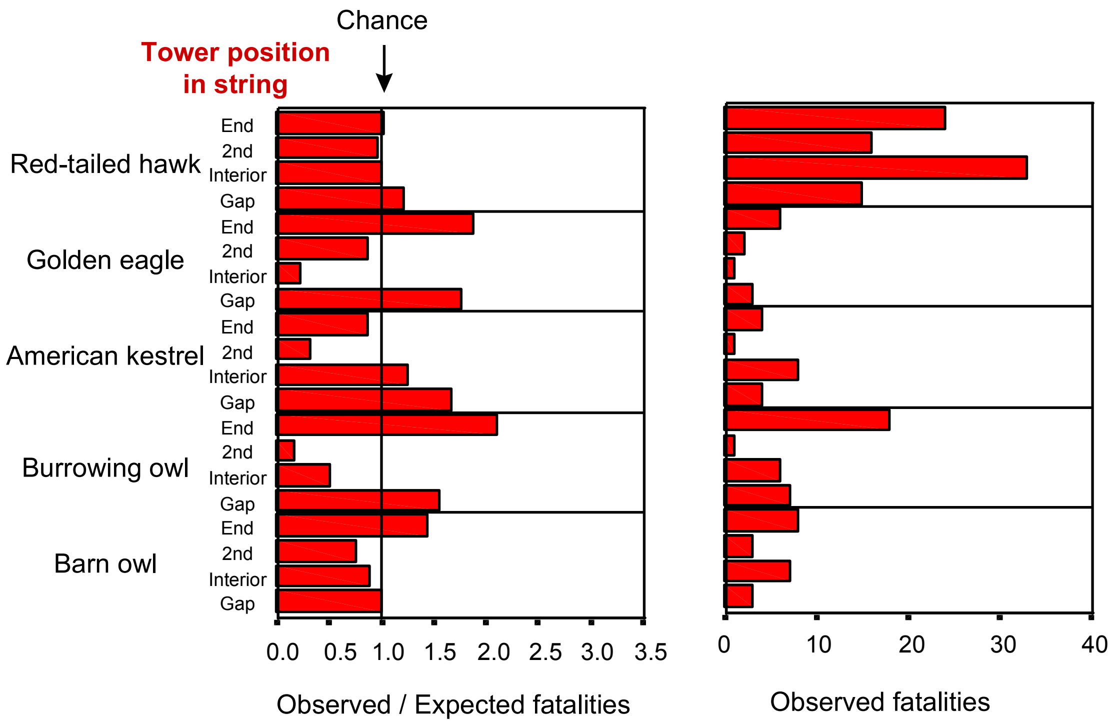

Figure 18. Associations between fatalities and tower position in the string among raptor species. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

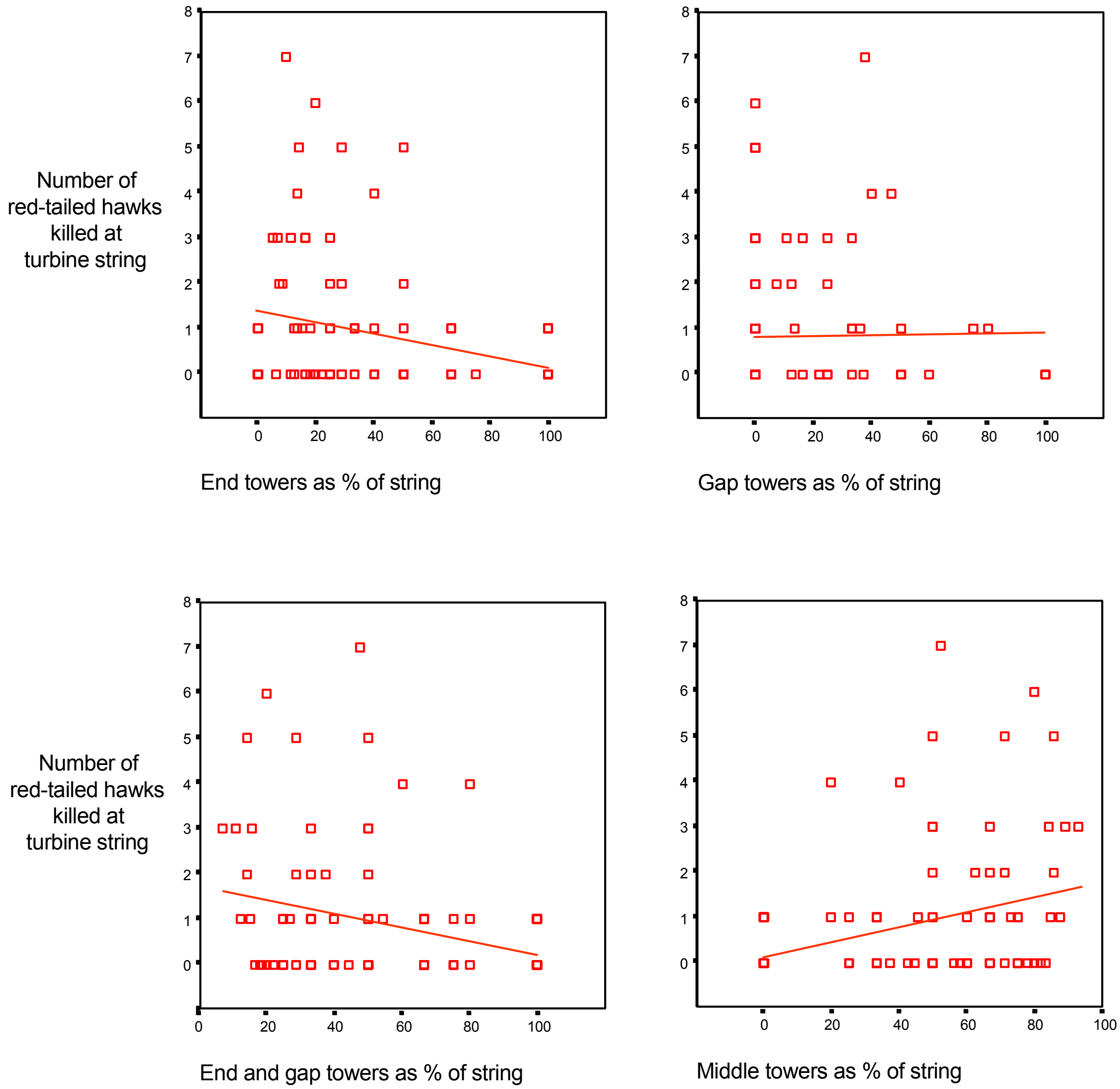

Figure 19. The number of red-tailed hawks plotted against the percentage of the string composed of end towers, gaps, ends and gaps, and interior towers.

