# CHAPTER 8

# BIRD BEHAVIORS IN THE ALTAMONT PASS WIND RESOURCE AREA

## 8.1 INTRODUCTION

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

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

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

## 8.2 METHODS

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

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

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

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

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

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

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

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


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

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

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

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

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

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

### 8.2.1 Plot Level of Analysis

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

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

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

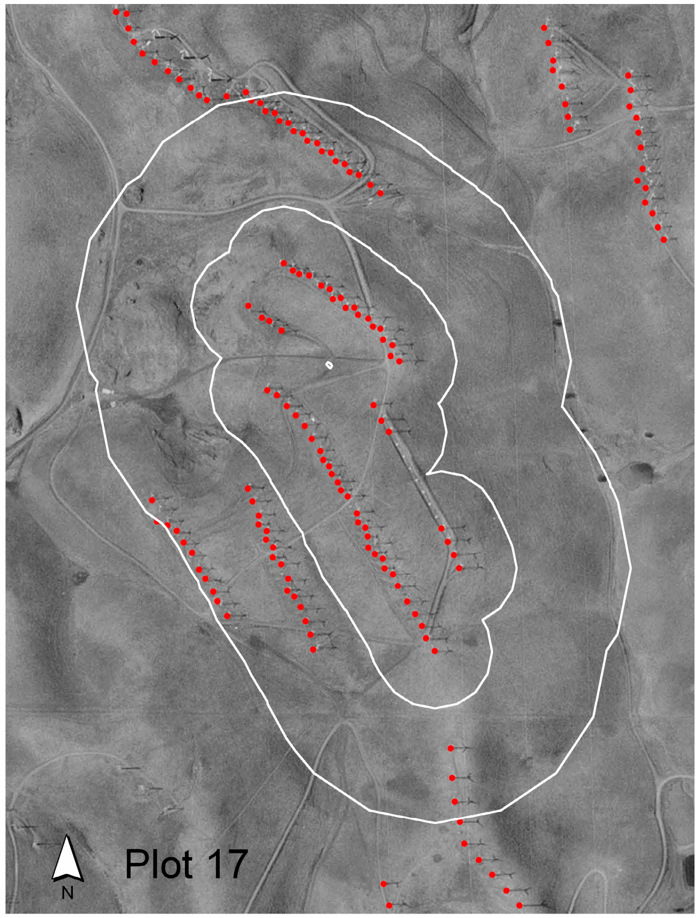



**Figure 8-2.** An example of a buffer created in GIS and corrected to fit the 3-D landscape in order to test for patterns of behavior in relation to proximity to wind turbines. The inner white line encompasses the wind turbines composing the sample that is the subject of the study plot, and it is 100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

### 8.2.2 Wind Turbine Level of Analysis

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

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

We classified each wind turbine by the slope aspect where it was situated, and we estimated slope grade and recorded elevation. Slope aspect was classified as facing north, northeast, east, southeast, south, southwest, west, northwest, or located in a valley. For analysis we aggregated slope aspect into five categories: northeast and east, southeast and south, southwest and west, northwest and north, and no aspect (flat terrain). Slope grade was estimated at the base of the wind turbine and recorded along with elevation as attributes when mapping the wind turbines using a Trimble Pathfinder Pro-XR GPS. For analysis, slope grade and elevation were lumped into ranges of values with fairly even distributions of wind turbine frequencies.

We also recorded the physical relief on which each wind turbine was situated, such as on ridge crests, ridgelines, slopes, saddles, peaks, or plateaus. Wind turbines were classified by whether they were in or out of three major canyons in the APWRA, although our "canyons" were really deeper, larger drainage basins as compared to the many ravines in the APWRA, and were not canyons in the usual sense of the term. Due to the complex topography of the APWRA, wind turbines could be classified as being on a ridge crest while also being inside a canyon, because peaks and ridge crests exist within the influence of canyons but of course at lower elevations than the canyon borders.

Our study area included three levels of rodent control intensity, which were attributed to the wind turbines. These were derived by interviews with the County staff person (Jim Smith) who conducted the rodent control program, for information on where and how chlorophacinone-treated oats were deployed across the APWRA. The levels of rodent control were none, intermittent, and intense. The intermittent control was applied to the land leased by EnXco, and consisted of the rancher applying poison bait on and around ground squirrel colonies on a less systematic and less frequent basis than applied elsewhere by Alameda County and some other ranchers.

### 8.2.3 Statistical Tests

Variables measured were tested for associations with the bird behaviors in chi-square analysis (Smallwood 1993). Statistical tests were performed only for the most commonly observed raptor species, because the results of tests involving small sample sizes are unreliable and we had enough bird species with larger sample sizes to recognize general inter-specific patterns. The species included in our more rigorous analyses reported herein include turkey vulture, red-tailed hawk, American kestrel, and golden eagle.

Chi-square tests were performed at two levels: across plots and across individual turbines. Observed values were either the number of minutes of activity of a particular behavior ($m_i$) or the number of behavioral events ($n_i$), and were related to expressed values for both statistical hypothesis testing and for deriving a measure of effect.

Expected values were based on sampling effort because sampling effort varied slightly among plots, strings, and wind turbines. Sampling effort was calculated as the following:

$e_{i,p}$ = number of sessions performed under the *i*th condition of the association variable;

$e_{i,s}$ = windswept area in turbine string ($m^2$) × number of sessions at corresponding plot under the *i*th condition of the association variable;

$e_{i,t}$ = rotor swept area of turbine ($m^2$) × number of sessions at corresponding plot under the *i*th condition of the association variable;

where e represents sampling effort, p represents the plot level of analysis, s represents the string level, and t represents the turbine level.

The expected values were calculated as a product of the total sample size of the dependent variable and the incidence (P), or relative frequency of occurrence, of the *i*th condition of the association variable:

$P_{i,p} = e_{i,p} \div S$;

$P_{i,s} = e_{i,s} \div \Sigma\, e_{i,s}$ ;

$P_{i,t} = e_{i,t} \div \Sigma\, e_{i,t}$ ;

where S is the total number of behavioral observation sessions, or 241 in this case.

The expected (E) number of minutes (M) of activity was then calculated as:

$E_p = M \times P_{i,p}$ ;

$E_s = M \times P_{i,s}$ ;

$E_t = M \times P_{i,t}$ .

And the expected number of events (N) of a specific type of behavior was calculated as:

$E_p = N \times P_{i,p}$ ;

$E_s = N \times P_{i,s}$ ;

$E_t = N \times P_{i,t}$ .

In many of our results we will state that a species "prefers" or "favors" a particular condition. We use this term in the statistical sense only, because we cannot know what an animal really prefers unless it communicates that sentiment to us directly. What we mean by preference is that a species occurred or performed some behavior more often or for longer than expected, which we assessed using either of two measures of effect.

### 8.2.4 Measures of Effect

In-depth examination of test results was based on two measures of effect. The first was the observed-divided–by-expected frequency of a particular behavior at the level or category of a measured variable, where the expected frequency of the behavior at that level or category was the frequency that would have resulted from a uniform or random distribution of that behavior throughout the measured set.

The second measure of effect was the percentage of total observations of a particular behavior that can be attributed to the independent variable's attribute, level, or category in question, and is measured as the following:

$$\text{Accountable Behavior} = (\text{Observed}_i - \text{Expected}_i) \div \text{Total observations of behavior} \times 100\%.$$

This measure is similar to the one used in Smallwood and Erickson (1995). Accountable behavior ranged from -100 to 100% of the total observations of the behavior attributable to a particular level or category of an association variable.

In this chapter we mostly report accountable behavior, because we are most interested in coming to a solution to the bird collision problem in the APWRA. Accountable behavior informs of the association variable's relative contribution to the total frequency of a particular behavior, and it does so by emphasizing the portion of the total observations of the behavior associated with an independent variable. Observed-divided-by-expected values, on the other hand, express the deviation of the observed from the expected value relative to the magnitude of the expected value, and neglects the association variable's relative contribution to the total frequency of the observed behavior. Both measures of effect are useful in this study, but accountable behavior, like accountable mortality in Chapter 3, puts the measure of effect in the context of the magnitude of the problem experienced in the APWRA.

## 8.3 RESULTS

### 8.3.1 Characteristics of the Observation Sessions

Most of the 30-minute sessions started between 0900 hours and 1700 hours, and the most common start time was mid-morning (Figure 8-3). The sessions peaked in frequency during January and were few during February due to wet, muddy roads in the APWRA (Figure 8-4). Most occurred during cool temperatures, from 55 to 65 ˚F (Figure 8-5).

The most frequent wind direction during the sessions was from the southwest, and northwest and north winds were also common (Figure 8-6). Most of the sessions were conducted during slow to modest wind speeds, mostly ranging from 5 to 20 kph (Figure 8-7). The average wind speed during these sessions was greatest when the winds blew from the southwest, followed by the west and northwest (Figure 8-8).

Special behaviors were noticed more quickly than other behaviors (Figure 8-9), with special behaviors reaching an asymptote in frequency of occurrence by about nine minutes and other behaviors doing so by about 20–27 minutes into the behavior observation sessions. Special behaviors included entry into and exit from study plots, as well as landings, diving, mating, flying through the wind turbine string, and a few others. That all behavior observations required 20 to 27 minutes before reaching an asymptote in frequency of occurrence suggests that 30 minutes was the minimum session time necessary for making behavior observations using the 360˚ visual scan approach.

We recorded observations of 10 raptor species during the 241 behavioral observation sessions, or 120.6 hours. Sightings averaged 2.48 raptors per observation session, or 4.96 raptors per hour, and we recorded 598 raptor sightings. We observed no raptors in 48 of the observation sessions.

### 8.3.2 Overall Raptor Use

We recorded 3,884 minutes of raptor activity, including 855 minutes spent flying (22%) and 3,029 minutes spent perching (78%). Half of the raptor observations were of raptors within 88 m of the wind turbines (Figure 8-10A). Nearly a third of the raptor perching observations were on wind turbines or their towers (Figure 8-10B).

Of 1,405 total flight observations recorded, 368 passed within 50 m of a wind turbine at the height domain of the rotor or below, and 153 passed through the rotor zone. The frequency of flights through the rotor zone of the wind turbine string was related more closely to the total number of minutes of flights recorded during the observation session (Figure 8-11A) than to the total number of minutes of perching (Figure 8-11B).

The average time raptors were observed flying was greatest during intermediate winds (Figure 8-12A), and the average time raptors were observed perching was greatest during slow winds (Figure 8-12B).

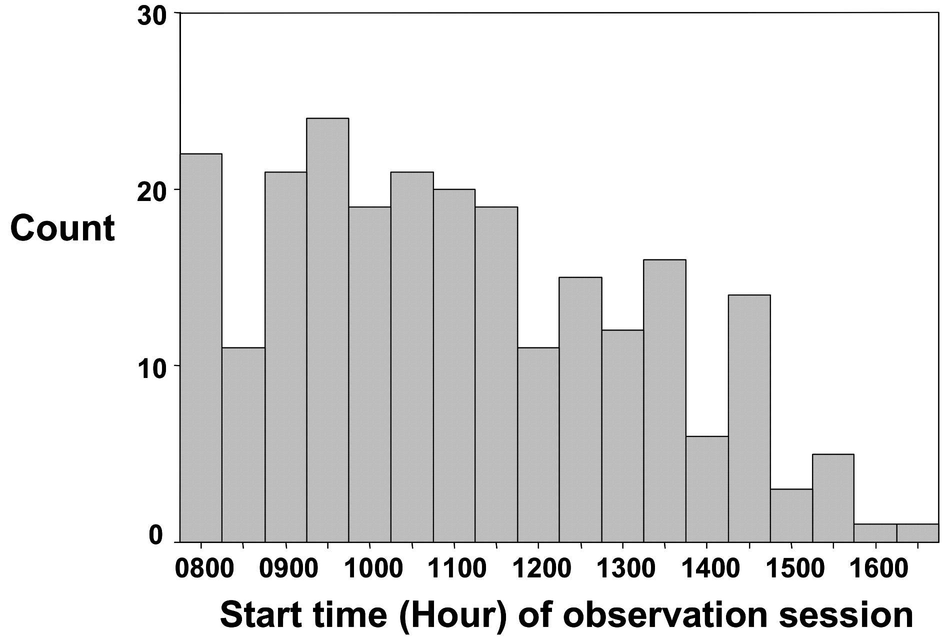



**Figure 8-3.** Frequency distribution of start times for the 241 behavioral observation sessions

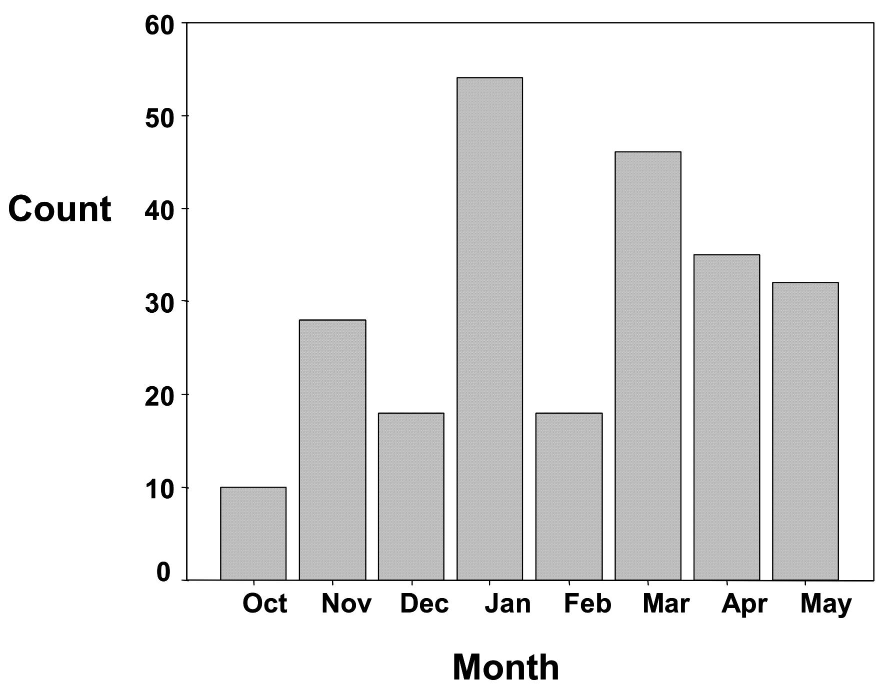



**Figure 8-4.** Frequency distribution of behavioral observation sessions among months of the year

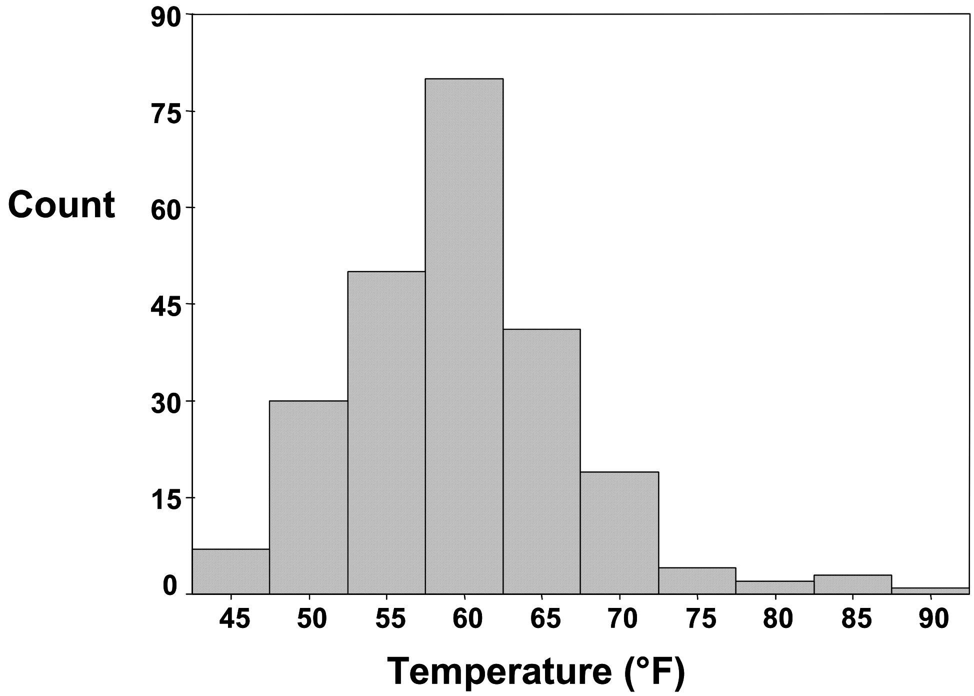



**Figure 8-5.** Frequency distribution of temperature at the start of 241 behavioral observation sessions

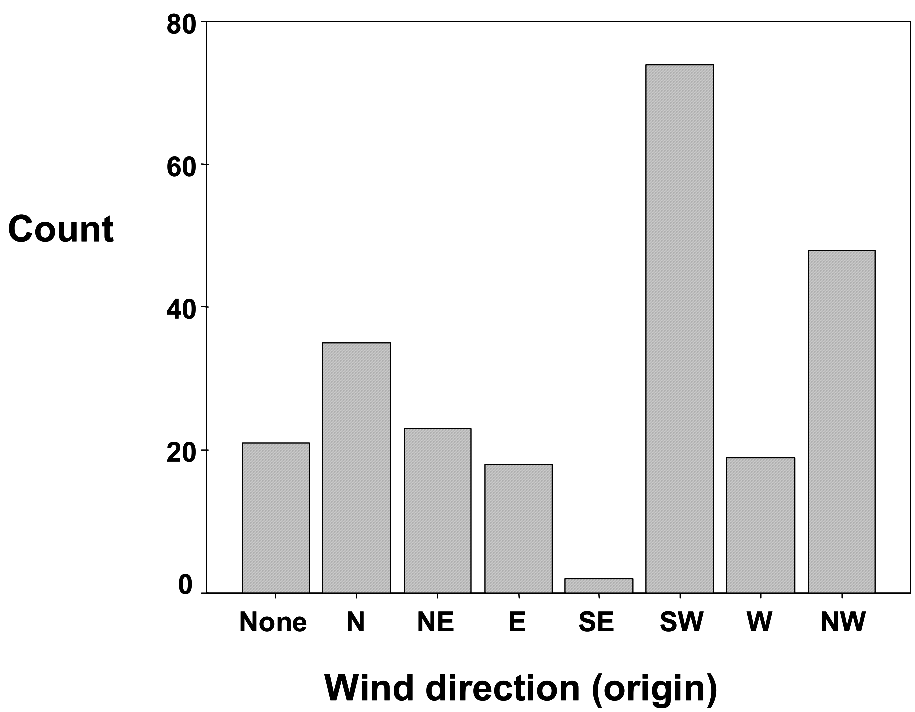



**Figure 8-6.** Frequency distribution of wind directions (origin) during behavioral observation sessions

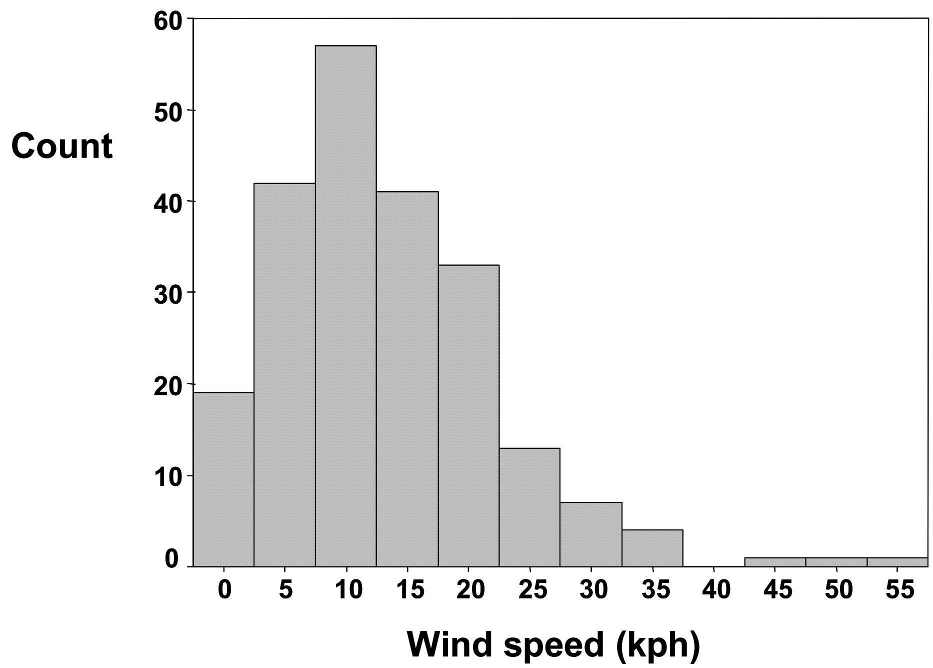



**Figure 8-7.** Frequency distribution of wind speeds among behavioral observation sessions

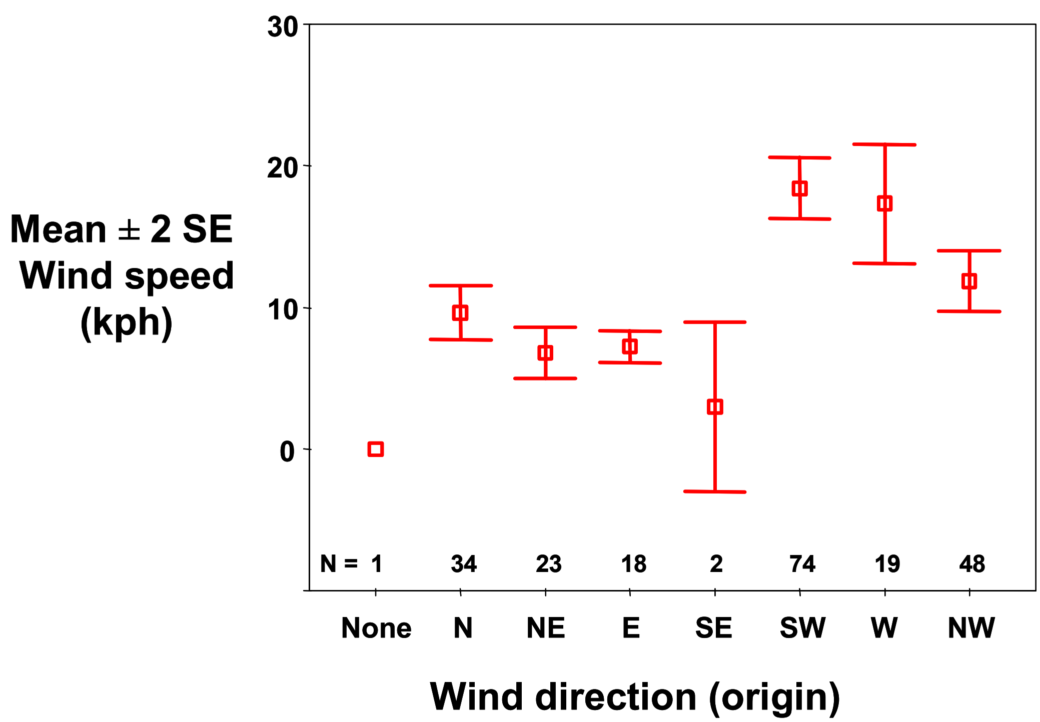
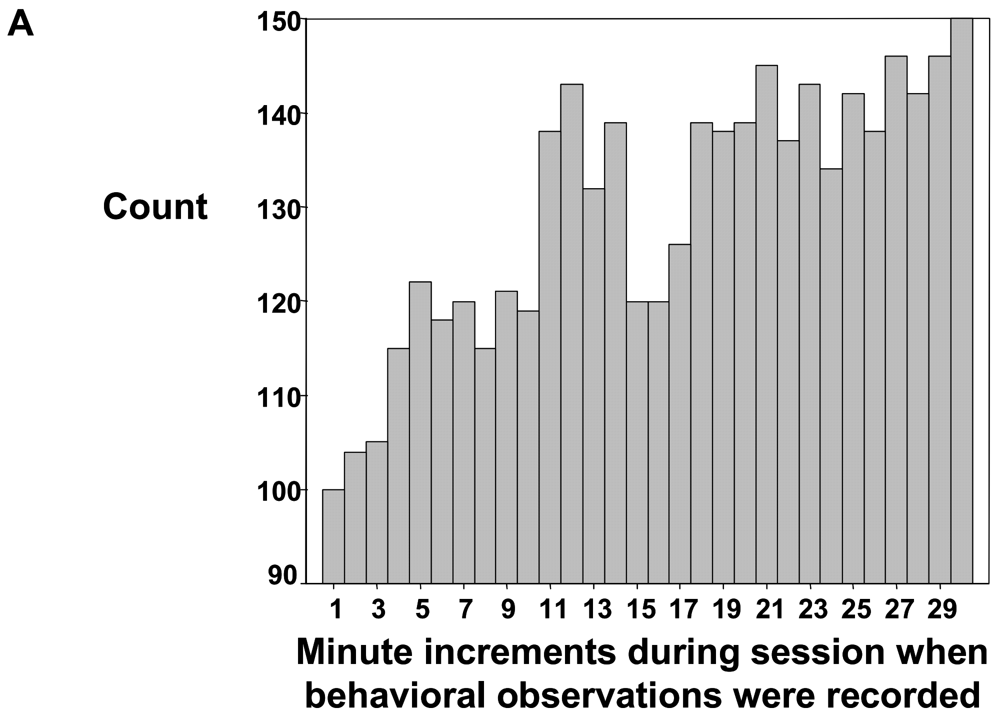