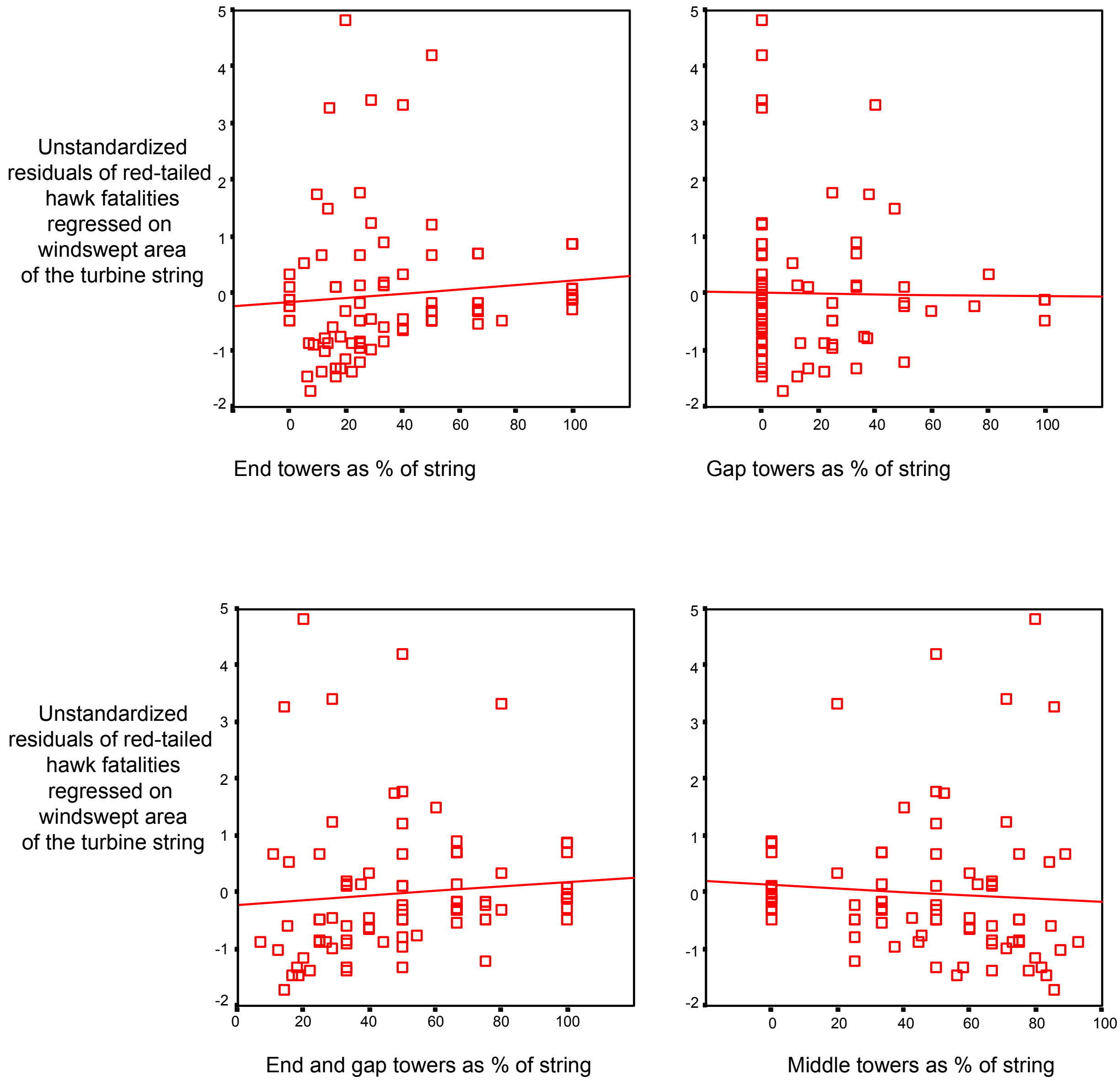

Figure 20. The residuals of number of red-tailed hawks regressed on windswept area, then plotted against the percentage of the string composed of end towers, gaps, ends and gaps, and interior towers. Note that strings with two towers are those with end towers composing 100% of the string.