**Figure 8-8.** Wind speed during behavioral observation sessions as functions of direction of origin



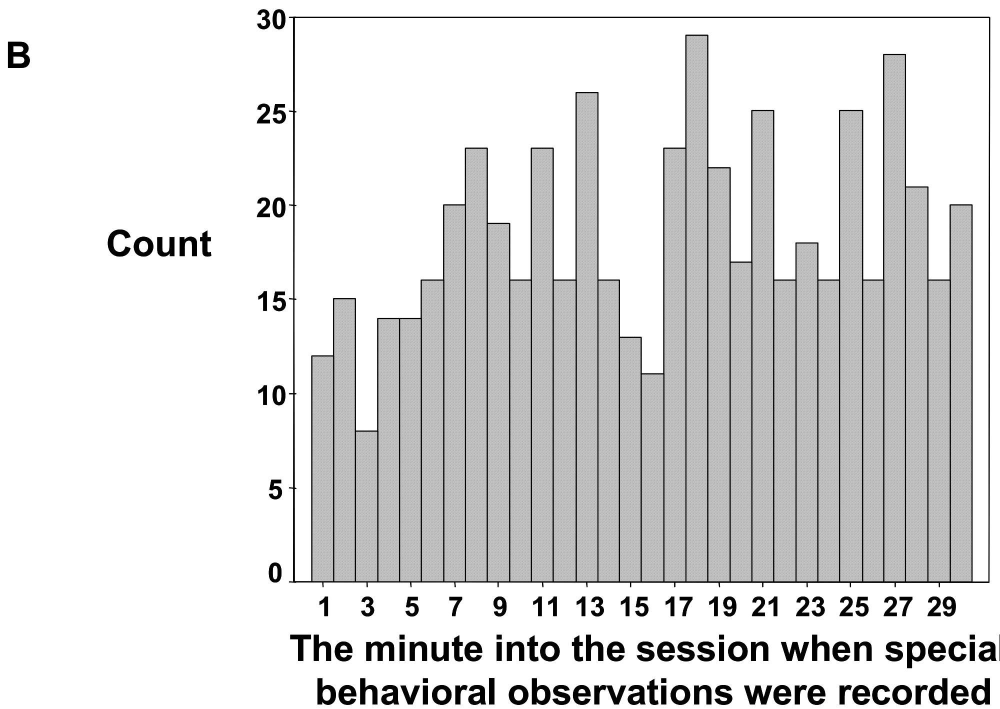
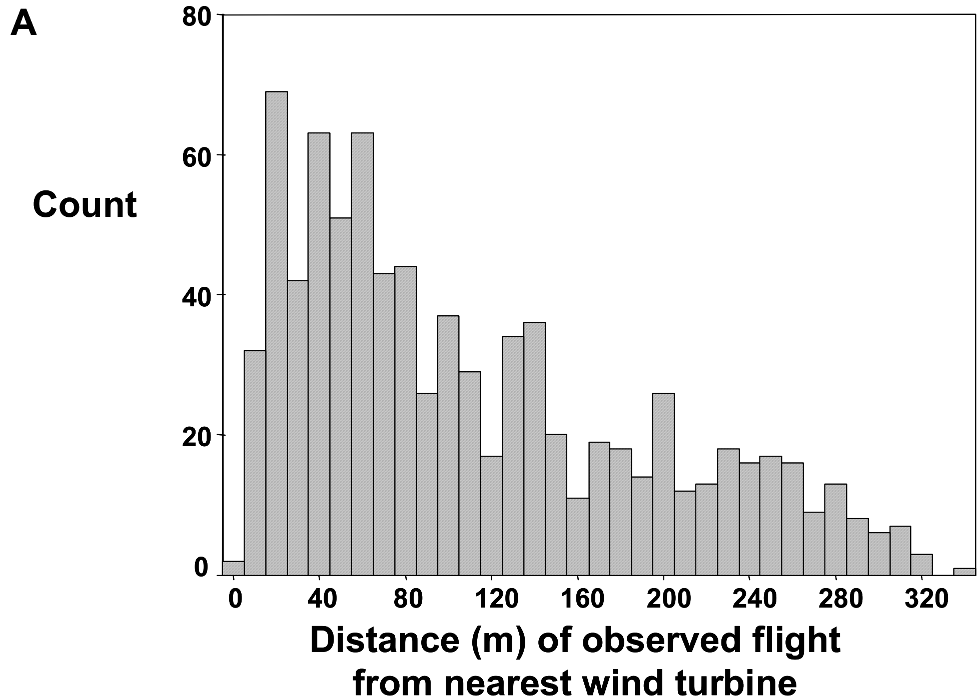




**Figure 8-9.** The by-the-minute frequency of behavioral observations increased with the number of minutes into the behavioral observation session and appeared to reach an asymptote by 25 minutes (A), whereas the frequency of special behavioral events (e.g., crossing the turbine string, entering or exiting the plot) appeared to increase only during the first 8 minutes of the session (B).



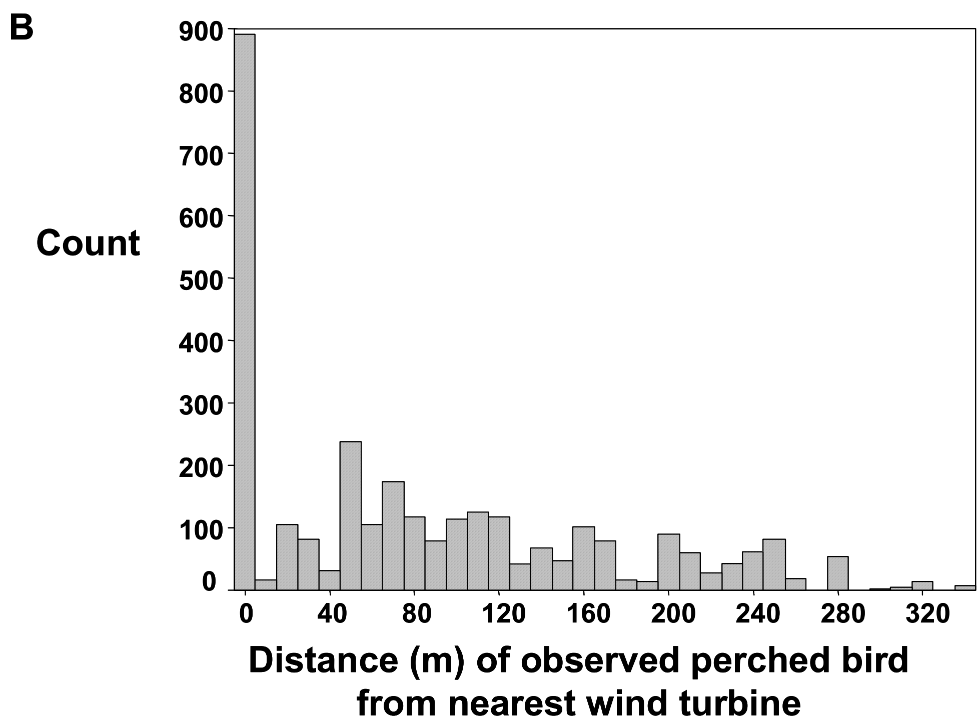




**Figure 8-10.** Frequency distribution of the distance to the nearest turbine recorded for raptors flying (A) and perching (B) during the behavioral observation sessions

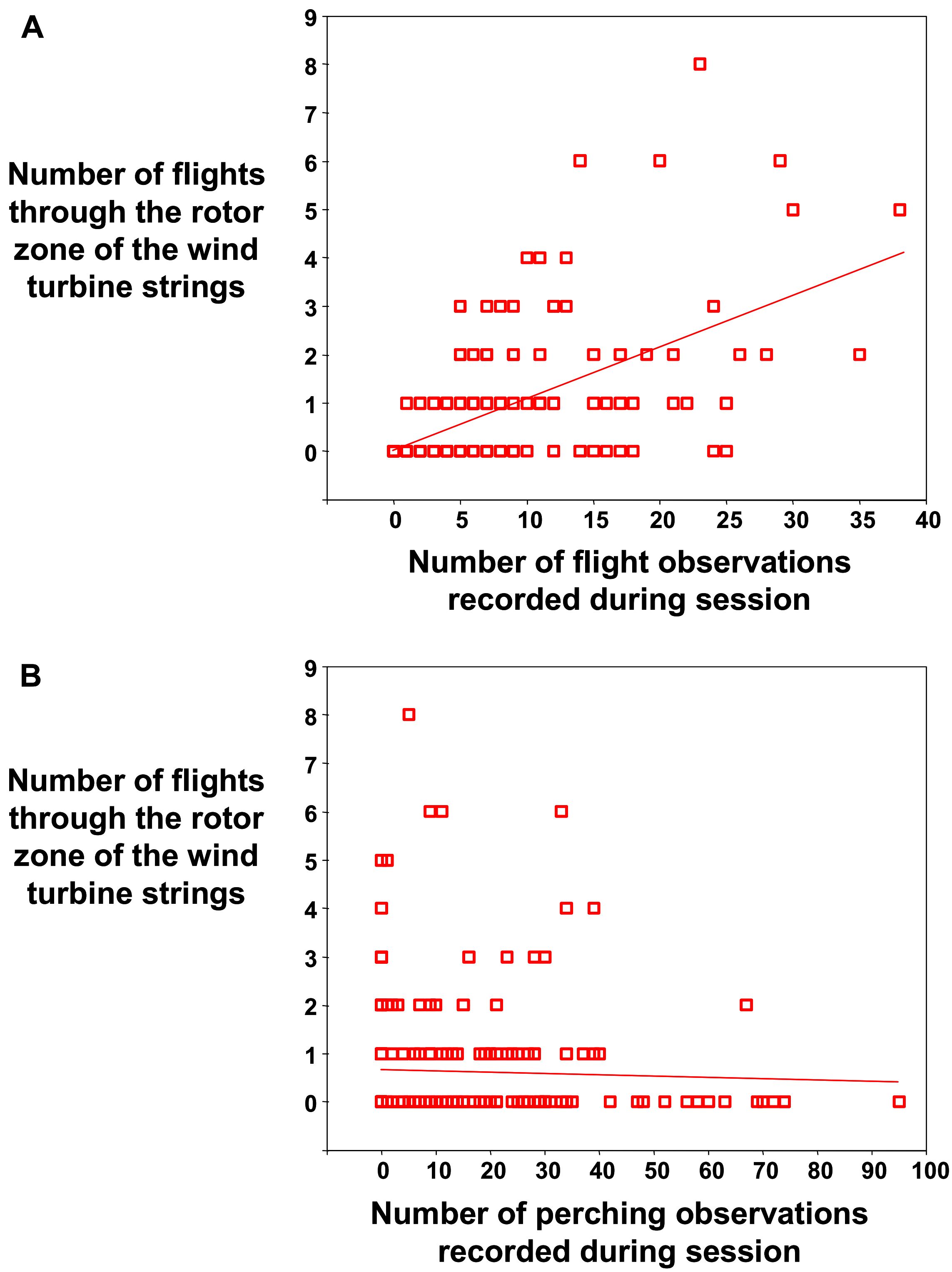
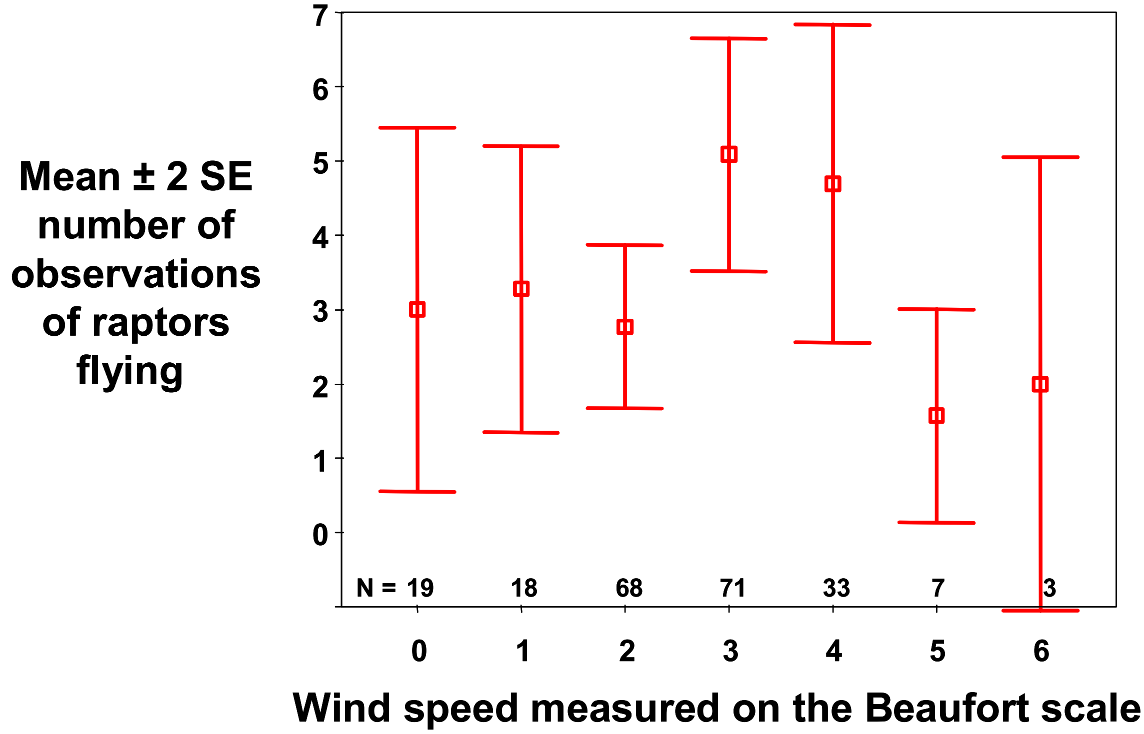



**Figure 8-11**. The number of passes of birds through the rotor zone increased with the number of observations of flights during the session (A), but not with the number of observations of perching (B)



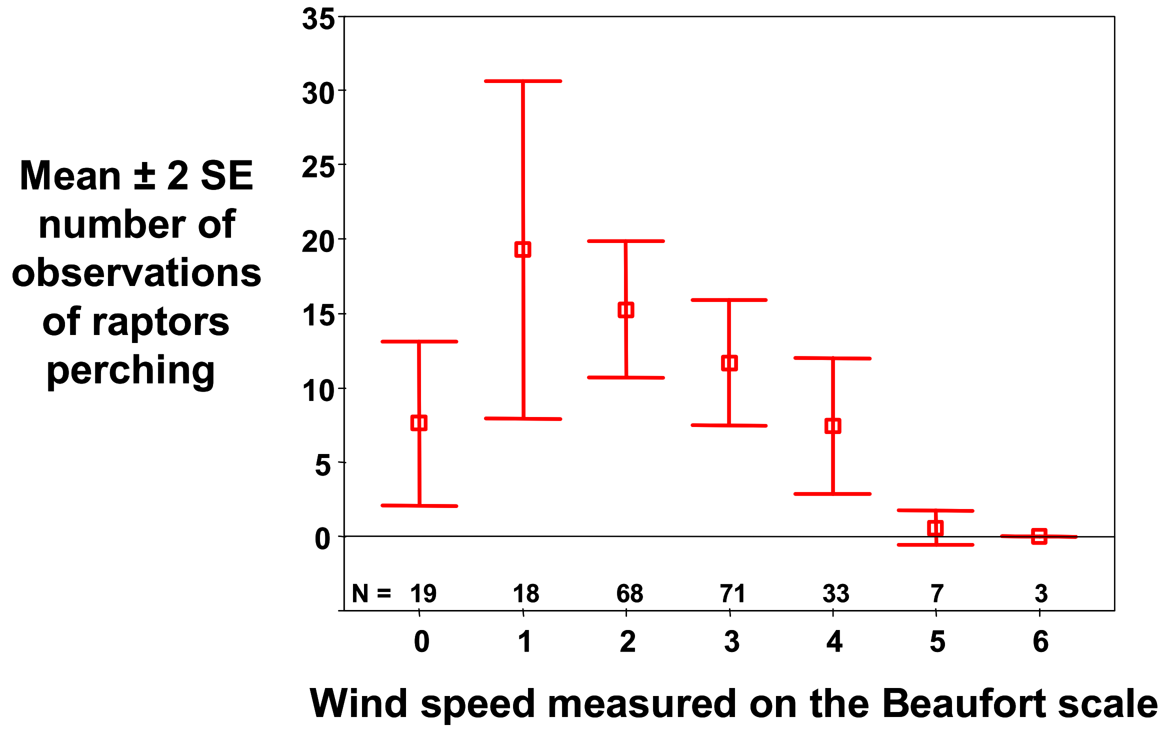




**Figure 8-12**. The average time raptors spent flying was greatest during intermediate winds (A), and the average time spent perching was greatest during slow winds (B)

Red-tailed hawk was one of the species most often observed in the APWRA and the species most often performing what we assumed to be more dangerous behaviors (Table 8-3). Other commonly observed raptors besides red-tailed hawks included turkey vulture, American kestrel, and golden eagle. Had our study extended into later spring and summer we likely would have seen more burrowing owls than we did.

We assumed that dangerous behaviors included flights through the turbine strings within the height domain of the blades, and we referred to these flights as *through the rotor zone* (rather than the rotor plane, which is specifically through the area swept by the blades). We also considered greater proximity to the turbines to be more dangerous, as well as the number of flights made within 50 m of the turbines. The species performing more of these dangerous behaviors included turkey vulture, red-tailed hawk, and American kestrel (Table 8-3).

Specific flight behaviors observed were mostly soaring, flying through the plot, and gliding, followed by surfing and hovering (Table 8-4). Wind turbines and their towers were commonly perched upon and for lengthy durations (Table 8-5). Other common perch structures included the ground and on power wires.

**Table 8-3.** Summary of behavioral activities by species

| Species | Scientific name | Sum of minutes | | Mean distance (m) to closest turbine | Mean flight height (m) above ground | Number of flights | |
|---|---|---|---|---|---|---|---|
| | | Flying | Perching | | | Through rotor zone | < 50 m to turbine |
| Turkey vulture | *Cathartes aura* | 229 | 1 | 126.4 | 66.4 | 73 | 83 |
| Golden eagle | *Aquila chrysaetos* | 35 | 115 | 162.7 | 84.4 | 4 | 9 |
| Red-tailed hawk | *Buteo jamaicensis* | 397 | 1,391 | 87.0 | 69.3 | 42 | 185 |
| Rough-legged hawk | *Buteo lagopus* | 0 | 30 | 0 | --- | 0 | 0 |
| Ferruginous hawk | *Buteo regalis* | 29 | 83 | 134.1 | 204.6 | 1 | 4 |
| Northern harrier | *Circus cyaneus* | 16 | 1 | 94.3 | 24.1 | 0 | 7 |
| Merlin | *Falco columbarius* | 2 | 0 | 71.9 | 196.8 | 1 | 2 |
| American kestrel | *Falco sparverius* | 116 | 1,103 | 73.9 | 23.4 | 23 | 66 |
| Prairie falcon | *Falco mexicanus* | 4 | 5 | 42.2 | 112.3 | 3 | 3 |
| Burrowing owl | *Athene cunicularia* | 0 | 180 | 119.9 | --- | 0 | 0 |
| **Raptors** | | **855** | **3,029** | **91.1** | **66.6** | **153** | **604** |

**Table 8-4**. Flight behaviors recorded per bird observation during 241 sessions, where AMKE = American kestrel, BUOW = burrowing owl, FEHA = ferruginous hawk, GOEA = golden eagle, MERL = merlin, NOHA = northern harrier, PRFA = prairie falcon, RLHA = rough-legged hawk, RTHA = red-tailed hawk, and TUVU = turkey vulture

| Flight behaviors observed within the 61 plots in the APWRA | Minutes of Flight Activity | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | RLHA | FEHA | NOHA | PRFA | AMKE | MERL | BUOW |
| Soaring | 121 | 27 | 3 | 78 | 0 | 8 | 1 | 0 | 2 | 0 | 0 |
| Column soaring | 140 | 16 | 5 | 105 | 0 | 11 | 4 | 0 | 0 | 1 | 0 |
| Flying through | 117 | 9 | 7 | 38 | 0 | 1 | 3 | 2 | 49 | 1 | 0 |
| Gliding | 267 | 164 | 17 | 57 | 0 | 9 | 6 | 0 | 0 | 4 | 0 |
| Surfing | 105 | 4 | 0 | 66 | 0 | 0 | 0 | 0 | 28 | 0 | 0 |
| Contouring | 18 | 7 | 1 | 4 | 0 | 0 | 4 | 0 | 1 | 0 | 0 |
| Circling/Searching | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kiting/Hovering | 52 | 0 | 0 | 27 | 0 | 0 | 0 | 0 | 25 | 0 | 0 |
| Fly-catching | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Diving | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ground hopping | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Display (interact) | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| Flocking | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Chase | 7 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| Mobbed/fleeing | 14 | 2 | 2 | 8 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Flushed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 8-5.** Perching behaviors recorded per bird observation during 241 sessions, where AMKE = American kestrel, BUOW = burrowing owl, FEHA = ferruginous hawk, GOEA = golden eagle, MERL = merlin, NOHA = northern harrier, PRFA = prairie falcon, RLHA = rough-legged hawk, RTHA = red-tailed hawk, and TUVU = turkey vulture

| Perch structures used within the 61 plots in the APWRA | Minutes of Perching | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | RLHA | FEHA | NOHA | PRFA | AMKE | MERL | BUOW |
| Ground, rock, shrub, fence | 596 | 1 | 56 | 243 | 0 | 28 | 0 | 0 | 73 | 0 | 180 |
| Electrical distribution pole | 384 | 0 | 0 | 294 | 0 | 0 | 0 | 2 | 59 | 0 | 0 |
| Transmission tower | 297 | 0 | 59 | 120 | 0 | 50 | 0 | 0 | 0 | 0 | 0 |
| Electric distribution line | 531 | 0 | 0 | 55 | 0 | 0 | 0 | 0 | 471 | 0 | 0 |
| Ancillary equipment | 170 | 0 | 0 | 80 | 0 | 0 | 0 | 0 | 90 | 0 | 0 |
| Wind turbine | 897 | 0 | 0 | 510 | 30 | 5 | 0 | 3 | 322 | 0 | 0 |
| Derelict wind turbine | 154 | 0 | 0 | 89 | 0 | 0 | 1 | 0 | 50 | 0 | 0 |

### 8.3.3 Association Analysis

Tables 8-6 through 8-10 summarize the chi-square tests of association between dependent variables and independent variables that express weather, time of day, and seasonal factors. These factors were measured and analyzed at the level of the observation plot. Table 8-11 summarizes the chi-square tests of association between dependent variables and proximity levels, which were analyzed at the wind turbine level. Tables 8-12 through 8-16 summarize the chi-square tests of association between dependent variables and independent variables that express attributes of the wind turbines and of the physiography and range conditions in the area where the turbines occur.

#### *Wind speed*

Raptors perched more often than expected by chance during slower wind speeds, which could account for 20% and 39% of red-tailed hawk and golden eagle perching time, respectively, although American kestrel did so during moderate wind speeds (Table 8-6). Raptors flew disproportionately more often during moderate wind speeds, which could account for 16%–26% of the flights observed for our focal species (Table 8-7).

Raptors tended to fly disproportionately lower to the ground during slow winds, and flew higher during moderate to high winds (Table 8-8). Though significant, the distance of raptors species from wind turbines did not display a clear pattern or gradient with wind speed (Table 8-9). However, dangerous flights, or those made within 50 m of the rotor zone, were observed disproportionately more often during moderate-fast wind speeds (Table 8-10).

#### *Wind Direction (origin)*

Golden eagles perched disproportionately longer during periods of no wind or when the winds blew from the north, whereas red-tailed hawks did so when winds blew from the east (Table 8-6). American kestrels also perched more often than expected by chance when no winds were blowing. Red-tailed hawks flew disproportionately more often during north and northwest winds, while turkey vultures did so during northwest winds and American kestrels did so during northwest and southwest winds (Table 8-7).

Turkey vultures flew disproportionately closer to the ground when no winds were blowing, and golden eagles did so during northeast winds, and red-tailed hawks and American kestrels did so during southwest winds (Table 8-8). Turkey vultures also flew disproportionately closer to wind turbines during periods of no winds, and golden eagles did so during northeast winds, and red-tailed hawks did so during southwest winds (Table 8-9). Turkey vultures performed disproportionately more of their dangerous flights during northwest winds, as did red-tailed hawks, but red-tailed hawks and American kestrels also did so during southwest winds (Table 8-10).

#### *Session Start Time*

Golden eagles perched disproportionately more often during the morning hours, but red-tailed hawks did so during the afternoon (Table 8-6). Most raptor species flew disproportionately more often during the noon period, although American kestrels did so during the late afternoon (Table

8-7). Raptors flew disproportionately closer to the ground and closer to wind turbines during the morning hours, and higher and farther from wind turbines after noon (Tables 8-8 and 8-9). The dangerous flights were observed disproportionately more often after noon for turkey vultures and red-tailed hawks, and after 16:00 hours for American kestrels (Table 8-10).

### *Month*

Raptors perched disproportionately more often during January (Table 8-6), and red-tailed hawks and American kestrels flew more often during November and spring, whereas turkey vultures flew more often than expected by chance during March (Table 8-7).

Golden eagles and American kestrels flew disproportionately closer to the ground and closer to wind turbines during mid to late spring (Tables 8-8 and 8-9), which is also when they made disproportionately more of their dangerous flights (Table 8-10). Red-tailed hawks made more of their dangerous flights during November and March, and turkey vultures did so during March and May.

### *Temperature*

Golden eagles and American kestrels perched more often than expected by chance during cooler temperatures, which was also more or less when they flew more often (Tables 8-6 and 8-7). Turkey vultures, golden eagles, and red-tailed hawks favored relatively cool temperatures for flying closer to the ground as well as closer to the wind turbines and when they made their dangerous flights (Tables 8-8 to 8-10).

### *Proximity Zone*

All raptors except turkey vulture perched more often than expected by chance within 50 m of wind turbines (Table 8-11). A turkey vulture was seen perching during only one minute sampling event, and so was not included in the species-specific analysis. Raptors also flew disproportionately more often within 50 m of wind turbines, as opposed to 100–300 m away, and they performed disproportionately more of their more dangerous flights within the height domain of the rotor zone within 50 m compared to 100–300 m away. As we found during the 1998–2000 behavior study, raptors favor flying and perching within close proximity to wind turbines compared to farther away.

Smallwood and Thelander (in review) reported that raptor species flew in the 50-m proximity zone 8–10 times more often than expected by chance, but that a potentially inherent error in data interpretation might have inflated these estimates of the magnitude of the effect by two-fold. This current behavior study removed the inherent error in data interpretation of the first study, and indeed we found that the magnitude of the measure of effect reduced by half. Regardless, as predicted in Smallwood and Thelander (in review), the apparent preference for the closest proximity zone to wind turbines remained.

**Table 8-6.** Chi-square tests of association between minutes of perching and independent variables expressing weather, time of day and seasonal factors; t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less time perching than expected of a uniform distribution, and positive values express longer time spent perching. *No test* indicates the sample size was insufficient for reliable statistical testing.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Wind speed (Beaufort scale) | 342.47** | No test | 72.98** | 239.94** | 213.07** |
| 0 (< 0.3 m/s) | -3 | | -9 | -2 | -8 |
| 1 (0.3 to 1.5 m/s) | 5 | | -8 | 6 | 5 |
| 2 (1.6 to 3.3 m/s) | 9 | | 39 | 14 | -4 |
| 3 (3.4 to 5.4 m/s) | -1 | | -4 | -10 | 15 |
| 4 (5.5 to 7.9 m/s) | -6 | | -14 | -4 | -3 |
| 5 (8 to 10.7 m/s) | -3 | | -3 | -3 | -3 |
| 6 (>10.8 m/s) | -1 | | -1 | -1 | -1 |
| Wind direction (origin) | 619.02** | No test | 182.96** | 494.05** | 145.54** |
| None | 5 | | 16 | 4 | 7 |
| North | 2 | | 36 | 4 | 0 |
| Northeast | -2 | | -10 | -2 | -5 |
| East | 8 | | -7 | 10 | 2 |
| South | 1 | | -1 | 3 | -1 |
| Southwest | -14 | | -8 | -16 | -7 |
| West | -3 | | -8 | -2 | -2 |
| Northwest | 3 | | -17 | -1 | 6 |
| Time of day (hour started) | 36.64** | No test | 54.40** | 47.65** | 40.18** |
| 0800 | -3 | | 12 | -3 | -3 |
| 1000 | -1 | | 14 | -6 | 2 |
| 1200 | 3 | | -27 | 5 | 3 |
| 1400 | 0 | | 5 | 4 | -4 |
| 1600 | 1 | | -4 | 0 | 2 |
| Month | 1043.30** | No test | 164.31** | 462.58** | 648.77** |
| October 2002 | -4 | | -4 | -4 | -3 |
| November 2002 | -1 | | -12 | 3 | -6 |
| December 2002 | 3 | | 17 | 0 | 4 |
| January 2003 | 18 | | -20 | 17 | 25 |
| February 2003 | 5 | | 17 | 0 | 6 |
| March 2003 | -10 | | -18 | -14 | -4 |
| April 2003 | -1 | | 7 | 6 | -10 |
| May 2003 | -10 | | 13 | -8 | -12 |
| Temperature (˚F) | 100.30** | No test | 134.08** | 56.05** | 117.21** |
| 40–49 | -2 | | -5 | -2 | 0 |
| 50–59 | 8 | | 7 | 1 | 13 |
| 60–69 | -3 | | -20 | 2 | -7 |
| 70–79 | -2 | | 21 | -3 | -4 |
| 80–89 | 0 | | -3 | 2 | -2 |

**Table 8-7.** Chi-square tests of association between minutes of flight and independent variables expressing weather, time of day and seasonal factors, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less flight time than expected of a uniform distribution, and positive values express longer flight time.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Wind speed (Beaufort scale) | 72.75** | 35.48** | 4.66 | 66.22** | 55.72** |
| 0 (< 0.3 m/s) | -2 | -5 | -3 | -5 | 2 |
| 1 (0.3 to 1.5 m/s) | -1 | -3 | -8 | -1 | -1 |
| 2 (1.6 to 3.3 m/s) | -9 | -7 | -1 | -6 | -24 |
| 3 (3.4 to 5.4 m/s) | 11 | 4 | 10 | 18 | 5 |
| 4 (5.5 to 7.9 m/s) | 3 | 12 | 0 | -4 | 21 |
| 5 (8 to 10.7 m/s) | -2 | 0 | 0 | -3 | -2 |
| 6 (> 10.8 m/s) | -1 | -1 | 2 | 0 | -1 |
| Wind direction (origin) | 126.58** | 46.02** | 11.94 | 73.27** | 25.89** |
| None | -6 | -9 | -3 | -7 | -1 |
| North | 5 | 0 | -9 | 9 | -7 |
| Northeast | -3 | -2 | -10 | -2 | -8 |
| East | -4 | -5 | -5 | -3 | -5 |
| South | -1 | -1 | -1 | -1 | -1 |
| Southwest | 0 | 4 | 9 | -2 | 12 |
| West | 0 | 3 | 6 | -2 | 1 |
| Northwest | 9 | 11 | 11 | 8 | 8 |
| Time of day (hour started) | 201.64** | 93.25** | 9.16 | 102.03** | 36.19** |
| 0800 | -11 | -12 | -11 | -13 | -8 |
| 1000 | -8 | -10 | 1 | -5 | -10 |
| 1200 | 18 | 26 | 19 | 17 | 4 |
| 1400 | 3 | -2 | -8 | 4 | 5 |
| 1600 | -1 | -3 | -1 | -3 | 10 |
| Month | 101.94** | 87.37** | 3.88 | 81.63** | 36.28** |
| October 2002 | -2 | -2 | -1 | -2 | -3 |
| November 2002 | 5 | -8 | 3 | 9 | 8 |
| December 2002 | -5 | -5 | -2 | -4 | -6 |
| January 2003 | -8 | -11 | -11 | -10 | -2 |
| February 2003 | 1 | 1 | 4 | 2 | -6 |
| March 2003 | 8 | 19 | 1 | 4 | 8 |
| April 2003 | 1 | -2 | 5 | 5 | -8 |
| May 2003 | 0 | 8 | 1 | -5 | 8 |
| Temperature (˚F) | 9.78 t | 29.60** | 5.55 | 10.98 t | 11.36* |
| 40–49 | -2 | 0 | -6 | -2 | -5 |
| 50–59 | -2 | -17 | 8 | 4 | 4 |
| 60–69 | 4 | 14 | 0 | -2 | 6 |
| 70–79 | 0 | 0 | -5 | 1 | -4 |
| 80–89 | 0 | 2 | 3 | -2 | -2 |

**Table 8-8.** Chi-square tests of association between mean flight height and independent variables expressing weather, time of day and seasonal factors, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express lower heights above the ground than expected of a uniform distribution, and positive values express higher flights.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Wind speed (Beaufort scale) | 147.07** | 1066.30** | 550.75** | 438.22** | 123.51** |
| 0 (< 0.3 m/s) | 0 | 2 | 0 | -4 | 1 |
| 1 (0.3 to 1.5 m/s) | -2 | 0 | -8 | -1 | -2 |
| 2 (1.6 to 3.3 m/s) | 1 | -8 | 23 | 10 | -6 |
| 3 (3.4 to 5.4 m/s) | 1 | 5 | -13 | 2 | 2 |
| 4 (5.5 to 7.9 m/s) | -3 | -5 | -5 | -5 | 8 |
| 5 (8 to 10.7 m/s) | 2 | 7 | 2 | -3 | -1 |
| 6 (> 10.8 m/s) | 0 | -1 | 2 | 1 | -1 |
| Wind direction (origin) | 237.20** | 639.58** | 578.10** | 659.58** | 330.28** |
| None | -2 | -9 | -2 | -1 | 4 |
| North | 3 | 1 | -3 | 5 | 2 |
| Northeast | -2 | 4 | -10 | -2 | -4 |
| East | 2 | -1 | 0 | 3 | -3 |
| South | -1 | -1 | -1 | 0 | -1 |
| Southwest | -3 | -1 | -4 | -12 | -12 |
| West | -1 | 2 | -2 | -3 | 0 |
| Northwest | 3 | 5 | 21 | 11 | 15 |
| Time of day (hour started) | 451.54** | 529.85** | 598.95** | 1221.50** | 294.80** |
| 0800 | -7 | -4 | -6 | -13 | -7 |
| 1000 | -1 | -8 | -21 | -6 | -3 |
| 1200 | 6 | 11 | 21 | 19 | -7 |
| 1400 | 4 | 5 | 9 | 2 | 15 |
| 1600 | -2 | -3 | -3 | -2 | 3 |
| Month | 966.32** | 779.53** | 651.47** | 520.99** | 1235.90** |
| October 2002 | 6 | 6 | 0 | 5 | -1 |
| November 2002 | 3 | -5 | 12 | 3 | 28 |
| December 2002 | -4 | -5 | -6 | -4 | 1 |
| January 2003 | -7 | 0 | 6 | -2 | -1 |
| February 2003 | 1 | 3 | 0 | 4 | -4 |
| March 2003 | 0 | 1 | -12 | -4 | -6 |
| April 2003 | 1 | -2 | -10 | 2 | -7 |
| May 2003 | 0 | 2 | 8 | -4 | -9 |
| Temperature (˚F) | 544.71** | 473.30** | 960.95** | 694.60** | 46.93** |
| 40–49 | -2 | 1 | -3 | -2 | -2 |
| 50–59 | -8 | -13 | 3 | 3 | 0 |
| 60–69 | 3 | 11 | -8 | -10 | 6 |
| 70–79 | 4 | -2 | -4 | 7 | -2 |
| 80–89 | 3 | 2 | 12 | 2 | -1 |

**Table 8-9.** Chi-square tests of association between mean distance from nearest wind turbine and independent variables expressing weather, time of day and seasonal factors, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express closer distances than expected of a uniform distribution, and positive values express farther distances.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Wind speed (Beaufort scale) | 298.67** | 807.90** | 1153.40** | 666.59** | 226.97** |
| 0 (< 0.3 m/s) | -2 | -5 | 0 | -2 | -2 |
| 1 (0.3 to 1.5 m/s) | -1 | 5 | -8 | -3 | 2 |
| 2 (1.6 to 3.3 m/s) | 2 | -2 | 22 | 7 | -2 |
| 3 (3.4 to 5.4 m/s) | 3 | -2 | -11 | 4 | 3 |
| 4 (5.5 to 7.9 m/s) | 0 | 5 | -4 | -4 | 2 |
| 5 (8 to 10.7 m/s) | -1 | 0 | -1 | -3 | -2 |
| 6 (> 10.8 m/s) | 0 | -1 | 3 | 0 | -1 |
| Wind direction (origin) | 375.89** | 1112.20** | 541.89** | 481.32** | 391.98** |
| None | -1 | -9 | -1 | 0 | 2 |
| North | 2 | 1 | 6 | 4 | 1 |
| Northeast | 2 | 1 | -10 | 2 | -4 |
| East | 1 | 0 | 1 | 0 | 1 |
| South | 0 | -1 | -1 | 0 | -1 |
| Southwest | -3 | -1 | 0 | -7 | -4 |
| West | -2 | 5 | -1 | -2 | -2 |
| Northwest | 1 | 3 | 5 | 4 | 7 |
| Time of day (hour started) | 528.31** | 1482.80** | 326.84** | 605.46** | 211.23** |
| 0800 | -3 | -11 | -8 | -4 | -1 |
| 1000 | 2 | -6 | -5 | 1 | -7 |
| 1200 | 6 | 10 | 6 | 8 | 4 |
| 1400 | -3 | 9 | 7 | -5 | 2 |
| 1600 | -1 | -2 | 0 | 0 | 2 |
| Month | 453.22** | 1605.40** | 773.57** | 763.10** | 1097.00** |
| October 2002 | 0 | 1 | -2 | -1 | -2 |
| November 2002 | 2 | -5 | 3 | 7 | 0 |
| December 2002 | -1 | -3 | -5 | 1 | 1 |
| January 2003 | -5 | -11 | 5 | -3 | 11 |
| February 2003 | 0 | -3 | 2 | 0 | -2 |
| March 2003 | 2 | 8 | -8 | -4 | 6 |
| April 2003 | 3 | 7 | -6 | 3 | -5 |
| May 2003 | -1 | 5 | 11 | -3 | -9 |
| Temperature (˚F) | 251.73** | 925.17** | 565.08** | 321.56** | 229.18** |
| 40–49 | -2 | -3 | -3 | -2 | 0 |
| 50–59 | -1 | -13 | 2 | 7 | 3 |
| 60–69 | 1 | 10 | -7 | -7 | 1 |
| 70–79 | 2 | 3 | 2 | 1 | -2 |
| 80–89 | 0 | 3 | 5 | 0 | -2 |

**Table 8-10**. Chi-square tests of association between flight time within 50 m of rotor zone and independent variables expressing weather, time of day and seasonal factors, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less close-by flight time than expected, and positive values express longer close-by flight time.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Wind speed (Beaufort scale) | 57.18** | 22.17** | 4.31 | 53.18** | 22.47** |
| 0 (< 0.3 m/s) | -3 | -1 | 4 | -5 | 2 |
| 1 (0.3 to 1.5 m/s) | -1 | -3 | -8 | -1 | -2 |
| 2 (1.6 to 3.3 m/s) | -12 | -7 | -19 | -10 | -23 |
| 3 (3.4 to 5.4 m/s) | 15 | -6 | 30 | 24 | 16 |
| 4 (5.5 to 7.9 m/s) | 3 | 17 | -3 | -3 | 10 |
| 5 (8 to 10.7 m/s) | -2 | 2 | -3 | -3 | -2 |
| 6 (> 10.8 m/s) | -1 | -1 | -1 | -1 | -1 |
| Wind direction (origin) | 72.16** | 28.92** | 10.37 | 39.44** | 18.15* |
| None | -6 | -9 | 2 | -7 | -3 |
| North | -1 | -6 | -15 | 2 | -7 |
| Northeast | -5 | -1 | -10 | -6 | -7 |
| East | -5 | -7 | -7 | -4 | -7 |
| South | -1 | -1 | -1 | -1 | -1 |
| Southwest | 8 | 5 | 3 | 10 | 15 |
| West | -1 | 3 | 25 | -4 | 3 |
| Northwest | 11 | 16 | 2 | 10 | 7 |
| Time of day (hour started) | 68.87** | 24.52** | 5.30 | 51.26** | 44.90** |
| 0800 | -11 | -10 | -14 | -14 | -8 |
| 1000 | -8 | -11 | 8 | -6 | -10 |
| 1200 | 11 | 18 | 18 | 11 | -4 |
| 1400 | 8 | 7 | -20 | 11 | 6 |
| 1600 | 1 | -4 | 7 | -3 | 16 |
| Month | 62.19** | 27.66** | 7.36 | 72.93** | 16.64* |
| October 2002 | -3 | -4 | -4 | -3 | -3 |
| November 2002 | 5 | -8 | -1 | 12 | 7 |
| December 2002 | -6 | -4 | 15 | -7 | -7 |
| January 2003 | -3 | -1 | -11 | -8 | 2 |
| February 2003 | -3 | -4 | 4 | -4 | -6 |
| March 2003 | 10 | 12 | -8 | 13 | 7 |
| April 2003 | 1 | -4 | 19 | 5 | -5 |
| May 2003 | -1 | 12 | -13 | -7 | 6 |
| Temperature (˚F) | 24.63** | 4.38 | 2.44 | 18.68** | 4.70 |
| 40–49 | -5 | -5 | -6 | -6 | -4 |
| 50–59 | 4 | -3 | 23 | 6 | 8 |
| 60–69 | 4 | 8 | -10 | 4 | 1 |
| 70–79 | -2 | 0 | -5 | -2 | -3 |
| 80–89 | -1 | 0 | -3 | -2 | -1 |

**Table 8-11.** Chi-square tests of association between dependent variables and proximity level to the wind turbines, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

| Dependent Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Minutes of perching | 6033.40** | No test | 54.19** | 3789.70** | 2132.20** |
| 0–50 m from turbines | 36 | | 17 | 44 | 33 |
| 51–100 m from turbines | 7 | | -11 | 3 | 18 |
| 101–300 m from turbines | -44 | | -5 | -46 | -50 |
| Minutes of flying | 781.57** | 148.64** | 9.99* | 431.14** | 212.51** |
| 0–50 m from turbines | 22 | 17 | 9 | 25 | 32 |
| 51–100 m from turbines | 13 | 13 | 12 | 13 | 16 |
| 101–300 m from turbines | -35 | -30 | -21 | -38 | -48 |
| Low flights (≤rotor zone) | 630.45** | 69.36** | 11.50* | 375.57** | 188.49** |
| 0–50 m from turbines | 25 | 15 | 12 | 30 | 32 |
| 51–100 m from turbines | 15 | 12 | 22 | 13 | 16 |
| 101–300 m from turbines | -39 | -27 | -34 | -43 | -48 |

### *Wind Turbine Model*

Golden eagles spent disproportionately more time perching amongst wind turbines at lower elevations, and these happened to be Micon, Windmatic, and Enertech wind turbines (Table 8-12). Red-tailed hawks perched more often than expected by chance near or on Flowind turbines. Raptors also spent disproportionately more time flying nearer to Flowind turbines than to most other turbine models, whereas American kestrels flew more often near KVS-33 turbines, golden eagle nearer Windmatic and Enertech turbines, and turkey vultures nearer Windmatic turbines (Table 8-13). Notably, golden eagles, red-tailed hawks, and American kestrels flew disproportionately less often nearer KCS-56 turbines.

Raptors flew disproportionately lower to the ground and closer to Bonus and KCS-56 turbines (Tables 8-14 and 8-15). However, the number of dangerous flights (i.e., those within 50 m of the rotor zone) made by raptors was disproportionately less in relation to these very same wind turbines (Table 8-16). Dangerous flights were disproportionately more common at Flowind turbines (note that many of these no longer operate).

### *Rotor Diameter*

Golden eagles perched and flew disproportionately more often near wind turbines with a smaller rotor diameter (Tables 8-12 and 8-13), likely because the Enertech turbines were located at the lower elevations where golden eagles preferred to perch. Turkey vultures and red-tailed hawks flew lower to the ground than expected by chance near wind turbines with larger rotor diameters (Table 8-14), and golden eagles and American kestrels also flew closer to these wind turbines (Table 8-15). However, golden eagles made disproportionately more dangerous flights near wind turbines with smaller rotor diameters (Table 8-16). Otherwise, clear patterns between dangerous flights and rotor diameter were few among raptor species.

### Tip Speed

Golden eagles and red-tailed hawks perched more often than expected by chance nearest wind turbines with slower tip speeds, and red-tailed hawks also flew disproportionately more often nearest these wind turbines (Tables 8-12 and 8-13). Turkey vultures, golden eagles, and American kestrels flew lower to the ground by wind turbines with faster tip speeds (Table 8-14), and all the focal raptors in our study flew disproportionately closer to wind turbines with faster tip speeds (Table 8-15). However, the dangerous behaviors were performed disproportionately nearer wind turbines with intermediate tip speeds (Table 8-16).

### Rotor Plane Swept Per Second

Golden eagles and red-tailed hawks perched and flew more often than expected by chance by wind turbines that swept less of the sky per second (Tables 8-12 and 8-13), but all our focal raptors flew closer to the ground near wind turbines that swept more of the sky per second (Table 8-14), and most flew disproportionately closer to turbines that swept the sky at intermediate rates (Table 8-15). All the raptors species in our study performed disproportionately more of their dangerous flights at wind turbines that swept the sky at the lowest rates (Table 8-16).

### Tower Type

Golden eagles preferred to perch near tubular towers, whereas red-tailed hawks did so near vertical axis towers (these tower types are very similar with regards to perching availability) (Table 8-12). All our focal raptor species spent disproportionately more time flying near vertical axis towers, perhaps because these do not operate as often in the APWRA (Table 8-13). Raptors also flew disproportionately lower to the ground near tubular towers, and they also flew closer to these towers (Tables 8-14 and 8-15). Disproportionately more of the dangerous flights were made near vertical axis towers (Table 8-16).

### Tower Height

Though chi-square tests were often significant, clear patterns between dependent variables and tower height were few, and the patterns we did recognize appeared to be highly correlated with tower type.

### Height of Low Blade Reach

The relationships observed for this variable also appeared to correlate strongly with tower type.

### Height of High Blade Reach

The relationships observed for this variable also appeared to correlate strongly with tower type.

### Derelict Turbines

Red-tailed hawks and American kestrels perched disproportionately more often on or near derelict wind turbines (Table 8-12). Red-tailed hawks performed disproportionately more of their dangerous flights by derelict wind turbines; and red-tailed hawks, golden eagles, and American kestrels did so by wind turbines next to derelict turbines (Table 8-16).

### Wind Walls

Golden eagles and red-tailed hawks perched disproportionately more often by wind turbines that were not part of wind walls; and golden eagles and American kestrels also flew more often by these turbines (Tables 8-12 and 8-13). Raptors flew disproportionately closer to the ground and closer to the wind turbines in wind walls (Tables 8-14 and 8-15), but most raptors performed disproportionately more of their dangerous flights near wind turbines that were not part of wind walls (Table 8-16).

### Position in String

All the focal raptors in our study perched and flew disproportionately more often nearer wind turbines at the ends of strings (Tables 8-12 and 8-13). However, at these turbines raptors also flew disproportionately higher and farther away than they did at wind turbines forming the interior of the turbine string (Tables 8-14 and 8-15). But despite these relationships connoting safer flights around end turbines, all the raptors in our study performed disproportionately more of their dangerous flights nearer wind turbines at the ends of the strings (Table 8-16).

### Location in Wind Farm

Raptors generally perched and flew disproportionately more often by wind turbines bordering the APWRA and local clusters of turbines within the APWRA (Tables 8-12 and 8-13). At these locations, most raptors flew disproportionately higher above the ground and farther from the wind turbines, while raptors in the interior of the APWRA flew lower to the ground and closer to the wind turbines (Tables 8-14 and 8-15). For most species, disproportionately more of their dangerous flights were made by wind turbines bordering local clusters of wind turbines or the edge of the APWRA (Table 8-16).

### Turbine Congestion

Raptor species perched and flew disproportionately more often by wind turbines that were more isolated from other wind turbines, or where the density of wind turbines was less (Tables 8-12 and 8-13). Golden eagles flew disproportionately lower to the ground where wind turbines were most densely distributed, and also where they were sparse (Table 8-14). Raptors also flew closer to wind turbines that were more densely distributed, but most likely this pattern was forced by the fact that any bird flying through a dense turbine field will necessarily be closer to wind turbines there (Table 8-15). Most raptor species performed disproportionately more of their dangerous flights in sparsely distributed turbine fields, the exception being golden eagle, which did so in relatively dense turbine fields (Table 8-16).

### Elevation

Golden eagles and red-tailed hawks preferred to perch at lower elevations in the APWRA, and American kestrels preferred to perch in the higher elevations (Table 8-12). Golden eagles flew disproportionately more often at lower elevations, red-tailed hawks at middle elevations, and American kestrels at highest elevations (Table 8-13). All the focal raptors except American kestrel flew disproportionately lower to the ground at higher elevations, and American kestrels did so at the lowest elevations (Table 8-14). Dangerous flights were made disproportionately more often by golden eagles at lowest elevations, red-tailed hawks at middle elevations, and American kestrels at highest elevations (Table 8-16).

### Physical Relief

Golden eagles and red-tailed hawks preferred to perch on slopes (Table 8-12). Red-tailed hawks flew preferentially over slopes and ridgelines, and American kestrels flew preferentially over ridge crests (Table 8-13). Raptors flew disproportionately lower to the ground when flying over ridge crests (Table 8-14), which is where most of them also flew disproportionately closer to wind turbines (Table 8-15). However, raptors generally made disproportionately more of their dangerous flights on slopes and ridgelines, and golden eagles also did so over peaks (Table 8-16).

### Canyons

Golden eagles, red-tailed hawks and American kestrels perched preferentially in canyons (Table 8-12), but they flew preferentially outside of canyons (Table 8-13). Nevertheless, flights inside canyons were disproportionately lower to the ground and for golden eagles they were closer to wind turbines (Tables 8-14 and 8-15). All the focal raptor species in our study made disproportionately more of their dangerous flights by wind turbines while within canyons (Table 8-16).

### Edge Index

Red-tailed hawks perched preferentially where wind turbines were surrounded by more vertical edge, or where the tower laydown area and access road cut deeply into the hillside (Table 8-12). All the focal raptors in our study flew disproportionately more often near wind turbines with lots of vertical edge (Table 8-13), and most flew lower to the ground but farther away from the wind turbines with these greater edge conditions (Tables 8-14 and 8-15). Nevertheless, all of the focal raptor species made disproportionately more of their dangerous flights near wind turbines with either some or lots of vertical edge around their bases (Table 8-16).

### Rock Piles

Golden eagles and red-tailed hawks preferred to perch where there were no rocks piled within 50 m of wind turbines (Table 8-12) and red-tailed hawks also preferred to fly where no such rocks were piled (Table 8-13). American kestrels, on the other hand, preferred to perch and fly where rocks had been piled near wind turbines. Red-tailed hawks flew disproportionately lower to the ground near wind turbines within 50 m of rock piles, and most focal raptors flew closer to these wind turbines (Tables 8-14 and 8-15). American kestrels made disproportionately more of their dangerous flights near wind turbines with rock piles nearby (Table 8-16).

### Rodent Control

Golden eagles and American kestrels perched more often than expected by chance in areas of intense rodent control, and red-tailed hawks did so in areas of intermittent control (Table 8-12). Turkey vultures flew disproportionately longer over areas where no control was implemented, but golden eagles did so where control was applied intermittently and American kestrels did so where rodent control was applied intensively (Table 8-13). Red-tailed hawks showed no discernable response to the rodent control program in terms of time spent flying.

Turkey vultures, golden eagles, and American kestrels flew disproportionately closer to the ground in areas of intense control, and red-tailed hawks did so in areas of intermittent rodent control (Table 8-14). All the focal raptor species in our study flew disproportionately closer to wind turbines in areas of intermittent rodent control, and golden eagles did so in areas of intense rodent control (Table 8-15). All the focal raptors also made disproportionately more of their dangerous flights in areas of intense rodent control (Table 8-16).

### Years of Past Rodent Control

Golden eagles perched longer than expected by chance in areas treated with rodent poisons for only one year, and avoided perching in areas treated for at least five years (Table 8-12). Time spent perching did not appear to relate to the duration of rodent control for the other focal raptor species. Time spent flying, however, was disproportionately greater in areas where no control had yet been applied for all species except American kestrel, which spent more time flying over areas treated for at least the past five years (Table 8-13).