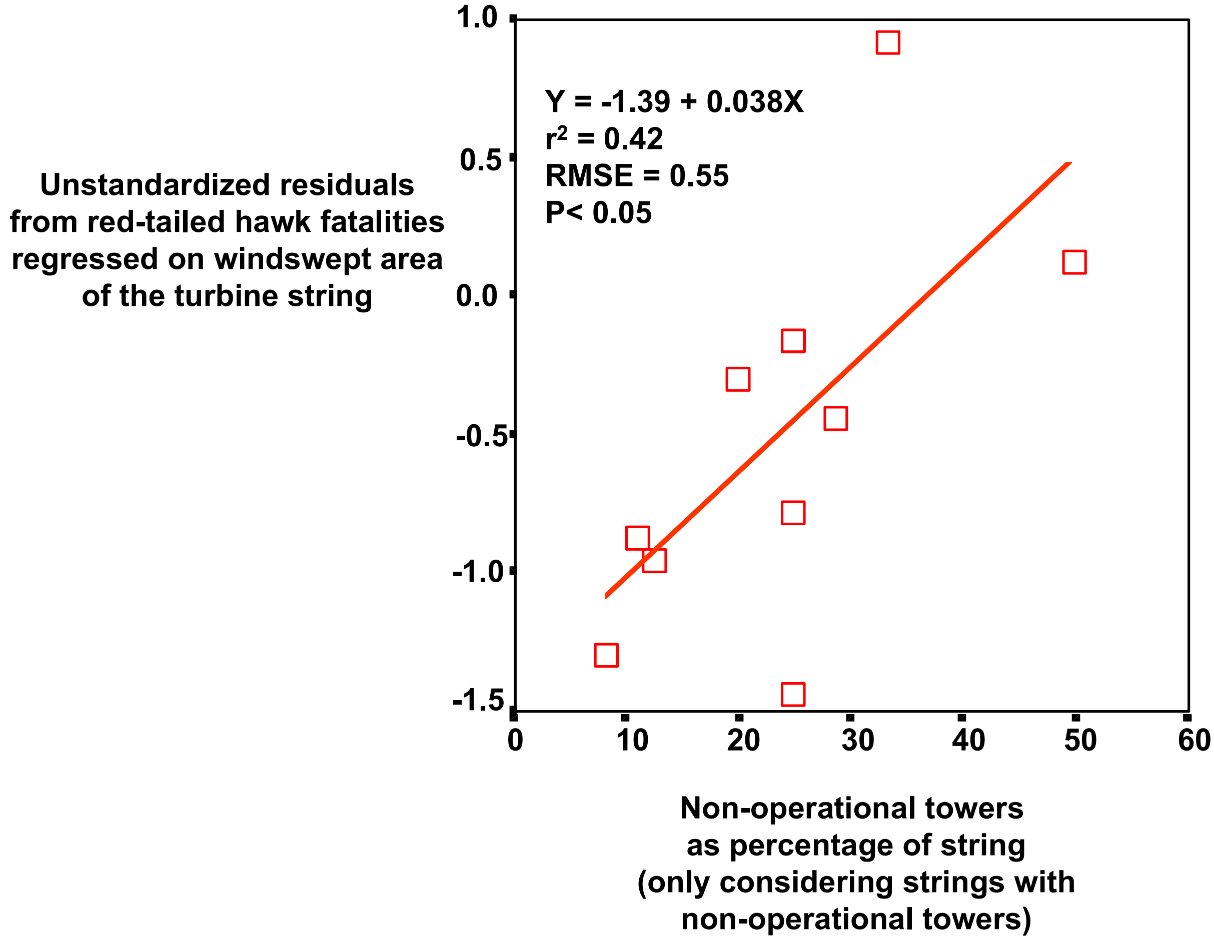

Figure 21. The residuals of number of red-tailed hawks regressed on windswept area, then plotted against the percentage of the string composed of non-operational towers.

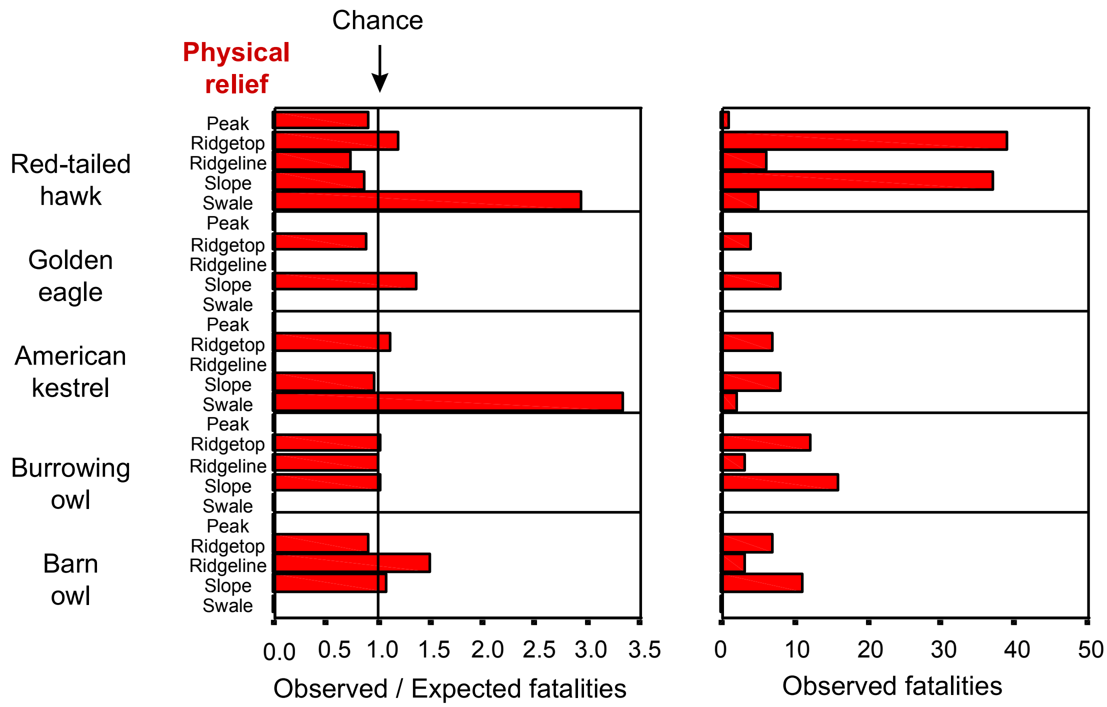

Figure 22. Associations between fatalities and physical relief among raptor species. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