Turkey vultures and golden eagles flew disproportionately lower to the ground in areas treated with rodent poisons for at least five years, and golden eagles and American kestrels did so in areas treated for only one year (Table 8-14). All focal raptor species flew disproportionately closer to wind turbines in areas that have undergone either one year or at least five years of rodent control (Table 8-15). American kestrels made disproportionately more of their dangerous flights near wind turbines in areas treated with rodent poison for at least five years (Table 8-16).

### Cattle Pats

Red-tailed hawks and American kestrels perched preferentially in areas where more cattle pats occurred near wind turbines, but golden eagles did so where cattle pats were sparse in the vicinity of wind turbines (Table 8-12). Turkey vultures flew disproportionately more often over areas where wind turbines had fewer cattle pats nearby, but golden eagles, red-tailed hawks, and American kestrels did so where there were many cattle pats nearby (Table 8-13).

Golden eagles flew disproportionately lower to the ground near wind turbines with many cattle pats nearby (Table 8-14), and turkey vultures, golden eagles, and American kestrels flew disproportionately closer to wind turbines with many cattle pats within 20 m of wind turbines (Table

8-15). Golden eagles, red-tailed hawks and American kestrels performed disproportionately more of their dangerous behaviors at wind turbines with many cattle pats nearby (Table 8-16).

### Cottontail Pellet Abundance

Golden eagles perched preferentially in areas where more cottontail pellets were counted at and near wind turbines (Table 8-12). Turkey vultures preferentially flew over areas where more cottontail pellets were counted at and near wind turbines, and golden eagles did so in areas where cottontail pellets occurred but were not numerous (Table 8-13).

Turkey vultures and golden eagles flew disproportionately lower to the ground where no cottontail pellets were counted at or near wind turbines (Table 8-14), and turkey vultures, golden eagles and red-tailed hawks flew closer to wind turbines in areas where no cottontail pellets were counted at or near wind turbines (Table 8-15). Only turkey vultures related to the abundance of cottontail pellets in terms of the number of dangerous flights made (Table 8-16). Turkey vultures made disproportionately more of their dangerous flights near wind turbines with abundant sign of cottontails, which probably means little ecologically.

### Vegetation Height

Golden eagles and red-tailed hawks perched preferentially in areas where the vegetation grew tallest around the wind turbines (Table 8-12), but red-tailed hawks flew disproportionately more often where the vegetation was shorter (Table 8-13). All the focal raptor species in our study flew disproportionately closer to the ground where the vegetation near wind turbines was taller (Table 8-14), and turkey vultures and golden eagles flew disproportionately closer to the wind turbines (Table 8-15). Turkey vultures and red-tailed hawks, however, made disproportionately more of their dangerous flights near wind turbines where the vegetation was the shortest, and golden eagles and American kestrels showed tendency to also make more of their dangerous flights in these conditions, but the statistical test results were non-significant (Table 8-16).

### Degree of Pocket Gopher Clustering at Wind Turbines

Though statistically significant, there was no clear pattern between the degree of pocket gopher clustering at wind turbines and the frequencies of red-tailed hawk and American kestrel perching (Table 8-12). Turkey vultures and red-tailed hawks flew disproportionately more often over areas where pocket gophers either did not occur near wind turbines or where they did not cluster at wind turbines (Table 8-13). Turkey vultures, golden eagles, and red-tailed hawks flew disproportionately lower to the ground where pocket gophers were most clustered at wind turbines, and American kestrels did so where no pocket gophers occurred (Table 8-14).

Where pocket gophers were more clustered at wind turbines, turkey vultures, golden eagles, red-tailed hawks, and American kestrels flew disproportionately closer to those same wind turbines (Table 8-15). However, turkey vultures and red-tailed hawks made disproportionately more of their dangerous flights near wind turbines with no clustering of gophers (Table 8-16).

### *Degree of Ground Squirrel Clustering at Wind Turbines*

Golden eagles and red-tailed hawks perched preferentially where ground squirrels were uniformly distributed within the 90-m sampling areas surrounding wind turbines (Table 8-12), and red-tailed hawks flew preferentially over areas lacking ground squirrels (Table 8-13). Golden eagles flew disproportionately lower to the ground where wind turbines either lacked ground squirrels nearby or where ground squirrel burrow systems were distributed uniformly out to 90 m (Table 8-14). Red-tailed hawks flew disproportionately lower to the ground where ground squirrels were clustered around wind turbines (Table 8-14).

Turkey vultures and golden eagles flew disproportionately closer to wind turbines that were in the midst of uniform ground squirrel burrow system distributions, red-tailed hawks did so where ground squirrels were clustered at wind turbines, and American kestrels did so where there were no ground squirrel burrows within 90 m of the turbines (Table 8-15). Where ground squirrels were most clustered around wind turbines, turkey vultures and American kestrels made disproportionately more of their dangerous flights by wind turbines, and red-tailed hawks did so where no ground squirrel burrow systems occurred within 90 m of wind turbines (Table 8-16).

### *Degree of Clustering of All Burrow Systems at Wind Turbines*

Golden eagles and red-tailed hawks perched preferentially where wind turbines lacked any burrow systems of the mammal species we searched for out to 90 m (Table 8-12), but turkey vultures flew disproportionately over areas with greatest clustering of all burrow systems at wind turbines (Table 8-13). American kestrels flew more often than expected by chance over areas where wind turbines lacked burrow systems of all the species we studied (Table 8-14).

Golden eagles flew disproportionately closer to the ground while near wind turbines with the greatest degree of clustering of burrow systems of all species, whereas turkey vultures, red-tailed hawks, and American kestrels did so near wind turbines with more modest levels of clustering (Table 8-14). Red-tailed hawks made disproportionately more of their dangerous flights near wind turbines with modest degrees of clustering of burrow systems of all species (Table 8-16).

### *Density of Pocket Gopher Burrow Systems ≤ 90 m from Wind Turbines*

Red-tailed hawks perched preferentially at or near wind turbines with highest densities of pocket gophers out to 90 m, and golden eagles and American kestrels did so where intermediate densities of gophers occurred (Table 8-12). Golden eagles flew more often than expected by chance near wind turbines with the highest densities of pocket gophers, and turkey vultures did so near wind turbines with the lowest gopher densities (Table 8-13). Red-tailed hawks and turkey vultures flew disproportionately lower to the ground where pocket gopher densities were highest, whereas golden eagles did so where gopher densities were lowest and American kestrels did so where gopher densities were intermediate (Table 8-14).

Turkey vultures flew disproportionately closer to wind turbines where pocket gopher densities were greater, and golden eagles did so where gopher densities were lowest (Table 8-15). Turkey vultures made disproportionately more of their dangerous flights near wind turbines with lowest densities of pocket gophers, and the frequencies of dangerous flights made by other focal species did not relate significantly with gopher density (Table 8-16).

### *Density of Ground Squirrel Burrow Systems ≤ 90 m from Wind Turbines*

Golden eagles and red-tailed hawks perched preferentially near wind turbines with highest densities of ground squirrel burrow systems (Table 8-12). However, red-tailed hawks flew preferentially near wind turbines that lacked ground squirrel burrow systems out to 90 m, and golden eagle flight time did not relate significantly to ground squirrel density (Table 8-13). Golden eagles and red-tailed hawks flew disproportionately closer to the ground near wind turbines with low to intermediate densities of ground squirrel burrow systems, and golden eagles flew disproportionately higher near wind turbines with the highest ground squirrel densities (Table 8-14).

Golden eagles, red-tailed hawks, and turkey vultures flew disproportionately closer to wind turbines with low to intermediate ground squirrel burrow system densities (Table 8-15). Red-tailed hawks and all raptor species combined made disproportionately more of their dangerous flights near wind turbines with no ground squirrel burrow systems out to 90 m (Table 8-16).

### *Density of All Burrow Systems ≤ 90 m from Wind Turbines*

Golden eagles, red-tailed hawks, American kestrels, and all raptor species combined perched more often than expected by chance on or near wind turbines with the highest densities of all fossorial mammal burrow systems combined (Table 8-12). American kestrels also flew disproportionately more often over these areas of higher burrow system density, but turkey vultures did so over areas lacking all burrow systems (Table 8-13).

At wind turbines with highest densities of burrow systems of all fossorial mammal species combined, golden eagles flew disproportionately higher and farther away, but red-tailed hawks and turkey vultures flew lower and closer to the wind turbines (Tables 8-14 and 8-15). Red-tailed hawks made disproportionately more of their dangerous flights near wind turbines with intermediate densities of burrow systems of all fossorial mammal species combined, and turkey vultures did so at lowest densities (Table 8-16).

**Table 8-12.** Chi-square tests of association between time spent perching and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less perching than expected by chance, and positive values express more perching.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Turbine model | 269.70** | No test | 533.83** | 279.84** | 20.01* |
| Micon | -1 | | 15 | -2 | -1 |
| Bonus | -2 | | -3 | 1 | 1 |
| Danwin | 0 | | -1 | -1 | 1 |
| Flowind | 6 | | -8 | 8 | 1 |
| Windmatic | 2 | | 24 | 0 | 0 |
| Enertech | 2 | | 16 | 6 | 0 |
| KCS-56 | -5 | | -39 | -10 | -3 |
| KVS-33 | -2 | | -4 | -3 | 0 |
| Rotor Diameter | 220.51** | No test | 329.82** | 255.12** | 24.05** |
| 13.5–14.8 | 4 | | 40 | 6 | 0 |
| 16.0 | -1 | | 15 | -2 | -1 |
| 17.2–17.8 | -1 | | -45 | -6 | 0 |
| 19.1–19.5 | 5 | | 5 | 12 | 4 |
| 23.4–25.2 | -6 | | -11 | -7 | -4 |
| 31.4–33.2 | -2 | | -4 | -3 | 0 |
| Blade tip speed (kph) | 59.25** | No test | 200.35** | 96.75** | 7.88* |
| 137.77–149.64 | 7 | | 63 | 12 | 4 |
| 173.77–194.69 | -1 | | -24 | -2 | -2 |
| 212.39–246.18 | -5 | | -39 | -10 | -3 |
| Rotor plane ($m^2$) swept/s | 195.98** | No test | 161.90** | 251.07** | 19.99** |
| 1499–1859 | 8 | | 47 | 13 | 0 |
| 2141 | 4 | | 9 | 8 | 5 |
| 2780–3287 | -10 | | -52 | -18 | -5 |
| 4014–5646 | -2 | | -4 | -3 | 0 |
| Tower type | 136.90** | No test | 12.28** | 142.23** | 2.01 |
| Vertical axis | 6 | | -8 | 8 | 1 |
| Tubular | -3 | | 11 | -2 | 1 |
| Lattice | -3 | | -3 | -7 | -2 |
| Tower height | 258.81** | No test | 23.91** | 177.31** | 20.55** |
| 14.0 | -2 | | -2 | -2 | -1 |
| 18.5 | 5 | | 16 | 0 | 5 |
| 24.0–25.2 | -10 | | -4 | -8 | -5 |
| 29.5–32.3 | 6 | | -8 | 8 | 1 |
| 36.9–43.1 | 1 | | -2 | 1 | 0 |

**Table 8-12. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| Height (m), low blade reach | 126.51** | No test | 85.50** | 125.37** | 41.93** |
| 4.0–5.1 | 4 | | -10 | 6 | 0 |
| 8.0–9.6 | -1 | | -27 | -8 | 5 |
| 11.1–14.85 | 3 | | 36 | 6 | 3 |
| 15.7–17.2 | -7 | | 3 | -5 | -8 |
| 25.2–34.2 | 1 | | -2 | 1 | 0 |
| Height (m), high blade reach | 113.45** | No test | 31.59** | 118.01** | 39.60** |
| 22.9–27.4 | 4 | | 14 | -2 | 4 |
| 29.5–33.6 | -1 | | -6 | 2 | -6 |
| 34.4 | 4 | | 9 | 8 | 5 |
| 36.9–52.0 | -7 | | -17 | -9 | -3 |
| Derelict turbines | 85.90** | No test | 7.73* | 78.34** | 28.48** |
| Away from derelict | -3 | | 6 | -5 | -2 |
| Derelict | 3 | | -3 | 4 | 3 |
| Next to derelict | 0 | | -3 | 1 | 0 |
| Wind wall | 11.52** | No test | 15.70** | 92.68** | 0.26 |
| Not in wind wall | 2 | | 12 | 8 | 1 |
| In wind wall | -2 | | -12 | -8 | -1 |
| Position in string | 2388.38** | No test | 168.08** | 1021.79** | 581.73** |
| End | 37 | | 51 | 36 | 31 |
| Edge of gap | -2 | | -9 | 0 | -2 |
| Interior | -35 | | -41 | -35 | -28 |
| Non-operational | 0 | | -1 | 0 | 0 |
| Location in wind farm | 90.61** | No test | 160.90** | 41.79** | 74.08** |
| Edge of farm | 3 | | 33 | -4 | 7 |
| Edge of local cluster | 4 | | 17 | 4 | 4 |
| Interior of wind farm | -6 | | -50 | 1 | -11 |
| Turbine congestion | 120.30** | No test | 25.18** | 53.31** | 56.02** |
| 0–12 within 300 m | 2 | | 12 | 4 | -4 |
| 13–24 within 300 m | 6 | | -19 | 3 | 6 |
| 25–36 within 300 m | -1 | | 0 | -1 | 4 |
| 37–72 within 300 m | -7 | | 6 | -7 | -7 |
| Elevation (m) | 154.19** | No test | 95.46** | 210.09** | 125.27** |
| 110–85 | -1 | | 7 | -1 | 0 |
| 160–135 | 3 | | 25 | 7 | -5 |
| 210–185 | 3 | | 11 | 10 | -3 |
| 260–235 | 1 | | -3 | -1 | 4 |
| 310–285 | -6 | | -13 | -5 | -4 |
| 360–335 | 3 | | -9 | -4 | 5 |
| 460–385 | -2 | | -19 | -4 | 3 |

**Table 8-12. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| Slope grade (degrees) | 74.45** | No test | 44.27** | 103.65** | 71.84** |
| 0 | -1 | | 2 | -2 | -2 |
| 2–5 | 2 | | -3 | 5 | 2 |
| 6–14 | -4 | | -20 | -3 | -8 |
| 15–58 | 2 | | 22 | 0 | 8 |
| Physical relief | 168.92** | No test | 131.10** | 257.57** | 76.03** |
| Peak | 1 | | -2 | 1 | 0 |
| Plateau | -4 | | 14 | -7 | -2 |
| Ridge crest | 0 | | -36 | -7 | 4 |
| Ridgeline | -3 | | -9 | -1 | -6 |
| Slope | 7 | | 38 | 16 | 0 |
| Saddle | -1 | | -4 | -4 | 3 |
| Ravine | 1 | | -1 | 1 | 1 |
| Canyon | 0.46 | No test | 13.62** | 4.67* | 2.80[t] |
| Not in canyon | 0 | | -12 | -2 | -2 |
| In canyon | 0 | | 12 | 2 | 2 |
| Slope aspect | 170.29** | No test | 18.98** | 125.17** | 57.75** |
| None (flat) | -1 | | -8 | -11 | 8 |
| East-Northeast | 3 | | 10 | 8 | -2 |
| South-Southeast | 4 | | 7 | 2 | 3 |
| West-Southwest | -3 | | -4 | -1 | -2 |
| North-Northwest | -3 | | -5 | 3 | -7 |
| Edge index at tower base | 177.45** | No test | 43.58** | 202.81** | 12.69* |
| No edge | -3 | | -4 | -4 | 0 |
| Some lateral edge | 3 | | 15 | 1 | 2 |
| Lots lateral edge | -5 | | -12 | -10 | 1 |
| Some vertical edge | -2 | | -8 | 1 | -4 |
| Lots vertical edge | 6 | | 9 | 12 | 2 |
| Rock piles ≤ 50 m away | 27.09** | No test | 16.26** | 35.02** | 6.17* |
| None | 4 | | 13 | 6 | -3 |
| One or more | -4 | | -13 | -6 | 3 |
| Rodent control through 2002 | 23.72** | No test | 43.74** | 8.17* | 12.36* |
| None | 0 | | 9 | -1 | 1 |
| Intermittent | -4 | | -28 | 4 | -5 |
| Intense | 4 | | 19 | -3 | 4 |
| Years of past rodent control | 23.91** | No test | 288.13** | 0.78 | 1.58 |
| 0 | 0 | | 9 | -1 | 1 |
| 1 | 2 | | 40 | 0 | -1 |
| 5 | -2 | | -49 | 1 | 0 |

**Table 8-12. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| Cattle pats 40 m from turbines | 76.90** | No test | 129.45** | 45.95** | 33.54** |
| 0 | -3 | | -8 | -2 | -4 |
| 1–9 | -4 | | 53 | -5 | -2 |
| 10–25 | 4 | | -33 | 3 | 4 |
| > 25 | 3 | | -12 | 5 | 2 |
| Cattle pats at turbines | 34.72** | No test | 164.87** | 79.57** | 42.89** |
| 0–2 | -4 | | 37 | -7 | -5 |
| 3–9 | 2 | | -32 | 6 | 5 |
| 10–25 | 1 | | -8 | -2 | 4 |
| > 25 | 1 | | 3 | 3 | -5 |
| Cottontails 40 m from turbines | 2.50 | No test | 105.43** | 13.89** | 21.13** |
| No pellets | 0 | | -25 | -3 | 5 |
| Some pellets | -1 | | 4 | 4 | -5 |
| Abundant pellets | 1 | | 21 | 0 | 0 |
| Cottontails at turbines | 35.75** | No test | 61.27** | 9.91* | 55.23** |
| No pellets | -1 | | -23 | -3 | -2 |
| Some pellets | 3 | | 4 | 3 | 7 |
| Abundant pellets | -2 | | 19 | 0 | -4 |
| Vegetation height (cm) | 12.42* | No test | 207.87** | 25.00** | 56.77** |
| 0–10 | -1 | | -17 | 1 | 1 |
| 11–20 | 0 | | -5 | -6 | -2 |
| 21–35 | 2 | | -30 | 4 | 8 |
| > 35 | -2 | | 52 | 2 | -7 |
| Pocket gopher clustering | 81.03** | No test | 263.89** | 51.61** | 111.58** |
| Obs/Exp in 15 m = 0 | 0 | | 87 | 1 | -9 |
| Obs/Exp in 15 m < 1.5 | 9 | | -16 | 6 | 16 |
| Obs/Exp in 15 m = 1.5–3.0 | -10 | | -37 | -15 | -5 |
| Obs/Exp in 15 m > 3 | 1 | | -34 | 7 | -1 |
| Ground squirrel clustering | 131.29** | No test | 43.65** | 147.37** | 23.68** |
| Obs/Exp in 15 m = 0 | -6 | | -28 | -3 | -11 |
| Obs/Exp in 15 m ≤ 1.14 | 17 | | 58 | 23 | 7 |
| Obs/Exp in 15 m > 1.14 | -11 | | -29 | -21 | 4 |
| Pocket gopher density ≤ 90 m | 148.88** | No test | 70.25** | 16.66** | 46.51** |
| 0–1.4/ha | -16 | | -42 | -1 | -13 |
| 1.41–3.5/ha | 15 | | 70 | -7 | 13 |
| > 3.5/ha | 1 | | -28 | 8 | 0 |
| Ground squirrel density ≤ 90 m | 54.59** | No test | 80.02** | 42.22** | 1.56 |
| 0/ha | -1 | | -17 | -6 | 0 |
| 0.01–5.99/ha | -8 | | -55 | -6 | -3 |
| ≥ 6/ha | 10 | | 71 | 12 | 2 |

**Table 8-12. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| Clustering of all burrows | 18.67** | No test | 81.47** | 15.50** | 2.79 |
| Obs/Exp in 15 m = 0–1.2 | 6 | | 71 | 7 | -3 |
| Obs/Exp in 15 m = 1.2–3.0 | -5 | | -50 | -7 | 4 |
| Obs/Exp in 15 m > 3 | -1 | | -21 | 1 | -1 |
| Density of all burrow systems | 105.27** | No test | 65.99** | 127.12** | 16.81** |
| < 5/ha | -10 | | -33 | -10 | -9 |
| 5–9/ha | -3 | | -34 | -13 | 7 |
| > 9/ha | 14 | | 67 | 23 | 2 |
| | | | | | |

**Table 8-13.** Chi-square tests of association between time spent flying and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less time flying than expected by chance, and positive values express more time flying.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | **Raptors** | **TUVU** | **GOEA** | **RTHA** | **AMKE** |
| Turbine model | 284.41** | 142.43** | 28.64** | 168.60** | 141.64** |
| Micon | 1 | 4 | -3 | -1 | -5 |
| Bonus | -9 | -16 | -3 | -4 | -12 |
| Danwin | 2 | -1 | -1 | 5 | 1 |
| Flowind | 11 | 11 | 9 | 12 | 13 |
| Windmatic | 4 | 8 | 10 | 2 | -1 |
| Enertech | -2 | 0 | 5 | -4 | -4 |
| KCS-56 | -7 | -2 | -17 | -8 | -10 |
| KVS-33 | 0 | -3 | -1 | -3 | 18 |
| Rotor Diameter | 48.83** | 41.51** | 12.21* | 48.50** | 111.75** |
| 13.5–14.8 | 2 | 7 | 15 | -2 | -5 |
| 16.0 | 1 | 4 | -3 | -1 | -5 |
| 17.2–17.8 | 0 | 1 | -5 | 1 | 5 |
| 19.1–19.5 | 4 | 0 | -8 | 11 | -6 |
| 23.4–25.2 | -7 | -9 | 2 | -7 | -7 |
| 31.4–33.2 | 0 | -3 | -1 | -3 | 18 |
| Blade tip speed (kph) | 23.35** | 2.41 | 4.21 | 13.16** | 40.78** |
| 137.77–149.64 | 1 | 5 | 7 | 1 | -15 |
| 173.77–194.69 | 6 | -3 | 10 | 7 | 26 |
| 212.39–246.18 | -7 | -2 | -17 | -8 | -10 |
| Rotor plane ($m^2$) swept/s | 82.00** | 59.65** | 8.30* | 27.98** | 106.00 |
| 1499–1859 | 14 | 22 | 22 | 9 | 3 |
| 2141 | -1 | -6 | -5 | 3 | -5 |
| 2780–3287 | -12 | -13 | -16 | -10 | -16 |
| 4014–5646 | 0 | -3 | -1 | -3 | 18 |
| Tower type | 136.04** | 43.14** | 4.45 | 77.07** | 33.42** |
| Vertical axis | 11 | 11 | 9 | 12 | 13 |
| Tubular | -5 | -13 | -7 | 0 | -16 |
| Lattice | -5 | 2 | -2 | -12 | 2 |
| Tower height | 144.17** | 42.18** | 10.03* | 76.36** | 31.02** |
| 14.0 | -1 | 0 | -2 | -1 | -2 |
| 18.5 | -4 | -6 | 14 | -7 | -3 |
| 24.0–25.2 | -4 | -3 | -19 | -3 | -7 |
| 29.5–32.3 | 11 | 11 | 9 | 12 | 13 |
| 36.9–43.1 | -2 | -2 | -2 | -1 | -1 |

**Table 8-13. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | **Raptors** | **TUVU** | **GOEA** | **RTHA** | **AMKE** |
| Height (m), low blade reach | 115.99** | 90.10** | 6.81 | 57.93** | 48.21** |
| 4.0–5.1 | 10 | 11 | 7 | 11 | 11 |
| 8.0–9.6 | -6 | -17 | -2 | -8 | 20 |
| 11.1–14.85 | -5 | -9 | 11 | 0 | -16 |
| 15.7–17.2 | 2 | 17 | -14 | -2 | -14 |
| 25.2–34.2 | -2 | -2 | -2 | -1 | -1 |
| Height (m), high blade reach | 101.05** | 85.72** | 2.52 | 60.05** | 8.86* |
| 22.9–27.4 | -5 | -6 | 12 | -7 | -5 |
| 29.5–33.6 | 15 | 27 | -6 | 15 | 1 |
| 34.4 | -1 | -6 | -5 | 3 | -5 |
| 36.9–52.0 | -9 | -15 | -1 | -11 | 10 |
| Derelict turbines | 5.22 [t] | 3.32 | 0.03 | 26.57** | 1.99 |
| Away from derelict | -2 | 2 | 1 | -5 | 1 |
| Derelict | 1 | -2 | 0 | 4 | -2 |
| Next to derelict | 1 | 0 | -1 | 1 | 1 |
| Wind wall | 9.81** | 0.03 | 4.78* | 4.59 | 7.68* |
| Not in wind wall | 4 | 0 | 12 | 4 | 8 |
| In wind wall | -4 | 0 | -12 | -4 | -8 |
| Position in string | 599.31** | 188.69** | 35.84** | 468.00** | 12.81* |
| End | 33 | 38 | 43 | 33 | 11 |
| Edge of gap | -3 | -2 | -3 | -2 | -7 |
| Interior | -33 | -35 | -39 | -37 | -3 |
| Non-operational | 2 | -1 | -1 | 6 | -1 |
| Location in wind farm | 162.64** | 51.06** | 7.67* | 130.73** | 0.83 |
| Edge of farm | 8 | 9 | 14 | 4 | 3 |
| Edge of local cluster | 10 | 10 | 6 | 15 | -1 |
| Interior of wind farm | -17 | -19 | -19 | -19 | -1 |
| Turbine congestion | 67.86** | 5.50 | 2.53 | 75.66** | 33.28** |
| 0–12 within 300 m | 8 | 3 | -1 | 13 | 4 |
| 13–24 within 300 m | 2 | -7 | 9 | 1 | 22 |
| 25–36 within 300 m | -4 | 3 | 3 | -6 | -12 |
| 37–72 within 300 m | -7 | 1 | -10 | -8 | -14 |
| Elevation (m) | 32.24** | 40.81** | 3.85 | 49.58** | 68.93** |
| 110–85 | 1 | 4 | 7 | -3 | -8 |
| 160–135 | -6 | 0 | 8 | -10 | -10 |
| 210–185 | 0 | -3 | -3 | 5 | -10 |
| 260–235 | 2 | 1 | -1 | 4 | 4 |
| 310–285 | 2 | 11 | -7 | 1 | -8 |
| 360–335 | 2 | -3 | -3 | 3 | 7 |
| 460–385 | -1 | -10 | -2 | -1 | 25 |