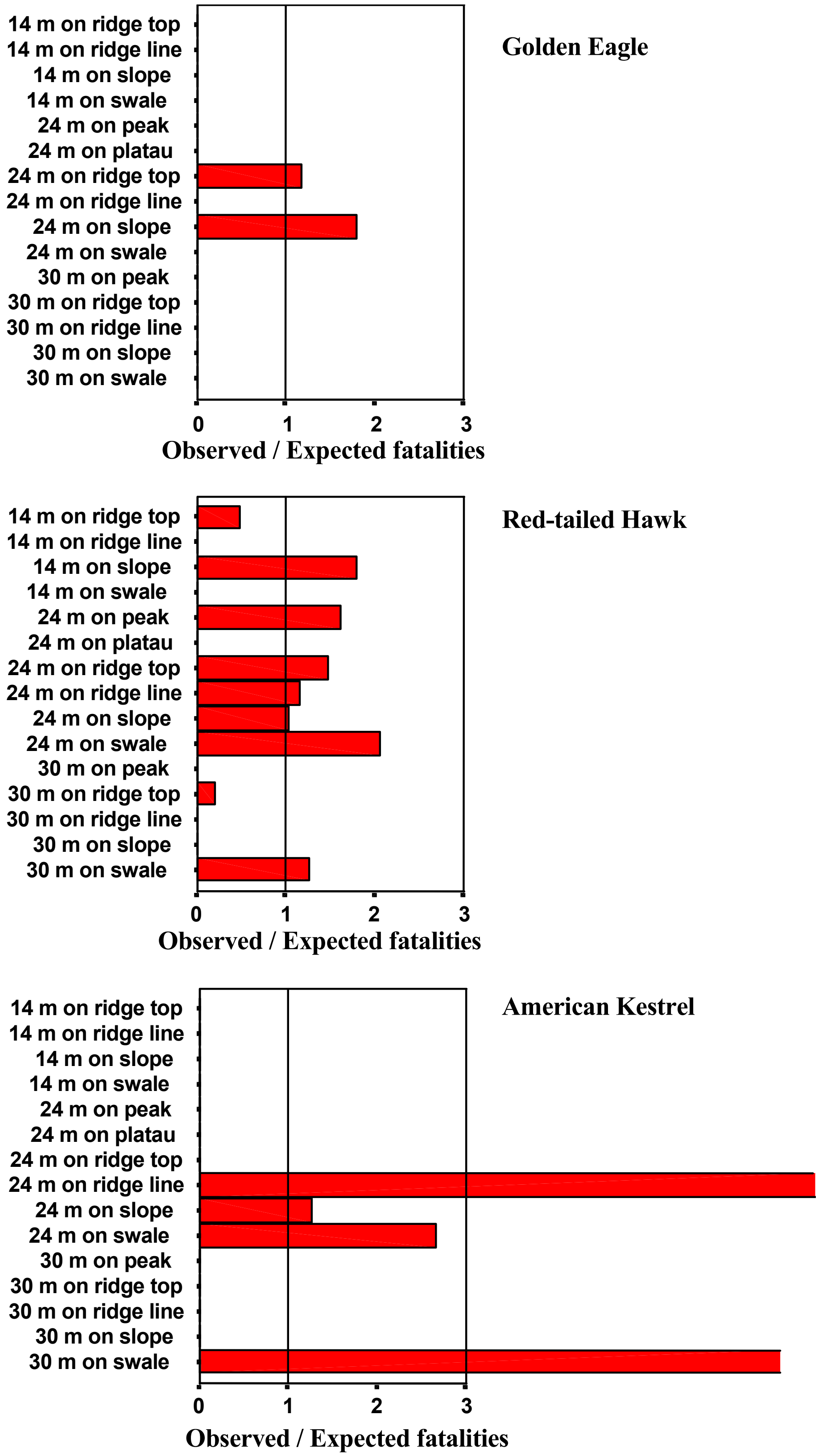

Figure 23. Associations between raptor fatalities and the interaction between physical relief and tower height.

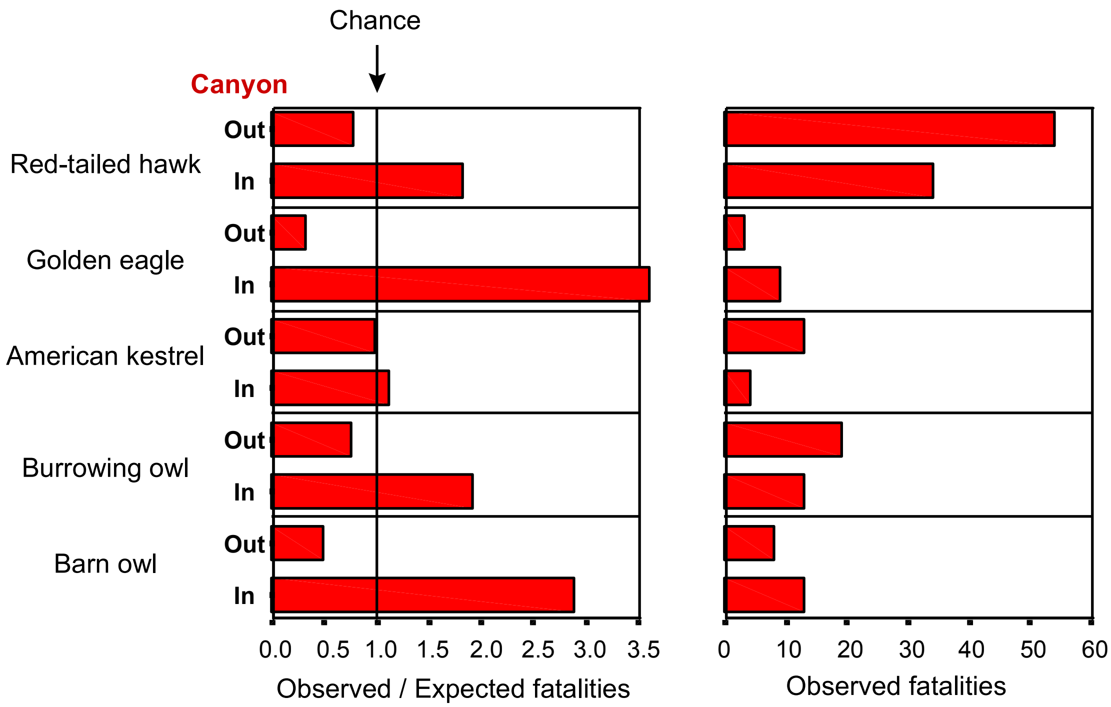

Figure 24. Associations between fatalities and whether in or out of canyons among raptor species. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