**Table 8-13. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Slope grade (degrees) | 51.85** | 5.52 | 2.91 | 53.18** | 17.13** |
| 0 | -8 | -5 | -5 | -10 | -12 |
| 2–5 | -1 | -2 | -1 | -2 | -3 |
| 6–14 | -2 | 5 | -7 | -5 | 0 |
| 15–58 | 11 | 2 | 13 | 17 | 16 |
| Physical relief | 66.06** | 33.88** | 5.37 | 83.57** | 8.89 |
| Peak | -1 | -1 | 4 | -1 | -2 |
| Plateau | -3 | 4 | -4 | -6 | -5 |
| Ridge crest | -10 | -15 | -8 | -15 | 6 |
| Ridgeline | 3 | -3 | 3 | 8 | 4 |
| Slope | 11 | 13 | 3 | 15 | -2 |
| Saddle | 0 | 2 | 4 | -1 | -1 |
| Ravine | 0 | 0 | -1 | 0 | -1 |
| Canyon | 16.25** | 10.58** | 0.16 | 4.23* | 2.26 |
| Not in canyon | 5 | 8 | 2 | 4 | 5 |
| In canyon | -5 | -8 | -2 | -4 | -5 |
| Slope aspect | 79.47** | 10.99* | 0.80 | 93.78** | 15.96** |
| None (flat) | -10 | -8 | 0 | -18 | 11 |
| East-Northeast | 7 | 4 | 3 | 11 | -6 |
| South-Southeast | -1 | 6 | -4 | -5 | -7 |
| West-Southwest | 2 | 1 | -1 | 4 | -4 |
| North-Northwest | 3 | -2 | 2 | 8 | 6 |
| Edge index at tower base | 59.10** | 22.89** | 1.25 | 47.83** | 6.37 |
| No edge | 0 | 2 | -2 | -1 | 0 |
| Some lateral edge | -3 | -6 | -4 | -3 | 0 |
| Lots lateral edge | -9 | -7 | -3 | -13 | -7 |
| Some vertical edge | 4 | 3 | 5 | 8 | -2 |
| Lots vertical edge | 8 | 8 | 3 | 9 | 9 |
| Rock piles ≤ 50 m away | 9.50** | 1.98 | 0.00 | 13.38** | 4.10* |
| None | 4 | 3 | 0 | 7 | -9 |
| One or more | -4 | -3 | 0 | -7 | 9 |
| Rodent control through 2002 | 32.49** | 27.35** | 2.62 | $4.91^{t}$ | 7.78* |
| None | 6 | 11 | 3 | 3 | -4 |
| Intermittent | -7 | -12 | 10 | -4 | -9 |
| Intense | 1 | 1 | -13 | 1 | 13 |
| Years of past rodent control | 29.78** | 19.80** | 1.33 | 8.13* | 9.15* |
| 0 | 6 | 11 | 3 | 4 | -4 |
| 1 | -3 | -2 | 4 | -3 | -7 |
| 5 | -3 | -9 | -10 | 0 | 10 |

**Table 8-13. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Cattle pats 40 m from turbines | 38.83** | 10.03* | 5.51 | 30.77** | 16.26** |
| 0 | 0 | 4 | -8 | 1 | -5 |
| 1–9 | -1 | 3 | 6 | -6 | -1 |
| 10–25 | -6 | -8 | -6 | -4 | -5 |
| > 25 | 7 | 2 | 9 | 9 | 11 |
| Cattle pats at turbines | 4.52 | 22.72** | 2.28 | 35.54** | 4.15 |
| 0–2 | 0 | 8 | -1 | -3 | -3 |
| 3–9 | -2 | 6 | 11 | -7 | -6 |
| 10–25 | -1 | -3 | -10 | -2 | 7 |
| > 25 | 3 | -10 | -1 | 12 | 2 |
| Cottontails 40 m from turbines | 12.98** | 9.86* | 3.99 | 8.06* | 7.17* |
| No pellets | -5 | -7 | -15 | -5 | 10 |
| Some pellets | 4 | 3 | 11 | 6 | -7 |
| Abundant pellets | 1 | 4 | 4 | 0 | -3 |
| Cottontails at turbines | 16.51** | 31.49** | 6.96* | 3.60 | 0.83 |
| No pellets | -4 | -11 | -18 | 2 | 2 |
| Some pellets | 0 | 1 | 17 | -3 | 0 |
| Abundant pellets | 4 | 10 | 1 | 1 | -2 |
| Vegetation height (cm) | 39.14** | 38.74** | 2.40 | 15.93** | 1.18 |
| 0–10 | 3 | 6 | 3 | 3 | 4 |
| 11–20 | 4 | 8 | 6 | 0 | -1 |
| 21–35 | 2 | 2 | -12 | 5 | -2 |
| > 35 | -9 | -16 | 3 | -8 | 0 |
| Pocket gopher clustering | 30.85** | 36.27** | 0.04 | 30.74** | 2.31 |
| Obs/Exp in 15 m = 0 | 9 | 9 | -1 | 14 | -14 |
| Obs/Exp in 15 m < 1.5 | 3 | 14 | 0 | -5 | 4 |
| Obs/Exp in 15 m = 1.5–3.0 | 3 | -4 | 2 | 8 | 7 |
| Obs/Exp in 15 m > 3 | -15 | -19 | -1 | -17 | 4 |
| Ground squirrel clustering | 43.63** | 29.26** | 0.18 | 59.01** | 8.60* |
| Obs/Exp in 15 m = 0 | 16 | 8 | 5 | 29 | -23 |
| Obs/Exp in 15 m ≤ 1.14 | -14 | -24 | 1 | -15 | 28 |
| Obs/Exp in 15 m > 1.14 | -2 | 16 | -6 | -13 | -6 |
| Pocket gopher density ≤ 90 m | 9.18* | 35.68** | 4.81 [t] | 0.47 | 0.96 |
| 0–1.4/ha | 5 | 18 | -25 | 0 | -7 |
| 1.41–3.5/ha | 3 | 8 | 4 | -2 | 9 |
| > 3.5/ha | -8 | -26 | 21 | 2 | -2 |
| Ground squirrel density ≤ 90 m | 61.25** | 7.13* | 2.62 | 72.98** | 8.69* |
| 0/ha | 16 | 9 | 2 | 25 | -8 |
| 0.01–5.99/ha | -12 | -4 | -22 | -15 | -19 |
| ≥ 6/ha | -5 | -5 | 20 | -11 | 27 |

**Table 8-13. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Clustering of all burrows | 1.10 | 6.19* | 0.23 | 0.84 | 6.48* |
| Obs/Exp in 15 m = 0–1.2 | -1 | -10 | 2 | 1 | 23 |
| Obs/Exp in 15 m = 1.2–3.0 | -1 | 6 | 4 | -3 | -11 |
| Obs/Exp in 15 m > 3 | 2 | 4 | -6 | 3 | -11 |
| Density of all burrow systems | 21.26** | 45.70** | 3.70 | 5.37* | 7.93* |
| < 5/ha | 12 | 31 | -28 | 8 | -28 |
| 5–9/ha | -6 | -19 | 11 | 0 | 18 |
| > 9/ha | -6 | -12 | 16 | -7 | 10 |

**Table 8-14.** Chi-square tests of association between flight height and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express lower heights above the ground than expected by chance, and positive values express higher flights.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Turbine model | 3325.05** | 6040.01** | 20739.30** | 1340.39** | 1154.08** |
| Micon | 5 | 6 | -3 | 1 | -1 |
| Bonus | -6 | -13 | -6 | -5 | -4 |
| Danwin | -1 | -1 | -1 | -1 | 1 |
| Flowind | 6 | 15 | -1 | 4 | 16 |
| Windmatic | 2 | 5 | 35 | 2 | 0 |
| Enertech | 1 | 1 | -5 | 0 | 0 |
| KCS-56 | -4 | -9 | -16 | 2 | -12 |
| KVS-33 | -3 | -3 | -3 | -3 | 0 |
| Rotor Diameter | 2109.47** | 1820.92** | 3499.43** | 792.18** | 48.74** |
| 13.5–14.8 | 3 | 6 | 30 | 2 | 0 |
| 16.0 | 5 | 6 | -3 | 1 | -1 |
| 17.2–17.8 | 0 | -1 | -15 | 5 | 6 |
| 19.1–19.5 | 2 | 3 | -6 | -1 | -2 |
| 23.4–25.2 | -6 | -9 | -3 | -5 | -3 |
| 31.4–33.2 | -3 | -3 | -3 | -3 | 0 |
| Blade tip speed (kph) | 673.49** | 404.35** | 680.93** | 159.55** | 360.60** |
| 137.77–149.64 | 8 | 8 | 23 | 3 | -2 |
| 173.77–194.69 | -4 | 2 | -7 | -5 | 14 |
| 212.39–246.18 | -4 | -9 | -16 | 2 | -12 |
| Rotor plane ($m^2$) swept/s | 2760.68** | 3918.69** | 1018.93** | 727.03** | 368.56** |
| 1499–1859 | 13 | 27 | 26 | 8 | 15 |
| 2141 | 1 | -4 | -3 | 0 | -1 |
| 2780–3287 | -11 | -20 | -20 | -4 | -14 |
| 4014–5646 | -3 | -3 | -3 | -3 | 0 |
| Tower type | 1234.21** | 3431.77** | 137.13** | 377.19** | 1098.08** |
| Vertical axis | 6 | 15 | -1 | 4 | 16 |
| Tubular | -2 | -8 | -10 | -5 | -4 |
| Lattice | -4 | -7 | 11 | 0 | -12 |
| Tower height | 1605.70** | 3632.52** | 1189.58** | 675.64** | 1169.01** |
| 14.0 | -1 | -1 | -2 | -2 | -2 |
| 18.5 | -4 | -6 | 29 | 0 | -2 |
| 24.0–25.2 | 1 | -6 | -24 | -1 | -13 |
| 29.5–32.3 | 6 | 15 | -1 | 4 | 16 |
| 36.9–43.1 | -1 | -2 | -2 | -1 | 1 |

**Table 8-14. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Height (m), low blade reach | 2666.27** | 3969.48** | 714.53** | 744.81** | 733.34** |
| 4.0–5.1 | 5 | 14 | -3 | 2 | 14 |
| 8.0–9.6 | -10 | -15 | -3 | -5 | -2 |
| 11.1–14.85 | -4 | -8 | 22 | -4 | -3 |
| 15.7–17.2 | 10 | 12 | -14 | 8 | -10 |
| 25.2–34.2 | -1 | -2 | -2 | -1 | 1 |
| Height (m), high blade reach | 3404.32** | 3660.70** | 955.87** | 1166.56** | 72.37** |
| 22.9–27.4 | -6 | -7 | 27 | -2 | -4 |
| 29.5–33.6 | 15 | 26 | -16 | 11 | 7 |
| 34.4 | 1 | -4 | -3 | 0 | -1 |
| 36.9–52.0 | -10 | -15 | -7 | -9 | -2 |
| Derelict turbines | 12.24** | 110.50** | 48.40** | 284.10** | 114.50** |
| Away from derelict | 0 | -1 | 2 | -2 | -5 |
| Derelict | 0 | -1 | 0 | 2 | 1 |
| Next to derelict | 0 | 2 | -2 | -1 | 3 |
| Wind wall | 186.27** | 375.24** | 389.42** | 105.95** | 119.15** |
| Not in wind wall | 3 | 6 | 12 | 3 | 7 |
| In wind wall | -3 | -6 | -12 | -3 | -7 |
| Position in string | 3959.48** | 5200.43** | 3842.47** | 2546.80** | 384.80** |
| End | 17 | 30 | 49 | 18 | 13 |
| Edge of gap | -1 | -1 | -6 | -3 | -4 |
| Interior | -16 | -28 | -42 | -16 | -10 |
| Non-operational | 0 | -1 | -1 | 1 | 1 |
| Location in wind farm | 930.75** | 252.44** | 1621.63** | 605.90** | 1.36 |
| Edge of farm | 7 | 5 | 27 | 7 | 0 |
| Edge of local cluster | -1 | 1 | -2 | 2 | -1 |
| Interior of wind farm | -6 | -6 | -25 | -8 | 0 |
| Turbine congestion | 206.37** | 292.72** | 845.27** | 18.24** | 142.38** |
| 0–12 within 300 m | -3 | -5 | -7 | -1 | 0 |
| 13–24 within 300 m | -1 | 3 | 19 | 0 | 9 |
| 25–36 within 300 m | 1 | 0 | 6 | 0 | -2 |
| 37–72 within 300 m | 2 | 2 | -17 | 1 | -7 |
| Elevation (m) | 1508.96** | 1924.68** | 972.12** | 1719.44** | 601.60** |
| 110–85 | 5 | 5 | 21 | 0 | -1 |
| 160–135 | 0 | 1 | 1 | -2 | -9 |
| 210–185 | 2 | 2 | -4 | 1 | 9 |
| 260–235 | -1 | 5 | 0 | -2 | 0 |
| 310–285 | 3 | 2 | -11 | 3 | -6 |
| 360–335 | 0 | -5 | -2 | 8 | 9 |
| 460–385 | -9 | -11 | -4 | -8 | -1 |

**Table 8-14. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Slope grade (degrees) | 530.99** | 585.84** | 383.95** | 188.63** | 176.86** |
| 0 | 2 | -9 | -12 | 5 | -5 |
| 2–5 | -2 | -2 | 0 | 0 | -2 |
| 6–14 | 4 | 7 | -4 | -1 | -4 |
| 15–58 | -4 | 4 | 17 | -4 | 11 |
| Physical relief | 1294.96** | 3050.64** | 412.20** | 511.15** | 80.45** |
| Peak | -1 | -1 | -1 | 0 | -1 |
| Plateau | 0 | 2 | 0 | -1 | 0 |
| Ridge crest | -9 | -22 | -14 | -4 | -6 |
| Ridgeline | 1 | -1 | 3 | 1 | 1 |
| Slope | 8 | 22 | 8 | 0 | 7 |
| Saddle | 1 | 1 | 5 | 1 | 0 |
| Ravine | 1 | 0 | -1 | 1 | 0 |
| Canyon | 997.50** | 872.06** | 131.09** | 283.20** | 2.64 |
| Not in canyon | 7 | 10 | 8 | 5 | 1 |
| In canyon | -7 | -10 | -8 | -5 | -1 |
| Slope aspect | 2524.41** | 1987.07** | 156.08** | 1843.60** | 45.80** |
| None (flat) | -6 | -12 | -1 | -1 | 0 |
| East-Northeast | 9 | 13 | 4 | 11 | -3 |
| South-Southeast | -2 | 6 | 5 | -9 | 1 |
| West-Southwest | 1 | -2 | -3 | 3 | 2 |
| North-Northwest | -3 | -5 | -5 | -4 | 1 |
| Edge index at tower base | 900.35** | 526.81** | 592.42** | 1982.56** | 350.92** |
| No edge | 2 | 0 | -4 | 6 | -1 |
| Some lateral edge | -4 | -4 | -8 | -1 | -4 |
| Lots lateral edge | -4 | 1 | 3 | -13 | -7 |
| Some vertical edge | 1 | -4 | -4 | 5 | -1 |
| Lots vertical edge | 5 | 7 | 14 | 3 | 13 |
| Rock piles ≤ 50 m away | 0.10 | 84.28** | 0.10 | 451.68** | 392.68** |
| None | 0 | -3 | 0 | 7 | -12 |
| One or more | 0 | 3 | 0 | -7 | 12 |
| Rodent control through 2002 | 561.23** | 813.31** | 1770.83** | 97.80** | 12.49** |
| None | 6 | 10 | 28 | 1 | 1 |
| Intermittent | 0 | -1 | 0 | -4 | 2 |
| Intense | -5 | -9 | -29 | 3 | -3 |
| Years of past rodent control | 524.58** | 785.26** | 1786.22** | 14.03** | 29.59** |
| 0 | 6 | 10 | 30 | 1 | 1 |
| 1 | 0 | -1 | -7 | 1 | -3 |
| 5 | -5 | -10 | -23 | -1 | 1 |

**Table 8-14. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Cattle pats 40 m from turbines | 313.35** | 277.27** | 575.88** | 550.65** | 431.54** |
| 0 | 3 | 3 | -8 | 4 | -4 |
| 1–9 | -3 | 3 | 20 | -5 | -10 |
| 10–25 | -2 | -7 | -11 | -3 | 3 |
| > 25 | 2 | 0 | -1 | 4 | 11 |
| Cattle pats at turbines | 721.69** | 1156.88** | 838.38** | 37.73** | 24.99** |
| 0–2 | 4 | 9 | 8 | 1 | 2 |
| 3–9 | 3 | -7 | 19 | 2 | -2 |
| 10–25 | -4 | 6 | -16 | -1 | -2 |
| > 25 | -4 | -8 | -11 | -1 | 2 |
| Cottontails 40 m from turbines | 988.95** | 1140.56** | 1829.91** | 125.07** | 18.57** |
| No pellets | -6 | -13 | -29 | -1 | -2 |
| Some pellets | 8 | 13 | 13 | 2 | 3 |
| Abundant pellets | -2 | 1 | 16 | -2 | -1 |
| Cottontails at turbines | 1024.39** | 1142.89** | 1815.06** | 165.52** | 71.03** |
| No pellets | -8 | -14 | -33 | -3 | -2 |
| Some pellets | 8 | 9 | 16 | 4 | 5 |
| Abundant pellets | 0 | 5 | 17 | -1 | -3 |
| Vegetation height (cm) | 2252.40** | 2029.12** | 669.19** | 411.55** | 366.57** |
| 0–10 | 4 | 11 | 0 | 3 | 4 |
| 11–20 | 9 | 6 | 21 | 2 | -1 |
| 21–35 | -2 | -1 | -17 | 2 | 10 |
| > 35 | -11 | -16 | -5 | -7 | -13 |
| Pocket gopher clustering | 1571.17** | 1512.80** | 405.23** | 3831.99** | 605.81** |
| Obs/Exp in 15 m = 0 | 16 | 16 | -21 | 39 | -24 |
| Obs/Exp in 15 m < 1.5 | 2 | 2 | 14 | -2 | 21 |
| Obs/Exp in 15 m = 1.5–3.0 | -1 | 9 | 18 | -9 | 5 |
| Obs/Exp in 15 m > 3 | -17 | -27 | -10 | -28 | -1 |
| Ground squirrel clustering | 602.44** | 315.14** | 72.27** | 549.43** | 62.17** |
| Obs/Exp in 15 m = 0 | 11 | 9 | -9 | 14 | 8 |
| Obs/Exp in 15 m ≤ 1.14 | -6 | -12 | -6 | -4 | -12 |
| Obs/Exp in 15 m > 1.14 | -5 | 4 | 15 | -10 | 4 |
| Pocket gopher density ≤ 90 m | 704.30** | 1167.53** | 670.59** | 1074.16** | 465.74** |
| 0–1.4/ha | 12 | 16 | -42 | 17 | 12 |
| 1.41–3.5/ha | -3 | 7 | 4 | 2 | -33 |
| > 3.5/ha | -9 | -22 | 37 | -18 | 22 |
| Ground squirrel density ≤ 90 m | 355.50** | 471.97** | 644.72** | 836.12** | 34.24** |
| 0/ha | 7 | 10 | -1 | 14 | -6 |
| 0.01–5.99/ha | -5 | 1 | -39 | -13 | 8 |
| ≥ 6/ha | -2 | -10 | 40 | -1 | -3 |

**Table 8-14. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Clustering of all burrows | 1671.82** | 135.71** | 120.46** | 1247.48** | 431.26** |
| Obs/Exp in 15 m = 0–1.2 | 10 | 6 | 10 | 3 | 28 |
| Obs/Exp in 15 m = 1.2–3.0 | -20 | -8 | 7 | -21 | -20 |
| Obs/Exp in 15 m > 3 | 9 | 1 | -17 | 18 | -8 |
| Density of all burrow systems | 300.43** | 716.60** | 585.03** | 358.28** | 515.62** |
| < 5/ha | 8 | 12 | -36 | 12 | -18 |
| 5–9/ha | -5 | 6 | 0 | -7 | 34 |
| > 9/ha | -3 | -17 | 36 | -5 | -15 |
| | | | | | |

**Table 8-15.** Chi-square tests of association between mean distance from nearest wind turbine and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express closer distances than expected by chance, and positive values express farther distances.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Turbine model | 5604.98** | 17017.40** | 17506.87** | 4782.72** | 725.72** |
| Micon | 3 | 10 | 4 | 0 | 0 |
| Bonus | -8 | -22 | -6 | -6 | -4 |
| Danwin | 0 | -1 | -1 | -1 | 0 |
| Flowind | 3 | 11 | -1 | 4 | 2 |
| Windmatic | 4 | 9 | 23 | 5 | 1 |
| Enertech | 0 | -2 | -1 | 1 | 0 |
| KCS-56 | -1 | -2 | -18 | -1 | -3 |
| KVS-33 | 0 | -3 | 1 | -2 | 4 |
| Rotor Diameter | 2583.52** | 5143.68** | 3863.90** | 2228.46** | 660.50** |
| 13.5–14.8 | 4 | 7 | 21 | 6 | 0 |
| 16.0 | 3 | 10 | 4 | 0 | 0 |
| 17.2–17.8 | 1 | 3 | -17 | 2 | 1 |
| 19.1–19.5 | -2 | -7 | -6 | 0 | -3 |
| 23.4–25.2 | -6 | -10 | -4 | -7 | -3 |
| 31.4–33.2 | 0 | -3 | 1 | -2 | 4 |
| Blade tip speed (kph) | 568.63** | 218.43** | 1327.36** | 475.34** | 59.20** |
| 137.77–149.64 | 5 | 5 | 23 | 6 | 0 |
| 173.77–194.69 | -4 | -3 | -5 | -5 | 3 |
| 212.39–246.18 | -1 | -2 | -18 | -1 | -3 |
| Rotor plane ($m^2$) swept/s | 2172.99** | 7625.30** | 1843.71** | 1323.86** | 640.51** |
| 1499–1859 | 10 | 28 | 25 | 10 | 3 |
| 2141 | -2 | -12 | -2 | 0 | -1 |
| 2780–3287 | -7 | -12 | -23 | -8 | -6 |
| 4014–5646 | 0 | -3 | 1 | -2 | 4 |
| Tower type | 744.33** | 3200.85** | 42.43** | 812.29** | 116.14** |
| Vertical axis | 3 | 11 | -1 | 4 | 2 |
| Tubular | -5 | -12 | -3 | -7 | -4 |
| Lattice | 2 | 2 | 4 | 3 | 2 |
| Tower height | 1312.66** | 3081.42** | 1038.07** | 3020.85** | 611.68** |
| 14.0 | -1 | 0 | -2 | -1 | -2 |
| 18.5 | 2 | -1 | 19 | 4 | 8 |
| 24.0–25.2 | -5 | -8 | -14 | -11 | -8 |
| 29.5–32.3 | 3 | 11 | -1 | 4 | 2 |
| 36.9–43.1 | 1 | -2 | -2 | 4 | 0 |

**Table 8-15. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Height (m), low blade reach | 1139.31** | 7011.53** | 576.27** | 2012.12** | 936.66** |
| 4.0–5.1 | 2 | 11 | -3 | 3 | 0 |
| 8.0–9.6 | -2 | -12 | -1 | -4 | 12 |
| 11.1–14.85 | -5 | -15 | 14 | -1 | -4 |
| 15.7–17.2 | 4 | 18 | -7 | -2 | -8 |
| 25.2–34.2 | 1 | -2 | -2 | 4 | 0 |
| Height (m), high blade reach | 1279.79** | 8132.89** | 694.61** | 341.09** | 273.22** |
| 22.9–27.4 | 1 | -1 | 17 | 3 | 6 |
| 29.5–33.6 | 6 | 28 | -10 | 1 | -6 |
| 34.4 | -2 | -12 | -2 | 0 | -1 |
| 36.9–52.0 | -5 | -15 | -5 | -5 | 1 |
| Derelict turbines | 3.32 | 150.10** | 27.24** | 178.81** | 358.92** |
| Away from derelict | 0 | 2 | 2 | -2 | -2 |
| Derelict | 0 | -2 | 0 | 1 | -1 |
| Next to derelict | 0 | 0 | -1 | 0 | 3 |
| Wind wall | 121.76** | 139.65** | 750.48** | 0.74 | 450.14** |
| Not in wind wall | 2 | 3 | 12 | 0 | 6 |
| In wind wall | -2 | -3 | -12 | 0 | -6 |
| Position in string | 18870.45** | 13003.22** | 8109.67** | 15260.70** | 5162.52** |
| End | 27 | 36 | 51 | 34 | 28 |
| Edge of gap | -1 | -3 | -4 | -1 | -3 |
| Interior | -26 | -32 | -46 | -34 | -24 |
| Non-operational | 0 | -1 | -1 | 0 | 0 |
| Location in wind farm | 7676.48** | 7376.10** | 3043.06** | 2773.15** | 876.25** |
| Edge of farm | 13 | 20 | 24 | 11 | 10 |
| Edge of local cluster | 3 | 7 | 6 | 3 | 1 |
| Interior of wind farm | -16 | -27 | -30 | -14 | -10 |
| Turbine congestion | 1537.57** | 595.51** | 897.88** | 1655.70** | 914.86** |
| 0–12 within 300 m | 4 | 5 | 0 | 4 | 1 |
| 13–24 within 300 m | 1 | -6 | 13 | 3 | 13 |
| 25–36 within 300 m | 1 | 4 | 3 | 2 | -6 |
| 37–72 within 300 m | -6 | -2 | -15 | -10 | -7 |
| Elevation (m) | 1904.66** | 4018.40** | 1215.63** | 671.21** | 1456.34** |
| 110–85 | 7 | 15 | 14 | 4 | 3 |
| 160–135 | -5 | -6 | 2 | -6 | -6 |
| 210–185 | -1 | -6 | 0 | 0 | -1 |
| 260–235 | -1 | 2 | -1 | 0 | -1 |
| 310–285 | 0 | 5 | -11 | 0 | -7 |
| 360–335 | -1 | -2 | -4 | -1 | 2 |
| 460–385 | 2 | -8 | 1 | 3 | 11 |

**Table 8-15. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Slope grade (degrees) | 250.86** | 178.10** | 1679.04** | 589.37** | 240.57** |
| 0 | 0 | -4 | -10 | 3 | -5 |
| 2–5 | -1 | -1 | -1 | 0 | -1 |
| 6–14 | 0 | 1 | -13 | -6 | 1 |
| 15–58 | 1 | 4 | 25 | 4 | 5 |
| Physical relief | 1897.24** | 4580.54** | 1203.02** | 2234.48** | 209.71** |
| Peak | 0 | -1 | 0 | 1 | 0 |
| Plateau | -1 | 5 | -3 | -5 | -2 |
| Ridge crest | -7 | -19 | -16 | -7 | 0 |
| Ridgeline | 0 | -4 | 5 | -1 | -2 |
| Slope | 8 | 15 | 9 | 13 | 3 |
| Saddle | 1 | 4 | 6 | 0 | 1 |
| Ravine | 0 | 1 | -1 | -1 | -1 |
| Canyon | 758.54** | 1669.81** | 249.60** | 447.73** | 2.48 |
| Not in canyon | 5 | 11 | -8 | 5 | -1 |
| In canyon | -5 | -11 | 8 | -5 | 1 |
| Slope aspect | 1355.36** | 1660.65** | 64.61** | 1848.41** | 852.81** |
| None (flat) | -2 | -6 | 0 | -7 | 9 |
| East-Northeast | 6 | 5 | 2 | 8 | -6 |
| South-Southeast | -1 | 10 | 0 | -2 | -1 |
| West-Southwest | 0 | -2 | -2 | 3 | -3 |
| North-Northwest | -3 | -7 | -1 | -2 | 1 |
| Edge index at tower base | 310.92** | 2061.97** | 916.07** | 627.41** | 262.99** |
| No edge | -1 | 1 | -3 | -1 | -1 |
| Some lateral edge | -1 | -8 | -2 | 1 | 0 |
| Lots lateral edge | -1 | -4 | -6 | -6 | 0 |
| Some vertical edge | -1 | 3 | -5 | -1 | -5 |
| Lots vertical edge | 3 | 9 | 15 | 5 | 5 |
| Rock piles ≤ 50 m away | 221.53** | 810.05** | 52.03** | 133.81** | 107.33** |
| None | 3 | 8 | 4 | 3 | -4 |
| One or more | -3 | -8 | -4 | -3 | 4 |
| Rodent control through 2002 | 2602.10** | 5389.03** | 1428.99** | 990.12** | 172.21** |
| None | 8 | 18 | 19 | 7 | 2 |
| Intermittent | -8 | -18 | -6 | -7 | -6 |
| Intense | 0 | -1 | -13 | 0 | 4 |
| Years of past rodent control | 2188.41** | 4241.43** | 1585.79** | 909.84** | 280.93** |
| 0 | 8 | 18 | 20 | 7 | 2 |
| 1 | -2 | -2 | 1 | -3 | -4 |
| 5 | -5 | -16 | -21 | -4 | 2 |

**Table 8-15. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Cattle pats 40 m from turbines | 28.11** | 557.23** | 998.48** | 25.33** | 293.65** |
| 0 | 0 | 2 | -8 | 0 | -4 |
| 1–9 | 1 | 3 | 19 | -1 | 3 |
| 10–25 | -1 | -8 | -10 | 1 | 0 |
| > 25 | 0 | 3 | -1 | 0 | 1 |
| Cattle pats at turbines | 323.59** | 1518.42** | 1374.00** | 182.49** | 619.28** |
| 0–2 | 2 | 6 | 9 | 0 | -1 |
| 3–9 | 2 | 5 | 15 | -4 | 11 |
| 10–25 | -2 | -2 | -20 | 1 | -7 |
| > 25 | -2 | -10 | -3 | 3 | -3 |
| Cottontails 40 m from turbines | 522.85** | 367.86** | 1667.53** | 1648.93** | 12.52** |
| No pellets | -4 | -5 | -19 | -11 | -1 |
| Some pellets | 3 | 2 | 8 | 7 | 1 |
| Abundant pellets | 1 | 3 | 11 | 4 | 0 |
| Cottontails at turbines | 798.50** | 2412.45** | 1420.80** | 1768.27** | 1.06 |
| No pellets | -5 | -7 | -21 | -10 | 0 |
| Some pellets | 2 | -2 | 11 | 4 | 0 |
| Abundant pellets | 3 | 10 | 10 | 6 | 0 |
| Vegetation height (cm) | 476.33** | 1892.25** | 1010.46** | 207.99** | 171.32** |
| 0–10 | 0 | 7 | 0 | -3 | -2 |
| 11–20 | 5 | 6 | 7 | 4 | -3 |
| 21–35 | -2 | -2 | -18 | 0 | 3 |
| > 35 | -2 | -11 | 11 | -1 | 3 |
| Pocket gopher clustering | 3222.63** | 6973.71** | 615.76** | 1494.09** | 1458.25** |
| Obs/Exp in 15 m = 0 | 11 | 27 | 18 | -3 | -1 |
| Obs/Exp in 15 m < 1.5 | 5 | -3 | -9 | 13 | 21 |
| Obs/Exp in 15 m = 1.5–3.0 | -13 | -20 | -4 | -17 | 2 |
| Obs/Exp in 15 m > 3 | -3 | -3 | -5 | 7 | -21 |
| Ground squirrel clustering | 586.99** | 1220.50** | 206.30** | 916.33** | 635.79** |
| Obs/Exp in 15 m = 0 | 5 | 4 | 15 | 16 | -19 |
| Obs/Exp in 15 m ≤ 1.14 | -9 | -18 | -14 | -6 | 10 |
| Obs/Exp in 15 m > 1.14 | 4 | 14 | -1 | -10 | 10 |
| Pocket gopher density ≤ 90 m | 557.89** | 5602.93** | 1147.15** | 155.82** | 298.74** |
| 0–1.4/ha | 4 | 36 | -42 | -4 | 11 |
| 1.41–3.5/ha | 4 | -20 | 20 | 7 | -12 |
| > 3.5/ha | -8 | -17 | 22 | -2 | 2 |
| Ground squirrel density ≤ 90 m | 1259.93** | 646.46** | 795.25** | 2304.09** | 173.95** |
| 0/ha | 10 | 11 | 8 | 20 | -7 |
| 0.01–5.99/ha | -9 | -7 | -34 | -17 | 1 |
| ≥ 6/ha | -1 | -4 | 26 | -4 | 6 |

**Table 8-15. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Clustering of all burrows | 16.62** | 52.46** | 129.46** | 86.71** | 445.47** |
| Obs/Exp in 15 m = 0–1.2 | 1 | -2 | -5 | 2 | 12 |
| Obs/Exp in 15 m = 1.2–3.0 | 0 | 4 | 14 | -5 | 0 |
| Obs/Exp in 15 m > 3 | -1 | -2 | -9 | 3 | -12 |
| Density of all burrow systems | 912.94** | 2375.06** | 497.64** | 58.03** | 122.47** |
| < 5/ha | 11 | 26 | -23 | 4 | -9 |
| 5–9/ha | -8 | -14 | 1 | -1 | 5 |
| > 9/ha | -3 | -12 | 22 | -3 | 3 |

**Table 8-16.** Chi-square tests of association between time spent flying within 50 m of the rotor zone and independent variables expressing attributes of the nearest wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005. Negative measures of effect express less close-by flying than expected by chance, and positive values express more close-by flying.

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Turbine model | 360.06** | 110.57** | 38.22** | 262.56** | 101.52** |
| Micon | -1 | 3 | 0 | -1 | -4 |
| Bonus | -11 | -19 | -29 | -6 | -16 |
| Danwin | 4 | 0 | -1 | 8 | 0 |
| Flowind | 24 | 24 | 48 | 26 | 24 |
| Windmatic | 2 | 8 | -2 | 0 | -2 |
| Enertech | -5 | -5 | 16 | -6 | -4 |
| KCS-56 | -14 | -8 | -39 | -17 | -14 |
| KVS-33 | 0 | -4 | 8 | -4 | 15 |
| Rotor Diameter | 29.80** | 16.81** | 6.92 | 35.36** | 53.94** |
| 13.5–14.8 | -3 | 3 | 14 | -6 | -6 |
| 16.0 | -1 | 3 | 0 | -1 | -4 |
| 17.2–17.8 | 4 | 2 | 10 | 4 | 12 |
| 19.1–19.5 | 7 | 7 | -20 | 13 | -10 |
| 23.4–25.2 | -8 | -12 | -12 | -6 | -7 |
| 31.4–33.2 | 0 | -4 | 8 | -4 | 15 |
| Blade tip speed (kph) | 80.71** | 3.48 | 9.97* | 56.83** | 35.86** |
| 137.77–149.64 | -7 | 0 | -3 | -7 | -18 |
| 173.77–194.69 | 20 | 8 | 42 | 24 | 32 |
| 212.39–246.18 | -14 | -8 | -39 | -17 | -14 |
| Rotor plane ($m^2$) swept/s | 78.44** | 39.38** | 20.47** | 37.97** | 55.09** |
| 1499–1859 | 21 | 30 | 62 | 19 | 14 |
| 2141 | -3 | -7 | -17 | 0 | -9 |
| 2780–3287 | -17 | -20 | -53 | -15 | -21 |
| 4014–5646 | 0 | -4 | 8 | -4 | 15 |
| Tower type | 285.33** | 66.68** | 29.05** | 178.43** | 52.66** |
| Vertical axis | 24 | 24 | 48 | 26 | 24 |
| Tubular | -7 | -16 | -30 | 1 | -19 |
| Lattice | -16 | -8 | -17 | -27 | -5 |
| Tower height | 286.13** | 69.71** | 29.01** | 169.80** | 51.45** |
| 14.0 | -1 | 1 | -2 | -2 | -2 |
| 18.5 | -11 | -14 | -9 | -14 | -8 |
| 24.0–25.2 | -11 | -9 | -34 | -10 | -14 |
| 29.5–32.3 | 24 | 24 | 48 | 26 | 24 |
| 36.9–43.1 | -1 | -2 | -2 | 0 | 0 |

**Table 8-16. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Height (m), low blade reach | 213.11** | 80.59** | 21.01** | 119.63** | 47.62** |
| 4.0–5.1 | 23 | 25 | 46 | 24 | 22 |
| 8.0–9.6 | -9 | -21 | -16 | -12 | 14 |
| 11.1–14.85 | -10 | -16 | -16 | -4 | -22 |
| 15.7–17.2 | -4 | 14 | -12 | -8 | -13 |
| 25.2–34.2 | -1 | -2 | -2 | 0 | 0 |
| Height (m), high blade reach | 95.81** | 56.81** | 5.43 | 59.40** | 9.11* |
| 22.9–27.4 | -12 | -13 | -11 | -16 | -10 |
| 29.5–33.6 | 24 | 37 | 35 | 25 | 11 |
| 34.4 | -3 | -7 | -17 | 0 | -9 |
| 36.9–52.0 | -8 | -18 | -7 | -10 | 8 |
| Derelict turbines | 36.47** | 1.37 | 1.89 | 71.49** | 2.06 |
| Away from derelict | -7 | 0 | -5 | -12 | -2 |
| Derelict | 5 | -2 | -3 | 10 | -1 |
| Next to derelict | 2 | 2 | 8 | 2 | 3 |
| Wind wall | 2.15 | 0.53 | 1.23 | 1.07 | 3.14 $^t$ |
| Not in wind wall | 3 | -3 | 12 | 3 | 7 |
| In wind wall | -3 | 3 | -12 | -3 | -7 |
| Position in string | 330.65** | 54.58** | 5.74 | 526.57** | 6.93 $^t$ |
| End | 24 | 34 | 32 | 24 | 6 |
| Edge of gap | -2 | -2 | 2 | 0 | -9 |
| Interior | -28 | -32 | -34 | -37 | 4 |
| Non-operational | 6 | -1 | -1 | 13 | -1 |
| Location in wind farm | 94.16** | 3.46 | 2.97 | 131.88** | 1.66 |
| Edge of farm | 2 | 5 | 7 | -2 | 4 |
| Edge of local cluster | 14 | 4 | 14 | 24 | -3 |
| Interior of wind farm | -15 | -8 | -21 | -21 | 0 |
| Turbine congestion | 83.23** | 4.87 | 2.37 | 97.20** | 12.27* |
| 0–12 within 300 m | 15 | 7 | -2 | 24 | 2 |
| 13–24 within 300 m | -1 | -8 | -12 | -4 | 19 |
| 25–36 within 300 m | -5 | 4 | 21 | -7 | -9 |
| 37–72 within 300 m | -9 | -2 | -7 | -12 | -12 |
| Elevation (m) | 64.68** | 16.51* | 3.06 | 71.87** | 39.62** |
| 110–85 | -2 | 3 | 15 | -4 | -5 |
| 160–135 | -10 | -1 | -1 | -15 | -12 |
| 210–185 | 2 | -2 | -3 | 8 | -9 |
| 260–235 | 4 | 3 | -3 | 7 | 0 |
| 310–285 | -1 | 9 | 9 | -3 | -6 |
| 360–335 | 9 | 2 | -9 | 9 | 17 |
| 460–385 | -3 | -14 | -8 | -2 | 16 |

**Table 8-16. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Slope grade (degrees) | 103.07** | 7.63 [t] | 1.35 | 99.31** | 10.98* |
| 0 | -18 | -12 | -1 | -24 | -13 |
| 2–5 | -2 | -2 | -3 | -2 | -3 |
| 6–14 | -4 | 3 | -10 | -8 | -1 |
| 15–58 | 24 | 11 | 14 | 34 | 17 |
| Physical relief | 80.86** | 15.23* | 6.24 | 86.68** | 5.83 |
| Peak | -1 | 0 | 9 | -2 | -2 |
| Plateau | -2 | 5 | -10 | -4 | -2 |
| Ridge crest | -18 | -19 | -14 | -23 | -5 |
| Ridgeline | 11 | 3 | -1 | 17 | 7 |
| Slope | 10 | 7 | 10 | 13 | 4 |
| Saddle | 1 | 4 | 7 | 0 | -1 |
| Ravine | 0 | 0 | -1 | -1 | -1 |
| Canyon | 8.72** | 1.63 | 0.09 | 3.93* | 3.54 [t] |
| Not in canyon | 6 | 5 | 4 | 5 | 8 |
| In canyon | -6 | -5 | -4 | -5 | -8 |
| Slope aspect | 42.54** | 3.81 | 1.93 | 59.04** | 11.31* |
| None (flat) | -12 | -8 | 1 | -21 | 8 |
| East-Northeast | 5 | 2 | 8 | 7 | -6 |
| South-Southeast | -4 | 7 | -8 | -7 | -9 |
| West-Southwest | 1 | 1 | 7 | 2 | -4 |
| North-Northwest | 11 | -2 | -8 | 19 | 12 |
| Edge index at tower base | 34.19** | 12.99* | 5.52 | 32.19** | 4.96 |
| No edge | -1 | 1 | -4 | -3 | 0 |
| Some lateral edge | -4 | -10 | 13 | -4 | 0 |
| Lots lateral edge | -10 | -5 | -12 | -14 | -6 |
| Some vertical edge | 7 | 4 | 23 | 14 | -5 |
| Lots vertical edge | 8 | 10 | -19 | 7 | 11 |
| Rock piles ≤ 50 m away | 4.46* | 0.30 | 0.00 | 8.45** | 0.95 |
| None | 5 | 2 | 0 | 9 | -6 |
| One or more | -5 | -2 | 0 | -9 | 6 |
| Rodent control through 2002 | 9.40* | 7.78* | 0.22 | 1.85 | 5.68 [t] |
| None | 2 | 5 | -6 | 2 | -4 |
| Intermittent | -7 | -14 | 4 | -5 | -11 |
| Intense | 6 | 9 | 2 | 3 | 15 |
| Years of past rodent control | 10.58* | 2.95 | 2.81 | 4.59 | 6.58* |
| 0 | 2 | 5 | -6 | 2 | -4 |
| 1 | -5 | -4 | 15 | -4 | -8 |
| 5 | 3 | -1 | -9 | 2 | 12 |

**Table 8-16. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Cattle pats 40 m from turbines | 52.66** | 3.18 | 1.96 | 68.58** | 9.93* |
| 0 | -3 | 4 | -8 | -6 | -5 |
| 1–9 | -5 | 2 | 9 | -9 | -7 |
| 10–25 | -5 | -7 | -11 | -5 | 0 |
| > 25 | 12 | 1 | 10 | 20 | 12 |
| Cattle pats at turbines | 27.95** | 11.54* | 2.34 | 82.60** | 4.88 |
| 0–2 | -5 | 3 | -1 | -10 | -8 |
| 3–9 | -5 | 15 | 11 | -14 | 0 |
| 10–25 | 0 | -7 | -22 | -2 | 10 |
| > 25 | 10 | -11 | 12 | 26 | -2 |
| Cottontails 40 m from turbines | 1.79 | 1.78 | 1.67 | 5.56 [t] | 4.23 |
| No pellets | -2 | -3 | -10 | -3 | 11 |
| Some pellets | 3 | 0 | 15 | 6 | -9 |
| Abundant pellets | -1 | 3 | -5 | -2 | -2 |
| Cottontails at turbines | 2.38 | 15.16** | 4.47 | 5.09 [t] | 0.80 |
| No pellets | 1 | -12 | -18 | 7 | 4 |
| Some pellets | -2 | 1 | 26 | -6 | -1 |
| Abundant pellets | 2 | 11 | -8 | 0 | -3 |
| Vegetation height (cm) | 43.11** | 15.93** | 5.21 | 29.67** | 2.35 |
| 0–10 | 10 | 8 | 27 | 12 | 6 |
| 11–20 | 1 | 7 | 1 | 1 | 1 |
| 21–35 | 0 | 2 | -19 | 1 | -3 |
| > 35 | -11 | -17 | -10 | -13 | -5 |
| Pocket gopher clustering | 10.11* | 15.76** | No test | 11.04* | 4.44 |
| Obs/Exp in 15 m = 0 | 5 | 19 | | -3 | 7 |
| Obs/Exp in 15 m < 1.5 | 7 | -7 | | 16 | 9 |
| Obs/Exp in 15 m = 1.5–3.0 | -9 | -12 | | -7 | 13 |
| Obs/Exp in 15 m > 3 | -4 | 0 | | -5 | -29 |
| Ground squirrel clustering | 14.19** | 15.76** | No test | 20.21** | 5.58 [t] |
| Obs/Exp in 15 m = 0 | 11 | -6 | | 27 | -32 |
| Obs/Exp in 15 m ≤ 1.14 | -16 | -24 | | -17 | 14 |
| Obs/Exp in 15 m > 1.14 | 5 | 30 | | -9 | 17 |
| Pocket gopher density ≤ 90 m | 3.75 | 18.00** | No test | 1.78 | 1.40 |
| 0–1.4/ha | 8 | 32 | | -8 | 12 |
| 1.41–3.5/ha | -1 | -3 | | 3 | -15 |
| > 3.5/ha | -7 | -28 | | 5 | 2 |
| Ground squirrel density ≤ 90 m | 25.90** | 0.22 | No test | 39.66** | 3.11 |
| 0/ha | 17 | 1 | | 30 | -9 |
| 0.01–5.99/ha | -14 | -4 | | -18 | -12 |
| ≥ 6/ha | -3 | 3 | | -12 | 21 |

**Table 8-16. (cont'd)**

| Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Clustering of all burrows | 2.61 | 4.28 | No test | 5.95* | 3.28 |
| Obs/Exp in 15 m = 0–1.2 | -2 | -14 | | 0 | 21 |
| Obs/Exp in 15 m = 1.2–3.0 | 7 | 15 | | 13 | -20 |
| Obs/Exp in 15 m > 3 | -5 | -2 | | -13 | -1 |
| Density of all burrow systems | 7.48* | 10.44** | No test | 10.74** | 3.13 |
| < 5/ha | 6 | 26 | | -2 | -21 |
| 5–9/ha | 5 | -17 | | 18 | 20 |
| > 9/ha | -11 | -9 | | -16 | 2 |

### *Predicted Mortality*

Golden eagles perched disproportionately more often at or near wind turbines predicted by our empirical models to more likely kill golden eagles (Table 8-17). Golden eagles, red-tailed hawks, and American kestrels flew disproportionately more often nearest wind turbines predicted by our models to more likely kill them (Table 8-17). These species flew disproportionately lower to the ground nearest wind turbines predicted by our empirical models to more likely kill them, and golden eagles and American kestrels also flew disproportionately closer to these wind turbines (Table 8-17).

**Table 8-17.** Chi-square tests of association between dependent variables and whether model predicted lower or higher likelihood of fatalities to occur at wind turbine, where t denotes 0.10 > P > 0.05, * denotes P < 0.05, and ** denotes P < 0.005

| Dependent Variable | $\chi^2$ and percent deviation from expected value | | | | |
|---|---|---|---|---|---|
| | Raptors | TUVU | GOEA | RTHA | AMKE |
| Minutes of perching | 37.02** | No test | 27.27** | 1.27 | 0.43 |
| Less likely to kill bird | -5 | | -23 | -1 | -1 |
| More likely to kill bird | 5 | | 23 | 1 | 1 |
| Minutes of flying | 74.43** | No test | 6.58* | 11.70** | 6.99* |
| Less likely to kill bird | -14 | | -20 | -7 | -12 |
| More likely to kill bird | 14 | | 20 | 7 | 12 |
| Mean flight height (m) | 131.48** | No test | 634.46** | 54.52** | 9.01** |
| Less likely to kill bird | -3 | | -22 | -3 | -3 |
| More likely to kill bird | 4 | | 22 | 3 | 3 |
| Mean distance from turbine (m) | 463.76** | No test | 2938.90** | 82.37** | 32.32** |
| Less likely to kill bird | -5 | | -34 | 2 | -3 |
| More likely to kill bird | 5 | | 34 | -2 | 3 |
| Flights ≤ 50 m from turbines | 56.98** | No test | 0.72 | 4.60* | 2.66 |
| Less likely to kill bird | -18 | | -13 | -6 | -10 |
| More likely to kill bird | 19 | | 13 | 6 | 10 |

Red-tailed hawks and American kestrels were also observed making more than the expected number of their dangerous flights nearest wind turbines we predicted in Chapter 8 to more likely kill these species. The behavior most strongly associated with predicted mortality was mean flight distance from wind turbines by golden eagles, and total time seen flying nearest the wind turbines by red-tailed hawks and American kestrels.

### 8.3.4 Flight Heights Relative to Existing and Future Rotor Planes

We observed that most flights by raptors occurred within the height domains of currently operating wind turbines. The height distributions of flights and summary statistics are shown in Figures 8-13, 8-14, 8-15, and 8-16 for golden eagles, red-tailed hawks, American kestrels, and all raptors combined, respectively. No analysis was possible for burrowing owls because we did not observe burrowing owl flights during the CEC-funded behavior study, which was the study we relied on for analyzing flight heights.

The percentage of flights would be smaller within the rotor plane height domains of the proposed new wind turbines in the APWRA (Alameda County 1998, Contra Costa County 2004), but not much smaller because some of these wind turbines would have rotor planes that extend down to 13.8 m above ground, which is well within the range of rotor planes of existing wind turbines. However, the percentage of flights would be much smaller within the rotor plane of the wind turbines on the proposed tallest towers (Figures 8-13 to 8-16), ranging from half of the golden eagle flight observations to about 15% of the American kestrel flight observations. Therefore, if the repowering of the APWRA consisted only of the proposed tallest wind turbines, raptor flights within the new rotor plane height would be substantially fewer than occur currently.

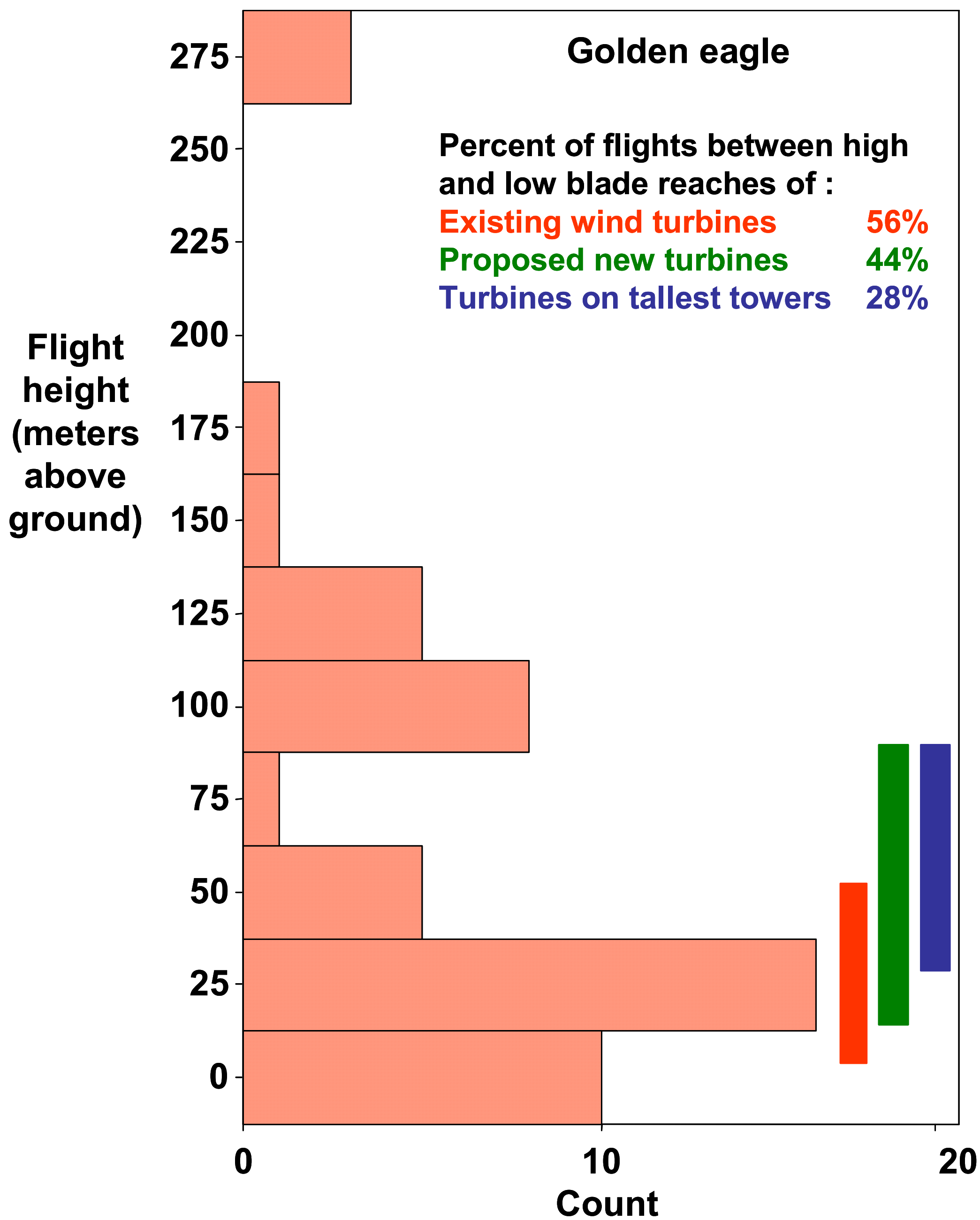



**Figure 8-13**. Histogram of flight heights by golden eagles and percentages of flights within the rotor height domains of existing wind turbines indicated by the red bar, proposed new wind turbines indicated by the green bar, and turbines on tallest tower indicated by the blue bar.