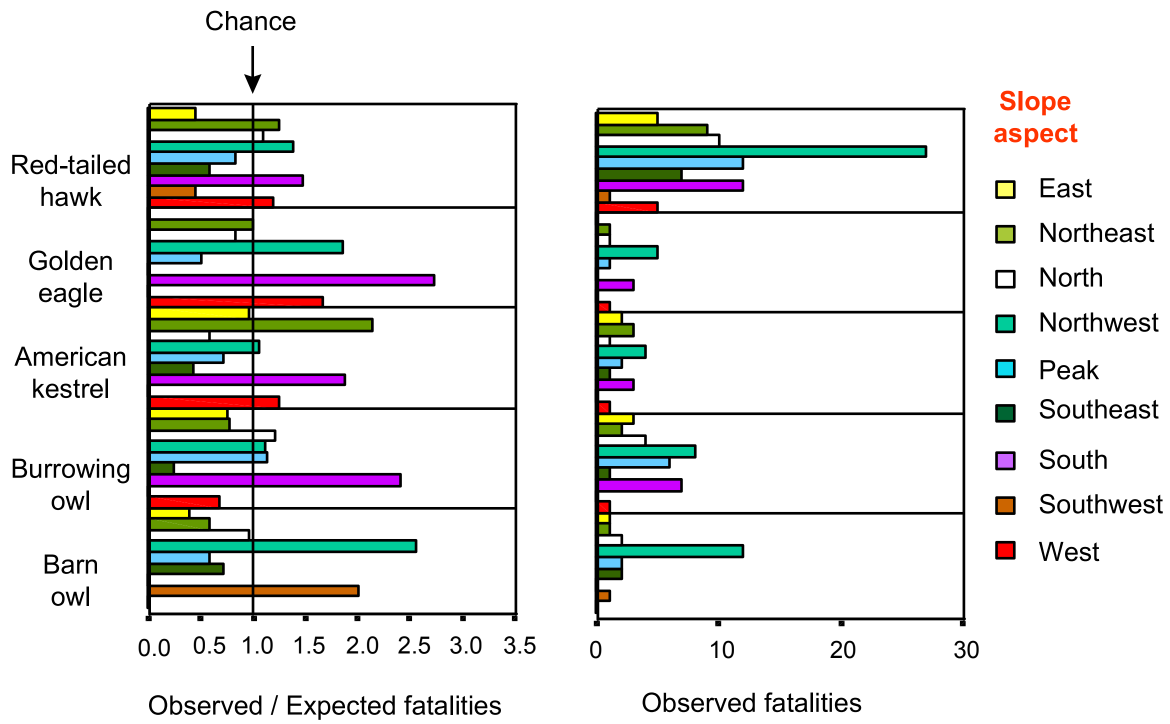

Figure 25. Associations between fatalities and slope aspect among raptor species. Observed/expected values greater than 1 indicate the degree to which the observed value exceeds the expected value based on chance.

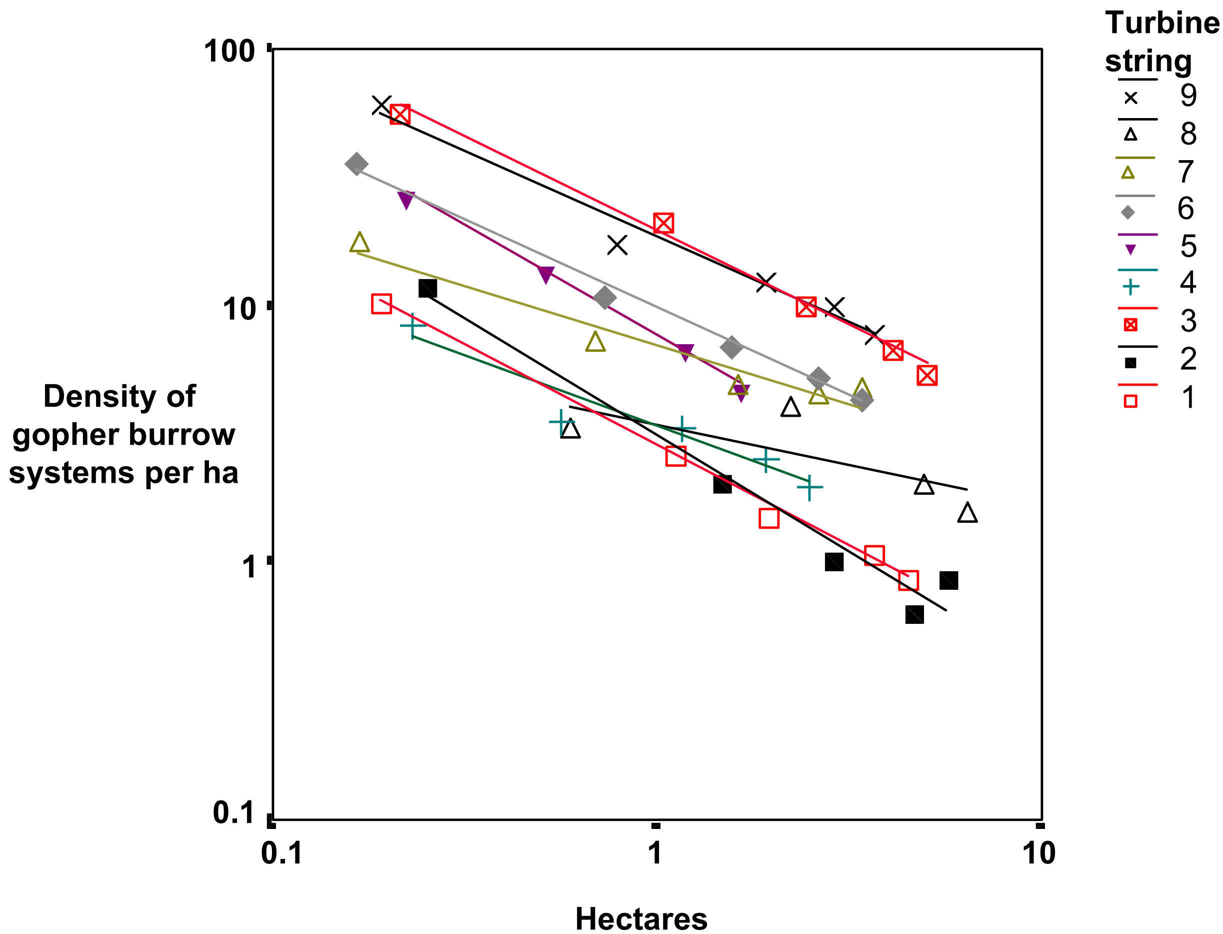

Figure 26. Pocket gopher burrow density displays an inverse power relationship to the search area surrounding each turbine string.