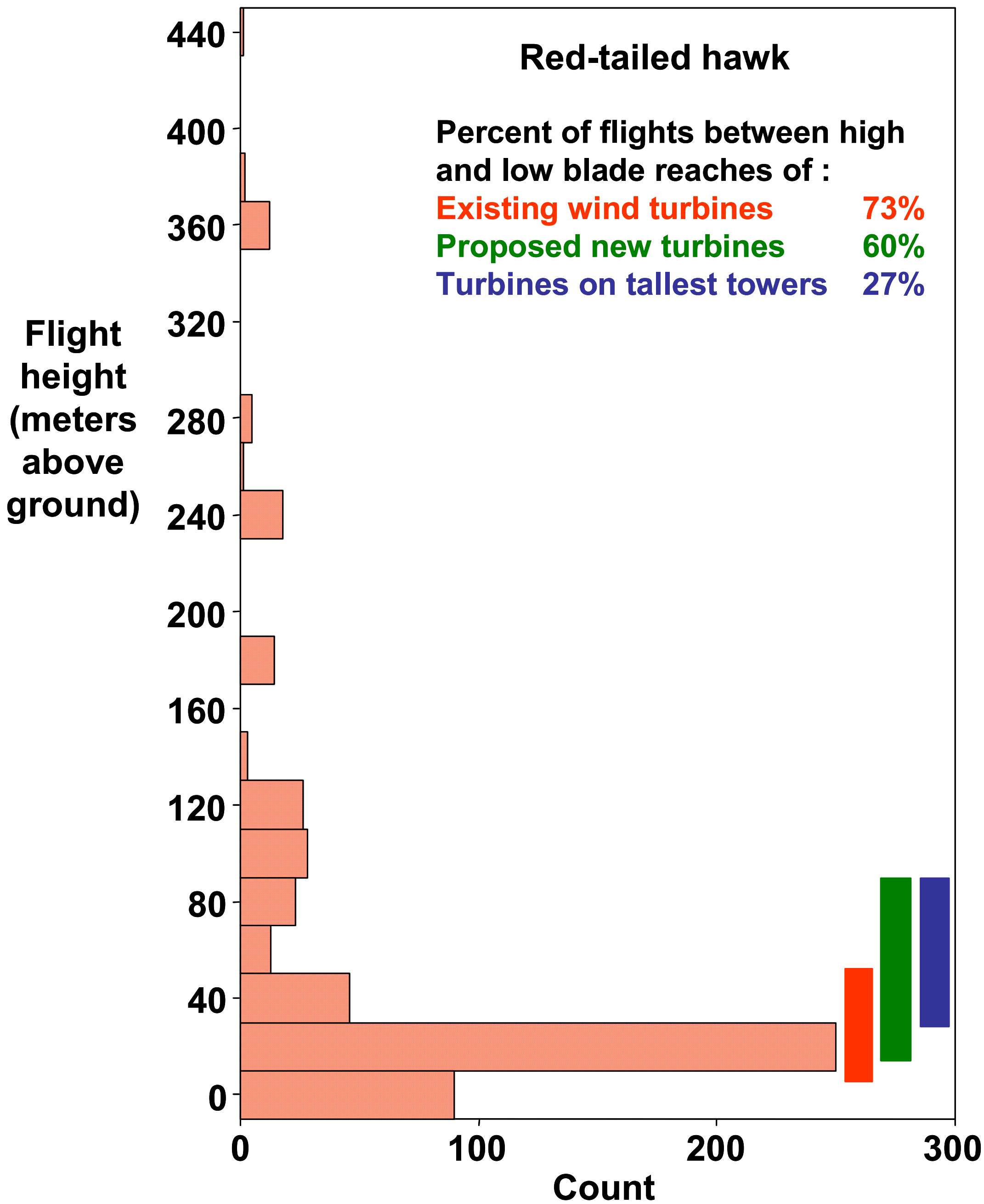



**Figure 8-14**. Histogram of flight heights by red-tailed hawks and percentages of flights within the rotor height domains of existing wind turbines indicated by the red bar, proposed new wind turbines indicated by the green bar, and turbines on tallest tower indicated by the blue bar.

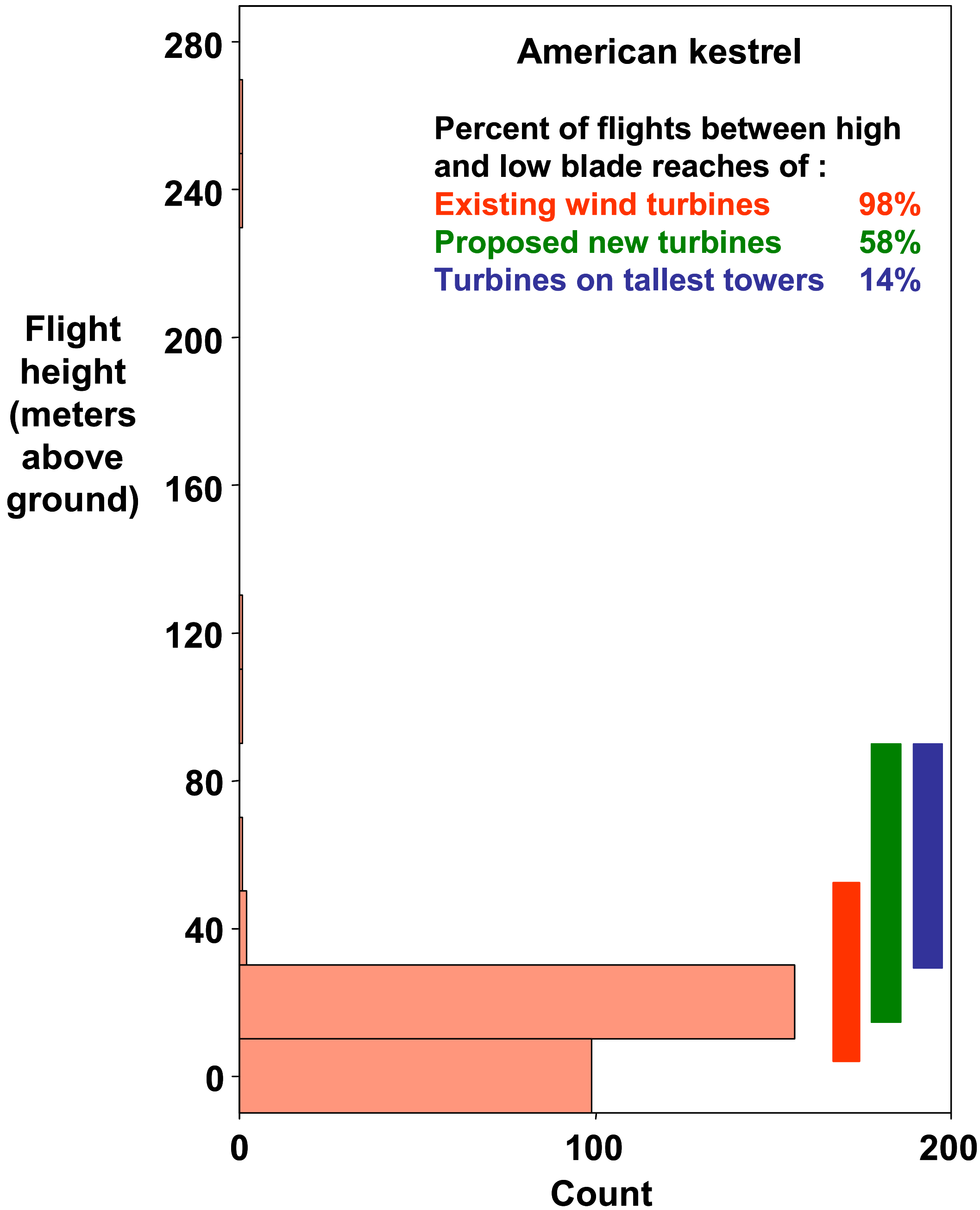



**Figure 8-15**. Histogram of flight heights by American kestrels and percentages of flights within the rotor height domains of existing wind turbines indicated by the red bar, proposed new wind turbines indicated by the green bar, and turbines on tallest tower indicated by the blue bar.

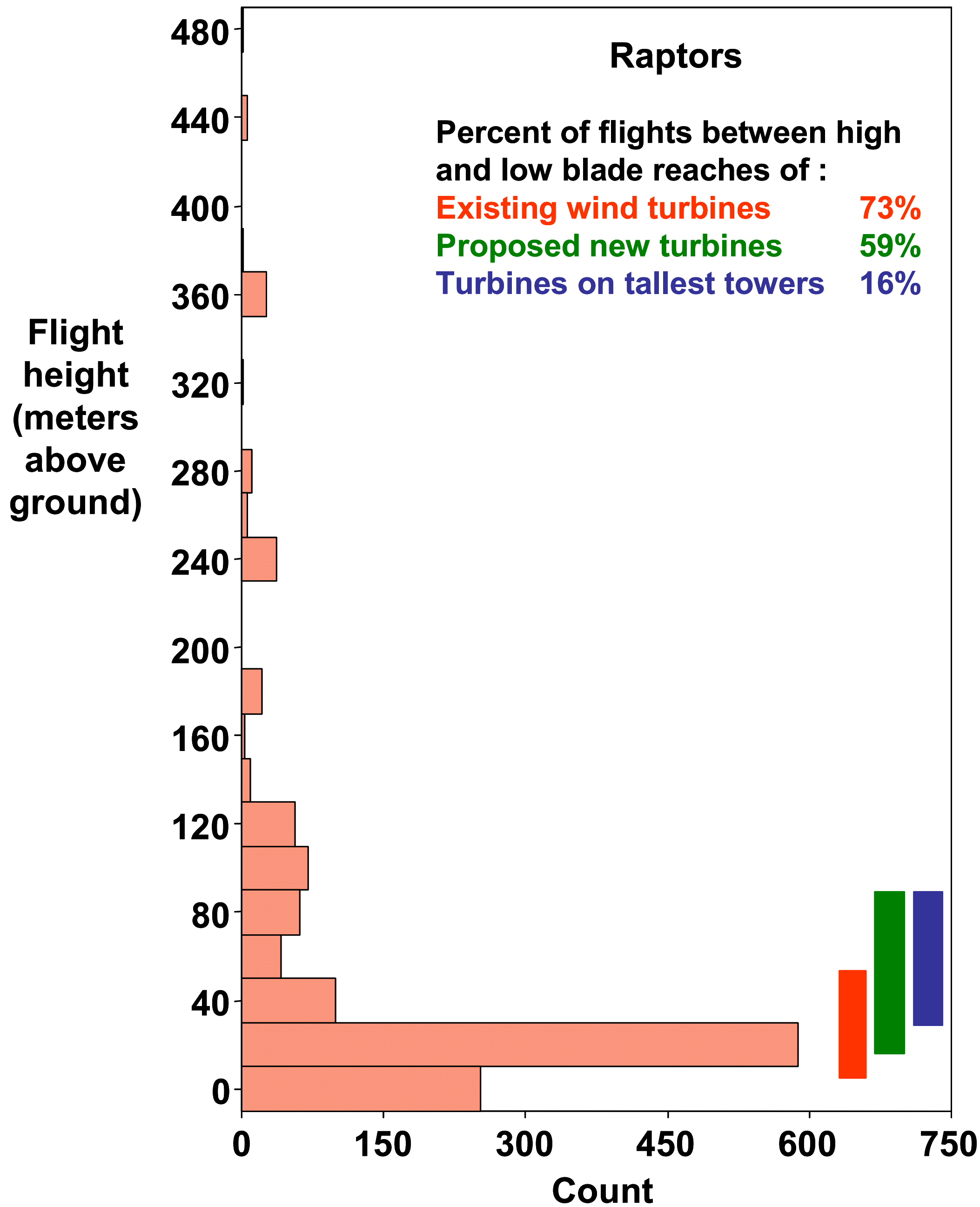



**Figure 8-16**. Histogram of flight heights by all raptors combined and percentages of flights within the rotor height domains of existing wind turbines indicated by the red bar, proposed new wind turbines indicated by the green bar, and turbines on tallest tower indicated by the blue bar.

## 8.4 DISCUSSION

Based only on significant associations, the largest measures of effect we calculated are summarized in Table 8-18 for golden eagles, Table 8-19 for red-tailed hawks, Table 8-20 for American kestrels, and Table 8-21 for turkey vultures. These results show that much of the variation in each behavior is shared among multiple association variables, groups of which obviously express common underlying factors.

### 8.4.1 Golden Eagle Behaviors

Golden eagles preferred to perch in areas of the APWRA with greater prey species abundance and lower vegetation, but also few cattle pats. They also preferentially selected locations where the wind turbines had smaller, slower-moving rotor blades, and they selected locations nearer turbines occurring at the ends of the strings and in less dense turbine fields. Steeper slopes were favored along with northeast- to south-facing slopes, and golden eagles spent disproportionately more time perching during mid to late morning during slow to moderate winds blowing from the northwest.

It appeared that golden eagles sought out perch locations that commanded superior views of areas where prey were abundant and available, and that were protected from the wind. Despite golden eagles' favoring prey-abundant locations, they perched disproportionately more often in areas of intense rodent control, which suggests that they choose locations not necessarily based on prey inventory, but rather on conditions of the landscape that have traditionally connoted prey availability.

Golden eagles spent disproportionately more time flying nearest wind turbines at the ends of turbine strings and at the edges of the wind farm and local clusters of turbines, and that swept the least area of the sky per second within the APWRA. They avoided flying in areas that were busier with wind turbines, such as wind walls and faster moving turbines. They also chose to fly over areas with higher pocket gopher densities, perhaps because these areas also conferred greater densities of favored prey items such as desert cottontails and ground squirrels.

Golden eagles flew lower to the ground and closer to wind turbines nearest those at the ends of turbine strings, as well as at the edges of gaps in strings. They did so also where fossorial mammal species were in lowest densities and where desert cottontail sign was absent, as well as where rodent control was applied intensively. Possibly, golden eagles use a different hunting strategy where prey species numbers are reduced. This strategy brings them closer to wind turbines and closer to the ground, which makes flights by turbines with blade reaches low to the ground more dangerous. However, golden eagles also flew disproportionately lower to the ground and nearer turbines when the turbines highest blade reach was the highest in the APWRA, so possibly golden eagles are flying low to duck under the rotor planes of these wind turbines, which also happen to be in areas of intense rodent control and reduced prey species densities. Golden eagles also fly lower than expected over ridge crests and at higher elevations, and during spring.

Dangerous flights were made disproportionately more frequently nearest wind turbines that swept less of the sky per second, including nearest vertical axis turbines. However, dangerous flights were not made more often than expected by chance near wind turbines we predicted in Chapter 8 to be more dangerous to golden eagles (Table 8-17). In fact, golden eagles preferred to fly higher and farther away from these wind turbines (Table 8-17), indicating that they recognize them as dangerous.

### 8.4.2 Red-tailed Hawk Behaviors

Red-tailed hawks perched preferentially nearest wind turbines at the ends of turbine strings, as well as in areas of highest densities of small mammal prey species. Like golden eagles, they also perched preferentially nearest wind turbines that were less busy or that swept smaller areas per second. Perching was more common than expected by chance during slow winds and during January and the middle of the day, as well as at low elevations, on slopes and in areas more intensively used by cattle.

Red-tailed hawks also flew preferentially nearest wind turbines at the ends of turbine strings, but contrary to golden eagles, in areas of lowest densities of mammalian prey species. They preferred to fly during the early afternoon in moderate winds, and over northerly slopes and steeper slopes, and where the grass was shorter and cattle presence more intense. They also flew preferentially at the edges of local clusters of wind turbines, but also nearest more sparsely distributed turbines that sweep less area per second.

Flights of red-tailed hawks were lower to the ground and nearest wind turbines located interior to turbine strings, and they flew higher to the ground and farther away from wind turbines at the ends of strings. They also flew lower to the ground and closer to wind turbines when over areas supporting modest to high densities of mammalian prey species. Red-tailed hawks appeared to recognize the end-of-row turbines as more dangerous and attempted to hunt lower to the ground when farther from these end turbines, such as nearer the interior turbines. Although red-tailed hawks spent more time flying over areas of lowest densities of mammalian species, they preferred to fly low over areas of highest densities of mammalian species.

Red-tailed hawks performed dangerous flights disproportionately more often over the steepest slopes and over ridgelines, and also where no ground squirrels occurred or only where all small mammal species studied occurred in moderate densities. Dangerous flights of red-tailed hawks were more common over more intensively grazed areas with shorter vegetation. They performed disproportionately more of their dangerous flights nearest vertical axis turbines and near end turbines, despite the finding that they also preferred to fly higher and farther away from end turbines. Apparently, they attempted to avoid end-of-row turbines, but still ended up making more of their dangerous flights by these turbines. Dangerous flights also occurred disproportionately near turbines at the edges of local turbine clusters and in areas of lowest density of turbines. And they occurred preferentially near derelict turbines and near where rocks had been piled after being cleared from the tower laydown areas.

### 8.4.3 American Kestrel Behaviors

American kestrels perched preferentially during the winter months compared to late fall or spring, and they did so during moderate winds and relatively cool temperatures. They perched preferentially nearest wind turbines at the ends of rows, and at the edges of the APWRA and local clusters of wind turbines. They also did so at the highest elevations in the APWRA and on the steepest slopes, and where fossorial mammal species occurred in moderate densities. They also chose to perch nearest wind turbines with the slowest tip speeds.

American kestrels favored flying in the APWRA at the highest elevations and where fossorial mammals occurred at the highest densities. They preferred to fly in low density turbine fields, nearest turbines at the ends of strings, and near vertical axis turbines. They also flew preferentially near wind turbines with rock piles nearby and where cattle grazed intensively.

American kestrels flew lower to the ground and closer to wind turbines disproportionately more often in areas of moderate pocket gopher density and where ground squirrels were lacking. They also did during the spring months and during the morning hours. They flew lower to the ground in southwest winds, slower winds, and over ridge crests and in less dense turbine fields.

American kestrels performed disproportionately more of their dangerous flights at highest elevations and in moderately fast winds, winds blowing from the southwest, and during mid- to late afternoon. They performed more of their dangerous flights where ground squirrels occurred within 15 m of wind turbines, in areas of intense rodent control, and where cattle grazed more intensively. They also preferentially performed more of these flights on the steepest slopes and in sparse turbine fields nearest the end-of-row turbines.

**Table 8-18.** The directions and magnitudes of significant associations between measured golden eagle behaviors and independent variables

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Time spent perching*** |
| Burrow system density | 70 in areas of intermediate gopher density;<br>71 in areas of highest ground squirrel density;<br>67 in areas of highest mammal density |
| Burrow clustering | 58 in areas of intermediate ground squirrel clustering;<br>71 in areas of no fossorial mammal burrow systems |
| Blade tip speed | 63 at turbines with slowest tip speed |
| Rotor diameter | 55 at turbines with small rotors |
| Cattle pats | 53 in areas with fewer cattle pats |
| Vegetation height | 52 in areas of tallest vegetation |
| Position in string | 51 at end turbines |

**Table 8-18. (cont'd)**

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Time spent perching (cont'd)*** |
| Elevation | 43 at lowest elevations |
| Wind speed | 39 in slow-moderate winds |
| Physical relief | 38 on slopes |
| Wind direction | 36 in north winds; 16 in no winds |
| Location in APWRA | 33 at edge of APWRA, 17 at edge of local cluster of turbines |
| Time of day | 26 in early to mid morning |
| Slope grade | 22 on steepest slopes |
| Cottontail abundance | 21 in areas of abundant pellets near wind turbines |
| Temperature | 21 in 70–79 ˚F |
| Rodent control | 19 in areas of intense poisoning |
| Slope aspect | 17 on northeast, east, southeast and south slopes |
| Rock piles | 13 in areas of no rock piles |
| Wind wall | 12 at turbines outside of wind walls |
| Turbine congestion | 12 at sparsest turbine fields |
| Canyon | 12 in canyons |
| Tower type | 11 at or near tubular towers |
| | ***Time spent flying*** |
| Position in string | 43 at end turbines |
| Rotor plane swept/s | 22 at turbines with slowest rates of sweeping the rotor plane |
| Burrow system density | 21 in areas of highest gopher density |
| Location in wind farm | 20 at edge of APWRA or local cluster |
| Cottontail abundance | 17 at wind turbines with some pellets |
| Rotor diameter | 15 at turbines with small rotors |
| Wind wall | 12 at turbines outside wind walls |
| Tower type | 9 at vertical axis turbines |
| Burrow clustering | 5 in areas of no ground squirrels;<br>4 in areas of moderate clustering of all fossorial mammals |
| | ***Flight height*** |
| Position in string | -42 at turbines in string interior; -6 at edge of gaps |
| Burrow system density | -42 at turbines with lowest densities of pocket gophers;<br>-39 at turbines with intermediate ground squirrel densities;<br>-36 at turbines with lowest densities of all mammal species |
| Cottontail abundance | -33 at turbines with no cottontail pellets |
| Rodent control | -29 in areas of intense rodent control |
| Cattle pats | -27 at turbines with the most cattle pats nearby |
| Time of day | -27 in early to mid morning |
| Location of wind farm | -25 in interior of APWRA |
| Blade tip speed | -23 at turbines with slowest to intermediate tip speeds |
| High blade reach | -23 at wind turbines with highest blade reach |
| Vegetation height | -22 at turbines with taller vegetation nearby |

**Table 8-18. (cont'd)**

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Flight height (cont'd)*** |
| Month | -22 in March and April |
| Turbine congestion | -17 in areas most densely packed with wind turbines |
| Elevation | -17 at highest elevations |
| Burrow clustering | -15 at turbines with no clustering of ground squirrel burrows;<br>-17 at turbines with greatest clustering of all fossorial mammals |
| Turbine model | -16 near KCS-56 |
| Physical relief | -14 over ridge crests |
| Edge index | -12 at turbines with little or no lateral edge |
| Wind wall | -12 at wind walls |
| Slope grade | -12 over flat terrain |
| Tower type | -10 at tubular towers |
| Canyons | -8 in canyons |
| | ***Distance from turbines*** |
| Position in string | -46 at string interior; -4 at gaps in string |
| Burrow system density | -42 in areas of lowest pocket gopher density;<br>-34 in areas of low to moderate ground squirrel density;<br>-23 in areas of lowest densities of all burrow systems |
| Location in wind farm | -30 in APWRA interior |
| Slope grade | -24 on shallow to moderate slopes |
| Cattle pats | -23 at turbines with the most cattle pats nearby |
| Blade tip speed | -23 at turbines with faster tip speeds |
| Cottontail abundance | -21 at turbines with no sign of cottontails |
| Rodent control | -19 in areas of rodent control |
| Burrow clustering | -18 at turbines with gophers clustered close by;<br>-14 at turbines with squirrels nearby but not clustered at turbine |
| Turbine model | -18 at KCS-56; -6 at Bonus |
| High blade reach | -17 at turbines with higher blade reaches |
| Physical relief | -16 on ridge crests |
| Turbine congestion | -15 in areas of highest turbine density |
| Month | -14 during March and April |
| Time of day | -13 during early to mid morning |
| Wind wall | -12 at wind walls |
| Canyon | -8 outside of canyons |
| Rock piles | -4 at turbines with rock piles nearby |
| | ***Dangerous flights*** |
| Rotor plane swept/s | 62 at turbines with slowest rates of sweeping the rotor plane |
| Turbine model | 48 at Flowind |

**Table 8-19.** The directions and magnitudes of significant associations between measured red-tailed hawk behaviors and independent variables

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Time spent perching*** |
| Position in string | 36 at end turbines |
| Burrow clustering | 23 where ground squirrels occur, but uniformly distributed |
| Burrow system density | 8 in areas of highest pocket gopher densities;<br>12 in areas of highest ground squirrel densities;<br>23 in areas of highest densities of all fossorial mammals |
| Rotor plane swept/s | 21 at turbines with slowest rates of sweeping the rotor plane |
| Wind speed | 20 in slow winds |
| Month | 17 in January |
| Elevation | 17 at low elevations |
| Physical relief | 16 on slopes |
| Edge index | 12 at turbines with lots of vertical edge nearby |
| Wind direction | 10 in east winds |
| Time of day | 9 in the middle of the day |
| Tower type | 8 at vertical axis turbines |
| Wind wall | 8 at turbines outside wind walls |
| Cattle pats | 8 at turbines with more cattle pats nearby |
| Slope aspect | 8 on east and northeast slopes |
| Turbine congestion | 7 in areas of low turbine density |
| Rock piles | 6 at wind turbines with no rock piles nearby |
| Vegetation height | 6 in areas of taller vegetation |
| Derelict turbines | 4 at derelict turbines |
| Location in wind farm | 4 at edge of local cluster |
| Rodent control | 4 in areas of intermittent rodent control |
| | ***Time spent flying*** |
| Position in string | 33 at end turbines |
| Burrow clustering | 14 in areas with no gophers; 8 in areas of moderate gopher clustering;<br>29 in areas with no ground squirrels near wind turbines |
| Burrow system density | 25 in areas with no ground squirrel burrow systems nearby turbines;<br>8 in areas of lowest mammal burrow system densities |
| Time of day | 21 in early afternoon |
| Slope aspect | 19 over northwest to northeast slopes |
| Wind speed | 18 in moderate winds |
| Wind direction | 17 in north and northwest winds |
| Slope grade | 17 over steepest slopes |
| Edge index | 17 at turbines with some to lots of vertical edge |
| Physical relief | 15 over slopes; 8 over ridgelines |
| Location in wind farm | 15 at edge of local cluster; 4 at edge of APWRA |
| Turbine congestion | 14 in areas of lowest turbine density |
| Turbine model | 12 at Flowind |