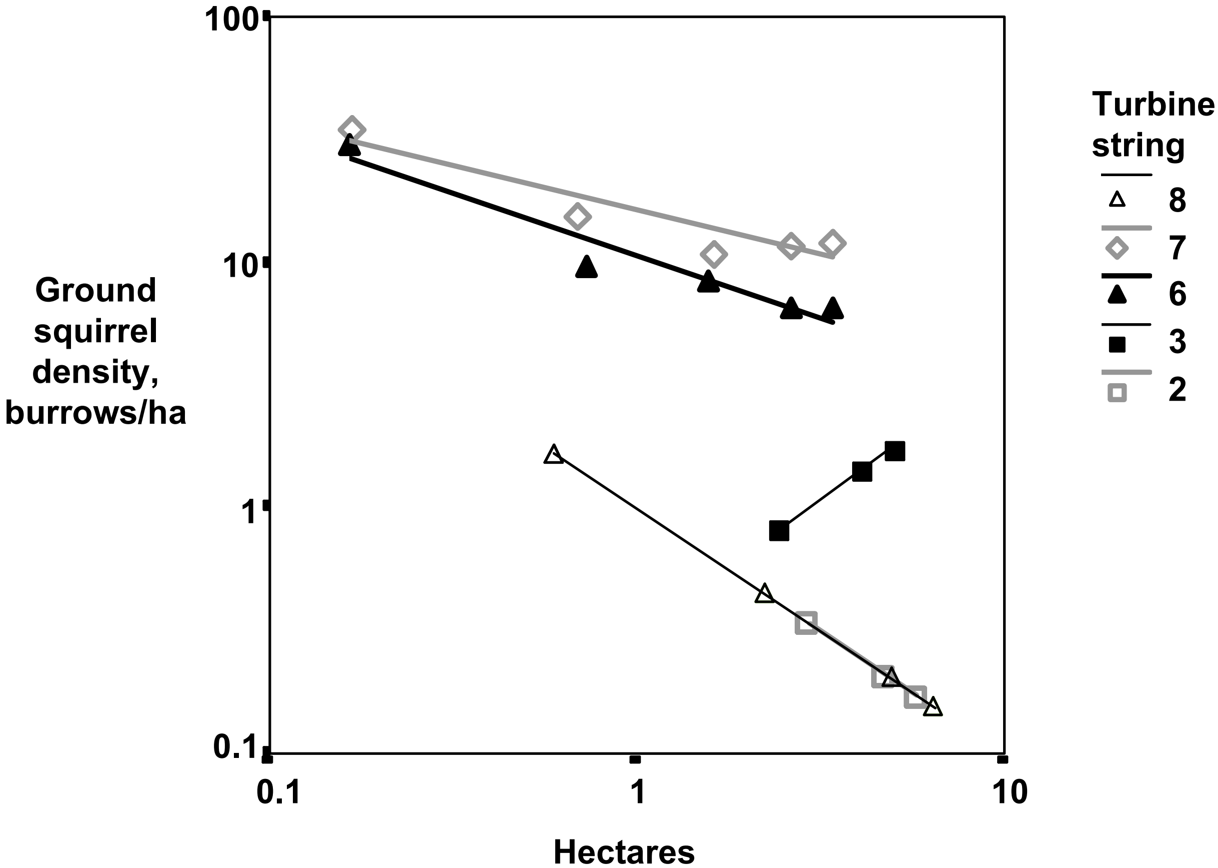

Figure 27. Ground squirrel burrow density displays two well-founded inverse power relationships to the search area surrounding the turbine string, but two others are based on one burrow system, and ground squirrels were absent at the other four turbine strings.

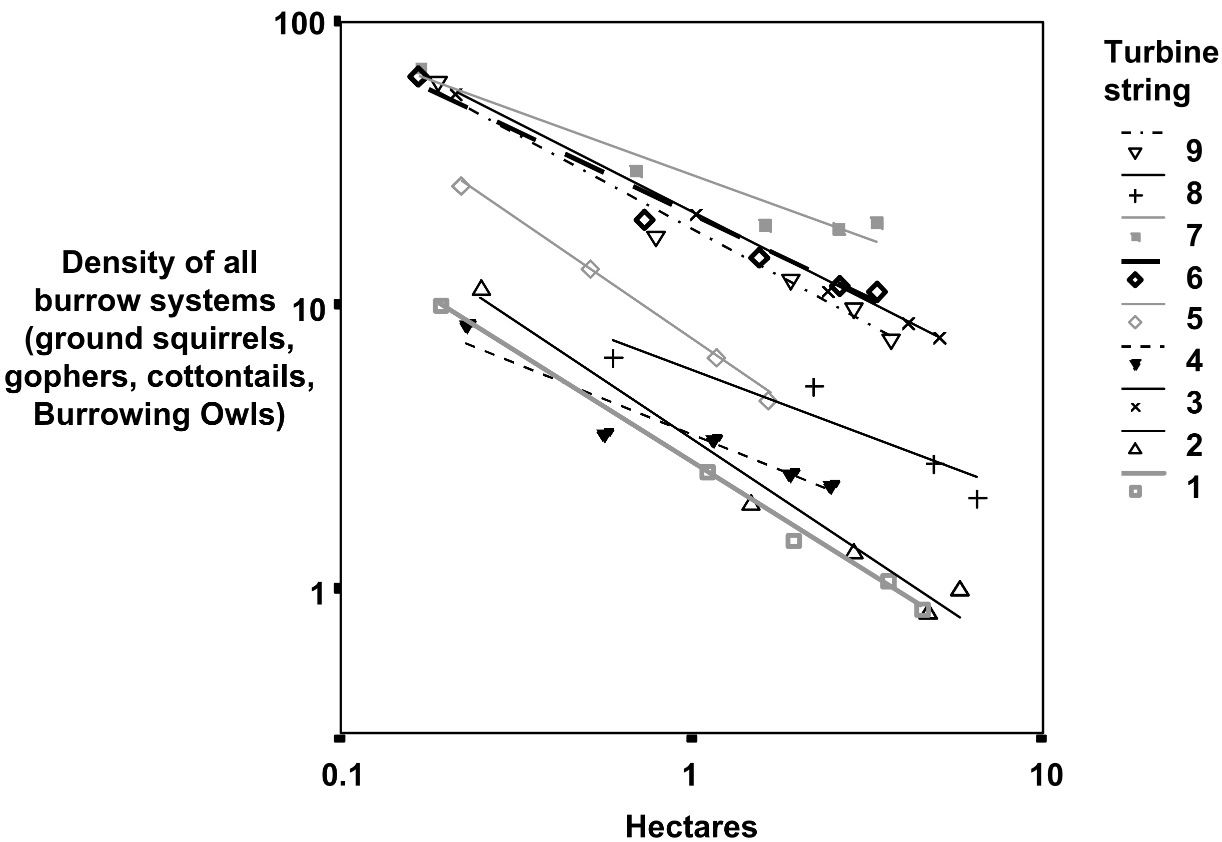

Figure 28. The density of all animal burrow systems displays an inverse power relationship to the search area surrounding each turbine string, but is likely driven mostly by the clustering of pocket gophers around the turbines.

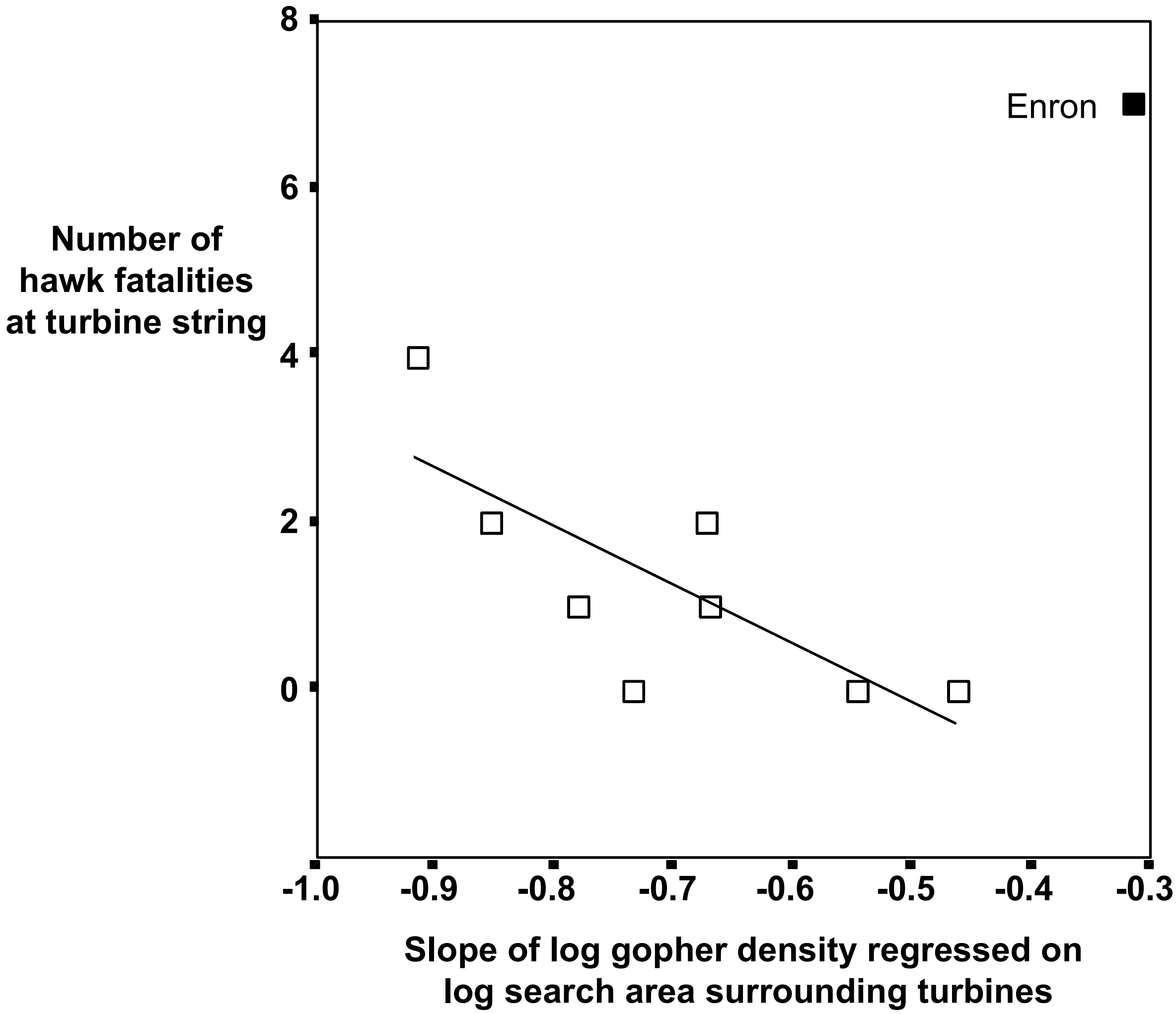

Figure 29. The number of hawk fatalities decreased with shallower slopes of log density of pocket gopher burrow systems regressed on log study area size.

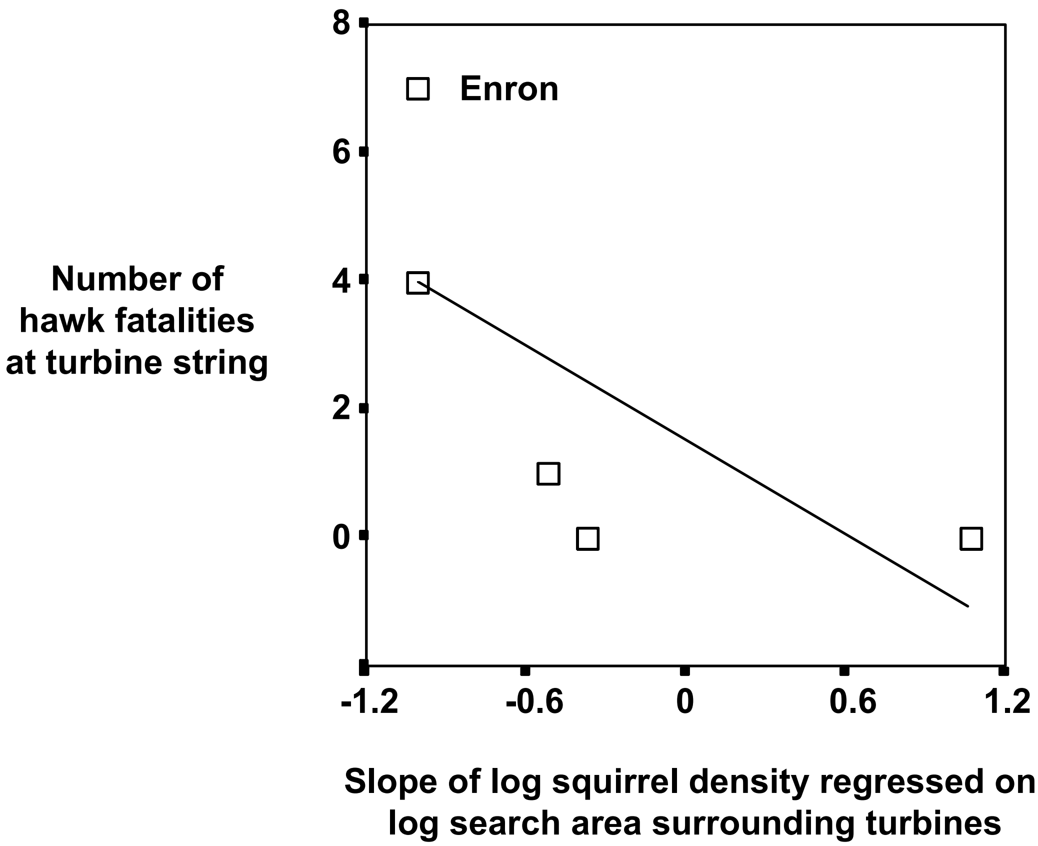

Figure 30. The number of hawk fatalities decreased with shallower slopes of log density of ground squirrel burrow systems regressed on log study area size, although the regression was not statistically significant.

APPENDIX: DATA DICTIONARY

```
"Altamont", Dictionary, "Turbines and fatalities @ Altamont Pass"
"Turbine", point
  "Type", menu,
    "Tubular Bonus"
    "Tubular Danwin"
    "Vertical Axis"
    "Diagonal Lattice"
    "Horizontal lattice", default
  "Row", numeric, 0, 0, 1000, 1
  "Number", numeric, 0, 0, 10000, 1
  "String", numeric, 0, 1, 100, 1, "Number of turbines in string"
  "Anemometer?", menu,
    "yes"
    "no", default
  "Location", menu,
    "Edge"
    "Interior", default
  "Height", menu,, "Relative height of turbine"
    "Tall"
    "Short", default
  "Topography", menu,
    "Ridge top", default
    "ridgeline"
    "Peak"
    "Slope, convex"
    "slope, concave"
    "slope, convex break"
    "slope, concave break"
    "swale"
    "plateau"
    "Ravine"
  "Aspect", menu,, "Direction faced by slope"
    "Peak", default
    "north"
    "northeast"
    "east"
    "southeast"
    "south"
    "southwest"
    "west"
    "northwest"
  "Notes", text, 30
  "Photo 1", filename
  "Photo 2", filename


"Fatality", point, "Attributes of killed bird"
  "Number", numeric, 0, 1, 1000, 1, "corresponding with data base key"
```

```
  "Species", text, 30
  "Type", menu,
    "Turbine collision", default
    "Electrocution"
    "Old bones"
    "Undetermined"
    "Predation"
    "Other"
  "Date", date, auto, dmy, "Date carcass was located"
  "Associated structure", menu,
    "Turbine"
    "Utility pole"
  "Notes", text, 30
  "Topography", menu,
    "Ridge top", default
    "Ridgeline"
    "Slope"
    "Slope Convex"
    "Slope concave"
    "Slope break, convex"
    "Slope break, concave"
    "Peak"
    "Ravine"
    "Stream"
    "Swale"
    "Plateau"
  "Aspect", menu,, "Direction faced by slope"
    "Peak", default
    "north"
    "northeast"
    "east"
    "southeast"
    "south"
    "southwest"
    "west"
    "northwest"
  "Photo 1", filename
  "Photo 2", filename
  "Photo 3", filename
  "Photo 4", filename

"Pond", area
  "Inundation", menu,
    "Perennial", default
    "Seasonal"
  "Photo 1", filename
  "Photo 2", filename

"Tree", point
  "Species", text, 30
```

```
  "Height", numeric, 0, 1, 100, 9, "in meters"
  "Photo", filename

"Plot number", point
  "Number", numeric, 0, 1, 20, 1
  "Notes", text, 30

"Topography", line
  "Topography", menu,
    "Ridgetop", default
    "Ridgeline"
    "Slope, Convex"
    "Slope, concave"
    "Slope break, convex"
    "Slope break, concave"
    "Swale"
    "Plateau"
    "Stream"
    "Ravine"
    "Ravine bottom"
    "Pond"
  "Aspect", menu,
    "Peak"
    "North"
    "Northeast"
    "East", default
    "Southeast"
    "South"
    "Southwest"
    "West"
    "Northwest"
  "Transect width", numeric, 0, 1, 30, 15, "Distance observable to either side"

"Burrow", point
  "Species", menu,
    "Pocket gopher", default
    "Ground squirrel"
    "Rabbit"
    "Badger"
    "Coyote"
    "Fox"
    "Burrowing Owl"
  "Notes", text, 30
  "Photo", filename


"Turbine count area", area, "for burrow counts"
  "Notes", text, 30
  "Photo 1", filename
  "Photo 2", filename
```

"Gopher burrow", point

"Gr squirrel burrow", point

"Burrowing owl", point

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13. ABSTRACT *(Maximum 200 words)*

It has been documented that wind turbine operations at the Altamont Pass Wind Resource Area kill large numbers of birds of multiple species, including raptors. We initiated a study that integrates research on bird behaviors, raptor prey availability, turbine design, inter-turbine distribution, landscape attributes, and range management practices to explain the variation in avian mortality at two levels of analysis: the turbine and the string of turbines. We found that inter-specific differences in intensities of use of airspace within close proximity did not explain the variation in mortality among species.

Unique suites of attributes relate to mortality of each species, so species-specific analyses are required to understand the factors that underlie turbine-caused fatalities. We found that golden eagles are killed by turbines located in the canyons and that rock piles produced during preparation of the wind tower laydown areas related positively to eagle mortality, perhaps due to the use of these rock piles as cover by desert cottontails. Other similar relationships between fatalities and environmental factors are identified and discussed. The tasks remaining to complete the project are summarized.

14. SUBJECT TERMS
wind energy; wind turbines; birds; avian issues; Altamont Pass Wind Resource Area; California.

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