**Table 8-19. (cont'd)**

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Time spent flying (cont'd)*** |
| Rotor plane swept/s | 12 at turbines with slowest rates of sweeping the rotor plane |
| Cattle pats | 12 at turbines with the most cattle pats |
| Elevation | 10 in areas of intermediate elevation |
| Month | 9 in November; 9 in March/April |
| Vegetation height | 8 at turbines with shorter vegetation nearby |
| Rock piles | 7 at turbines without rock piles nearby |
| Cottontail abundance | 6 at turbines with some pellets |
| Derelict turbine | 4 at derelict turbines |
| Rodent control | 4 in areas of no rodent control |
| | ***Flight height*** |
| Burrow clustering | -37 in areas of greatest gopher clustering at turbines;<br>-10 in areas of ground squirrel clustering at turbines;<br>-21 in areas of modest clustering of mammal burrows at turbines |
| Time of day | -19 during early to mid morning |
| Burrow system density | -18 in areas of highest pocket gopher density near turbines;<br>-13 in areas of modest density of ground squirrels;<br>-12 in areas of modes to high density of all mammal burrows |
| Position in string | -16 at turbines in the string interior; -3 at turbines at gaps |
| Wind direction | -15 in southwest and west winds |
| Edge index | -14 at turbines with some or lots of lateral edge |
| Rotor diameter | -9 at turbines with larger rotor diameters |
| Slope aspect | -9 over south and southeast slopes |
| Location in wind farm | -8 in APWRA interior |
| Elevation | -8 at highest elevations |
| Vegetation height | -7 at turbines with the tallest vegetation nearby |
| Rock piles | -7 at turbines with rock piles nearby |
| Wind speed | -5 in slowest winds;<br>-5 in strong winds |
| Tower type | -5 at tubular towers |
| Slope grade | -5 over steepest slopes |
| Canyon | -5 in canyons |
| Physical relief | -4 over ridge crests |
| Rodent control | -4 in areas of intermittent rodent control |
| | ***Distance from turbines*** |
| Position in string | -34 at turbines in the string interior |
| Burrow system density | -4 in areas of no pocket gophers near wind turbines;<br>-21 at turbines with ground squirrel burrows within 90 m |
| Burrow clustering | -17 in areas of moderate gopher clustering at turbines;<br>-10 in areas of ground squirrel clustering at turbines;<br>-5 in areas of modest clustering of mammal species at turbines |

**Table 8-19. (cont'd)**

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Distance from turbines*** |
| Location in wind farm | -14 in APWRA interior |
| Cottontail abundance | -11 at turbines with no pellets nearby |
| Turbine congestion | -10 in areas of highest turbine density |
| Rotor plane swept/s | -10 at turbines with highest rates of sweeping the rotor plane |
| Rotor diameter | -9 at turbines with largest rotor diameters |
| Rodent control | -7 in areas of rodent control |
| Wind speed | -5 in slowest winds;<br>-7 in strong winds |
| Tower type | -7 at tubular towers |
| Physical relief | -7 over ridge crests |
| Canyon | -5 in canyons |
| Rock piles | -3 at turbines with rock piles nearby |
| | ***Dangerous flights*** |
| Slope grade | 34 on steepest slopes |
| Burrow system density | 30 at turbines with no ground squirrel burrows nearby;<br>18 with moderate densities of all mammal burrows nearby |
| Burrow clustering | 16 at turbines with uniformly distributed gopher burrow systems;<br>27 at turbines with no ground squirrel burrows nearby<br>13 at turbines with moderate clustering of all mammal burrows |
| Turbine model | 26 at Flowind |
| Cattle pats | 26 at turbines with the most cattle pats nearby |
| Position in string | 24 at end turbines |
| Location in wind farm | 24 at edge of local clusters of turbines |
| Turbine congestion | 24 in areas of lowest turbine density |
| Wind speed | 24 in moderate winds |
| Time of day | 22 in early afternoon |
| Edge index | 21 at turbines with some or lots of vertical edge |
| Rotor plane swept/s | 19 at turbines with slowest rates of sweeping the rotor plane |
| Slope aspect | 19 on north and northwest slopes |
| Physical relief | 17 on ridgeline;<br>13 on slope |
| Month | 12 in November;<br>13 in March |
| Vegetation height | 12 at turbines with the shortest vegetation nearby |
| Derelict turbine | 10 at derelict turbines |
| Wind direction | 10 in northwest winds; 10 in southwest winds |
| Rock piles | 9 at turbines with no rock piles nearby |

**Table 8-20.** The directions and magnitudes of significant associations between measured American kestrel behaviors and independent variables

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Time spent perching*** |
| Month | 35 in December through February |
| Position in string | 31 at end turbines |
| Wind speed | 15 in moderate winds |
| Temperature | 13 in 50–59 ˚F |
| Burrow system density | 13 in areas of moderate gopher density;<br>9 in areas of moderate to high density of all mammal burrows |
| Elevation | 8 at highest elevations |
| Slope grade | 8 on steepest slopes |
| Location in wind farm | 7 at APWRA edge; 4 at edge of local turbine cluster |
| Wind direction | 6 in northwest winds; 7 in no winds |
| Time of day | 5 in late morning |
| Rodent control | 4 in areas of intense rodent control |
| Blade tip speed | 4 at turbines with the slowest tip speeds |
| Derelict turbine | 3 at derelict turbines |
| | ***Time spent flying*** |
| Elevation | 32 at highest elevations |
| Burrow system density | 27 in areas of highest ground squirrel density;<br>28 in areas of higher density of all mammal burrows |
| Burrow clustering | 28 where ground squirrels occur uniformly around wind turbines;<br>23 where all mammal burrows occur in uniform distribution |
| Turbine congestion | 26 in less dense turbine fields |
| Wind speed | 26 during intermediate winds |
| Time of day | 19 after noon |
| Turbine model | 18 at KVS-33 |
| Slope grade | 16 on steepest slopes |
| Rodent control | 13 in areas of intense rodent control |
| Tower type | 13 at vertical axis |
| Wind direction | 12 in southwest winds |
| Position in string | 11 at end turbines |
| Cattle pats | 11 at turbines with most cattle pats nearby |
| Cottontail abundance | 10 at turbines with no pellets nearby |
| Rock piles | 9 at turbines with rock piles nearby |
| Wind wall | 8 at turbines outside wind walls |
| | ***Flight height*** |
| Burrow system density | -33 in areas of modest gopher density out to 90 m;<br>-6 in areas of no ground squirrels out to 90 m from turbines |
| Month | -26 during spring months |

**Table 8-20. (cont'd)**

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Flight height (cont'd)*** |
| Burrow clustering | -24 in areas with no pocket gophers within 15 m of turbines;<br>-12 in areas of ground squirrels uniformly distributed by turbines;<br>-20 in areas of modest clustering of all burrows around turbines |
| Tower height | -17 at intermediate to shortest towers |
| Time of day | -17 during morning and early afternoon |
| Cattle pats | -14 at turbines with fewest cattle pats nearby |
| Vegetation height | -13 at turbines with tallest vegetation nearby |
| Turbine model | -12 at KCS-56; -4 at Bonus |
| Blade tip speed | -12 at turbines with fastest tip speeds |
| Wind direction | -12 in southwest winds |
| Edge index | -12 at turbines with no vertical edge |
| Rock piles | -12 at turbines with no rock piles nearby |
| Slope grade | -11 on shallow to intermediate slopes |
| Position in string | -10 at turbines in string; -4 at edges of gaps |
| Turbine congestion | -9 at turbines in dense turbine fields |
| Wind speed | -8 in slow winds |
| Wind wall | -7 near wind walls |
| Physical relief | -6 over ridge crests |
| Rodent control | -3 in areas of intense rodent control |
| | ***Distance from turbines*** |
| Position in string | -24 at turbines in string interior; -3 at edge of gap |
| Burrow clustering | -21 in areas of greatest gopher clustering at wind turbines;<br>-19 at turbines lacking ground squirrels within 15 m;<br>-12 at turbines with greatest clustering of all mammal burrows |
| Elevation | -15 at middle and lower elevations |
| Month | -14 during April and May |
| Turbine congestion | -13 in areas of greater turbine density |
| Burrow system density | -12 in areas of moderate gopher density to 90 m;<br>-7 at turbines lacking ground squirrels out to 90 m;<br>-9 at turbines with lowest densities of mammal burrows to 90 m |
| Cattle pats | -10 at turbines with the most cattle pats nearby |
| Location in wind farm | -10 at turbines interior to APWRA |
| Time of day | -8 during the morning |
| Slope grade | -6 on shallower slopes |
| Slope aspect | -6 on east and northeast slopes |
| Rodent control | -6 in areas of intermittent rodent control |
| Wind wall | -6 by wind walls |
| Tower type | -4 at tubular towers |
| Blade tip speed | -3 at turbines with fastest tip speeds |

**Table 8-20. (cont'd)**

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | *Dangerous flights* |
| Elevation | 33 at highest elevations |
| Burrow clustering | 31 at turbines with ground squirrels occurring within 15 m |
| Wind speed | 26 in moderately fast winds |
| Wind direction | 25 in southwest, west and northwest winds |
| Turbine model | 24 at Flowind;<br>15 at KVS-33 |
| Time of day | 22 during mid to late afternoon |
| Turbine congestion | 21 in sparsely distributed turbine fields |
| Slope grade | 17 on steepest slopes |
| Rodent control | 15 in areas of intense rodent control |
| Slope aspect | 12 on northwest slopes |
| Cattle pats | 12 at turbines with the most cattle pats nearby |
| Wind wall | 7 at turbines outside wind walls |
| Position in string | 6 at end turbines |

**Table 8-21.** The directions and magnitudes of significant associations between measured turkey vulture behaviors and independent variables

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | *Time spent flying* |
| Position in string | 38 by end turbines |
| Burrow system density | 26 at turbines with low to moderate gopher densities to 90 m;<br>9 at turbines with no ground squirrels to 90 m;<br>31 at turbines with no mammal burrows to 90 m |
| Time of day | 26 during noon to early afternoon |
| Burrow clustering | 23 at turbines with no or few gophers within 15 m;<br>10 at turbines with burrows of all mammals clustered within 15 m |
| Rotor plane swept/s | 22 at turbines with slowest rates of sweeping the rotor plane |
| Location in wind farm | 19 at edge of APWRA or local clusters of turbines |
| Month | 19 during March |
| Vegetation height | 16 at turbines with shorter vegetation nearby |
| Wind speed | 16 at moderate wind speeds |
| Cattle pats | 14 at turbines with fewest cattle pats nearby |
| Physical relief | 13 on slopes |
| Rotor diameter | 12 at turbines with smaller rotor diameters |
| Wind direction | 11 in northwest winds |
| Tower type | 11 at vertical axis |

Table 8-21. (cont'd)

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | *Time spent flying (cont'd)* |
| Edge index | 11 at turbines with vertical edge |
| Rodent control | 11 in areas of no rodent control |
| Cottontail abundance | 11 at turbines with pellets counted nearby |
| | ***Flight height*** |
| Position in string | -28 at turbines in string interior |
| Burrow clustering | -27 in areas of greatest gopher clustering at turbines;<br>-12 at turbines with ground squirrels uniformly distributed nearby |
| Rotor plane swept/s | -23 at turbines with fastest rates of sweeping the rotor plane |
| Burrow system density | -22 in areas of highest gopher density to 90 m<br>-10 in areas of highest ground squirrel density to 90 m;<br>-17 in areas of highest density of burrows of all mammals to 90 m |
| Physical relief | -22 over ridge crests |
| Vegetation height | -17 at turbines with taller vegetation nearby |
| Cottontail abundance | -14 at turbines with no pellets nearby |
| Temperature | -13 during 50–59 ˚F |
| Turbine model | -13 at Bonus;<br>-9 at KCS-56 |
| Rotor diameter | -12 at turbines with largest rotor diameters |
| Time of day | -12 during morning hours |
| Elevation | -11 at highest elevations |
| Slope grade | -11 on shallowest slopes |
| Canyon | -10 in canyon |
| Rodent control | -10 in areas of rodent control |
| Month | -10 during November and December |
| Wind direction | -9 during no winds |
| Blade tip speed | -9 at turbines with fastest tip speeds |
| Wind wall | -6 by wind walls |
| Location in wind farm | -6 in APWRA interior |
| Turbine congestion | -5 in sparsest turbine fields |
| | ***Distance from turbines*** |
| Burrow system density | -37 at turbines with moderate to high gopher density to 90 m;<br>-11 at turbines with moderate to high ground squirrel density;<br>-26 at turbines with moderate to high density of all mammals |
| Position in string | -32 at turbines in string interior; -3 at gaps |
| Rotor plane swept/s | -27 at turbines with faster rates of sweeping the rotor plane |
| Location in wind farm | -27 in APWRA interior |
| Burrow clustering | -23 at turbines with gopher burrows clustered within 15 m;<br>-18 in areas where ground squirrels occur uniformly by turbines |
| Turbine model | -22 at Bonus |

**Table 8-21. (cont'd)**

| Variable | Difference between observed and expected values as percent of total |
|---|---|
| | ***Distance from turbines (cont'd)*** |
| Rotor diameter | -20 at turbines with larger rotor diameters |
| Rodent control | -19 in areas of rodent control |
| Physical relief | -19 over ridge crests |
| Time of day | -17 during morning |
| Temperature | -13 during coolest temperatures |
| Vegetation height | -13 at turbines with taller vegetation nearby |
| Edge index | -12 at turbines with no vertical edge nearby |
| Cattle pats | -12 at turbines with more cattle pats nearby |
| Month | -11 during January |
| Canyon | -11 in canyons |
| Wind direction | -9 in no winds |
| Rock piles | -8 at turbines with rock piles nearby |
| Slope aspect | -7 on north and northwest slopes |
| Cottontail abundance | -7 at turbines with no pellets nearby |
| Slope grade | -5 on shallowest slopes |
| | ***Dangerous flights*** |
| Position in string | 34 at end turbines |
| Burrow system density | 32 at turbines with no gophers within 90 m;<br>26 at turbines with lowest densities of mammal burrows to 90 m |
| Burrow clustering | 19 at turbines with no gophers within 15 m;<br>30 at turbines with ground squirrels clustered within 15 m |
| Rotor plane swept/s | 30 at turbines with slowest rates of sweeping the rotor plane |
| Time of day | 25 during early and mid afternoon |
| Rotor diameter | 25 at turbines with moderate to smallest rotor diameters |
| Tower type | 24 at vertical axis |
| Wind speed | 19 in stronger winds |
| Cattle pats | 18 at turbines with fewer cattle pats nearby |
| Wind direction | 16 in northwest winds |
| Vegetation height | 15 at turbines with shorter vegetation nearby |
| Elevation | 14 at mid-elevations |
| Slope grade | 14 on steeper slopes |
| Month | 12 during March;<br>12 during May |
| Edge index | 14 at turbines with vertical edge nearby |
| Cottontail abundance | 11 at turbines with abundant pellets nearby |
| Rodent control | 9 in areas of intense control; 5 in areas of no control |

### 8.4.4 Bird Behaviors and Fatalities

Tables 8-22 through 8-24 present the fatality associations chosen for development of the indicators of relative threat to golden eagle, red-tailed hawk, and American kestrel summarized in this chapter, and these tables compare their magnitude of effect to those of the behaviors associated with the same variables. In other words, we compared the measures of effect of the relationships between fatalities and their most effective predictor variables to the measures of effect of the relationships between measured behaviors and the same predictor variables that most effectively associated with fatalities. Thus, these predictor variables are not the only associations that were statistically significant in either the behavior or fatality studies, but were those that we chose due to their easily interpretable patterns of association and relative degree of independence from other measured variables in representing underlying factors associated with fatalities. Blank cells in the tables indicate statistically insignificant test results or where tests were not performed due to inadequate sample sizes. The caption for Table 8-22 provides examples of how to interpret the numbers presented in Tables 8-22 to 8-24.

Where golden eagles collided with wind turbines disproportionately more often at highest mammal burrow system densities, they also perched disproportionately more often and they flew lower to the ground and closer to wind turbines where mammal burrow system densities were highest. It is possible that golden eagles perch and launch more dangerous flights for hunting purposes where small mammals more densely occur near wind turbines. Augmenting this pattern, golden eagles collided with wind turbines disproportionately less often in areas of intense rodent control, which is where they also perched disproportionately more often and flew lower to the ground and closer to wind turbines.

Golden eagles were killed disproportionately more often by wind turbines with lower heights of the high blade reach, but flew lower to the ground and closer to wind turbines with highest reaches of the high blade reach. It appears that golden eagles make an effort to fly under the rotor planes of wind turbines, and perhaps more frequently fail to fly under the rotor planes that reach lower to the ground. These results were consistent with our observations that golden eagles give a wider flight berth to those wind turbines we predicted to be more dangerous to golden eagles (Table 17).

Golden eagles were disproportionately killed by wind turbines in sparse turbine fields, and they perched preferentially in the lowest-density turbine fields. However, they flew preferentially lower to the ground in the highest-density turbine fields. That they flew preferentially closer to wind turbines in the densest turbine fields is likely an artifact of the average distances being forced closer as the density of turbine fields increases. However, all evidence considered, golden eagles appear to seek out areas that are more sparsely occupied by wind turbines.

Collisions of golden eagles occurred at turbines on ridgelines more often than expected by chance, but these are not the locations where golden eagles preferred to perch or to fly low to the ground. However, collisions occurred disproportionately more often in canyons and on steeper slopes, which is also where golden eagles preferred to perch. Also, golden eagles preferred to fly lower to the ground in canyons. Golden eagles appear to prefer to hunt from perch sites and to ambush prey items within the larger drainage structures of the APWRA, and in doing so they tend to fly higher while maneuvering over ridgelines in these drainage systems. It is this rise in altitude over ridgelines that may lead to more than the expected number of fatalities at wind turbines on ridgelines.

Whereas golden eagles preferred to perch in areas with fewer cattle pats, they flew lower to the ground and closer to wind turbines where cattle pats were most abundant, and this is also where they were killed disproportionately more often. Possibly, golden eagles expect to ambush prey where many cattle pats cover the ground because this is also where the grass is shortest, which is why they fly in close to wind turbines and low to the ground in these areas of high cattle pat abundance.

Golden eagles preferred to both perch and fly near end-of-row wind turbines, where they also flew disproportionately lower to the ground and closer to wind turbines, and where they died disproportionately more often. Contrary to red-tailed hawks, golden eagles do not appear to be making any extra effort to avoid end-of-row turbines, unless it is the lower flight that is the avoidance measure. However, this dangerous flight pattern appears to contribute significantly to golden eagle mortality.

Red-tailed hawks died at wind turbines disproportionately more often on steep slopes with lots of vertical edge and in canyons, and it was over these conditions red-tailed hawks also preferred to perch and fly and where they flew lower to the ground, closer to wind turbines, and where they performed disproportionately more of their dangerous flights. They also collided disproportionately more often with end-of-row turbines, where they also preferred to perch and fly and to make their dangerous flights. Their disproportionate collisions at wind turbines with larger rotor diameters and on tubular towers also corresponded with preferential perching and flight time and with the frequency of dangerous flights associated with these turbine characteristics. The same was true for wind turbines at the edges of local clusters, and to a smaller extent at wind turbines in areas of intermittent rodent control.

American kestrels died at wind turbines disproportionately more often at highest elevations within the APWRA, and this is where they preferred to perch and fly, and to make more of their dangerous flights by wind turbines. They collided with KVS-33 turbines disproportionately more often, and these turbines happened to also occur at the highest elevations, so the correspondence with behavior variables was likely a result of shared variation in conditions.

**Table 8-22.** Correspondence between measures of the magnitude and directions of fatalities with independent variables and behaviors with independent variables for golden eagles. As an example, the first cell under fatalities means, “33% of total golden eagle fatalities can be attributed to wind turbines in areas of highest mammal burrow system density within a 90-m radius of the wind turbines.” The first cell under perching time means, “67% of total observed golden eagle perching time can be attributed to locations within areas of highest mammal burrow system density.” The first cell under flight height means, “36% less of the summed golden eagle flight heights can be attributed to locations of highest mammal burrow system density,” meaning that golden eagles flew considerably lower to the ground where mammal burrow systems were abundant.

| | Percent of total of dependent variable attributed to accompanying category or level of wind turbine | | | | | |
|---|---|---|---|---|---|---|
| **Variable** | **Fatalities** | **Perching time** | **Flight time** | **Flight height** | **Flight distance from turbines** | **Dangerous flight time** |
| Mammal burrow density to 90 m | 33 at highest | 67 at highest | | -36 at lowest | -23 at lowest | |
| Pocket gopher density to 90 m | 30 at highest | 70 at highest | 21 at highest | -42 at lowest | -42 at lowest | |
| Edge index | 27 with more vertical edge | | | -12 with little or no edge | | |
| Height of high blade reach | 25 at lower | | | -23 at highest | -17 at highest | |
| Turbine density | 21 low | 12 lowest | | -17 highest | -15 highest | |
| Physical relief | 21 on ridgeline | 38 on slopes<br>14 on flat | | -14 on ridge crest | -16 on ridge crest | |
| Areas of intense rodent control | -20 | 19 | | -29 | -13 | |
| Cattle pat abundance | 19 with more | 53 with fewer | | -27 with most | -23 with most | |
| Position in string:<br>At the string end<br>At the edges of gaps | <br>17<br>2 | 51 | 43 | <br>-42<br>-6 | <br>-46<br>-4 | |
| In canyons | 13 | 12 | | -8 | 8 | |
| Slope grade | 13 on steeper slopes | 22 on steepest slopes | | -12 on flat terrain | -24 on shallow-moderate slopes | |
| Turbines *not* in wind walls | 12 | 12 | 12 | 12 | 12 | |
| Location in APWRA | 12 cluster edge | 33 farm edge<br>17 cluster edge | 14 farm edge<br>6 cluster edge | -25 in interior | -30 in interior | |

**Table 8-23**. Correspondence between measures of the magnitude and directions of fatalities with independent variables and behaviors with independent variables for red-tailed hawks. As an example, the first cell under fatalities means, "15% of total red-tailed hawk fatalities can be attributed to wind turbines located in 'canyons.'"

| | **Percent of total of dependent variable attributed to accompanying category or level of wind turbine** | | | | | |
|---|---|---|---|---|---|---|
| **Variable** | **Fatalities** | **Perching time** | **Flight time** | **Flight height** | **Flight distance from turbines** | **Dangerous flight time** |
| Whether in canyon | 15 in canyon | | | -5 in canyon | -5 in canyon | |
| Edge index | 13 at greater vertical edge | 12 with greater vertical edge | 17 at greater vertical edge | -14 at greater vertical edge | | 21 at greater vertical edge |
| Slope grade | 11 on steeper slopes | | 17 on steepest slopes | -5 on steepest slopes | | 34 on steepest |
| Position in turbine string | 11 at string end 1 at gap edge | 36 at string end | 33 at string end | -16 at interior<br>-3 at gap edge | -34 at interior | 24 at string end |
| Rotor diameter | 10 at larger | 12 from intermediate | 12 from intermediate | -9 from largest | -9 from largest | 17 from intermediate |
| Height of highest blade reach | 9 at highest | 10 at intermediate | 18 at intermediate | 11 at intermediate | 4 at lowest | 25 at intermediate |
| Location in wind farm | 9 cluster edge | 4 at cluster edge | 15 at cluster edge | -8 in interior | -14 in interior | 24 at cluster edge |
| Turbine density | 8 at lower | 7 at lower | 14 at lowest | | -10 at highest | 24 in lowest |
| Elevation | 8 at middle | 17 at low | 10 at middle | -8 at highest | | |
| Rodent control | 8 at intermittent control | 4 at intermittent control | 4 at no control | -4 at intermittent control | -7 at intermittent control | |
| Tower type | 7 at tubular | 8 at vertical axis | 12 at vertical axis | -5 at tubular | -7 at tubular | 26 at vertical axis |
| Slope aspect | 5 on North/ NW<br>4 on South/SE | 8 on East/NE | 19 NW to NE | -9 on S/SE | | 19 on N/NW |

**Table 8-24.** Correspondence between measures of the magnitude and directions of fatalities with independent variables and behaviors with independent variables for American kestrels

| | Percent of total of dependent variable attributed to accompanying category or level of wind turbine | | | | | |
|---|---|---|---|---|---|---|
| **Variable** | **Fatalities** | **Perching time** | **Flight time** | **Flight height** | **Flight distance from turbines** | **Dangerous flight time** |
| Elevation | 12 at highest<br>5 at lowest | 8 at highest | 32 at highest | -10 at lowest | 13 at highest | 33 at highest |
| Rotor-swept area/second | 10 at highest rates | 4 at low-moderate rates | 18 at highest rates | -14 at moderate high rates | -6 at low-moderate rates | 15 at highest<br>14 at lowest |
| Physical relief | 10 on ridgeline 5 on ridge crest | 5 on ridge crest<br>3 on saddle | | -6 on ridge crest | | |

### 8.4.5 Wind Turbine Perceptions by Birds

As was the case for the NREL study (Smallwood and Thelander, in review), we found evidence that raptors recognize wind turbines as dangerous and that they take measures to avoid wind turbines, such as attempting to fly around the turbines at the ends of strings, and flying lower to the ground or higher to the ground around the end turbines (to name two examples), depending on the species. Nevertheless, dangerous flights are still made, and these are made disproportionately more often under certain conditions. Also, raptors perform disproportionately more of their perching and flying within 50 m of wind turbines, despite the evidence that they generally attempt to avoid wind turbines while perching and flying. Raptors apparently are drawn to the vicinity of wind turbines while also minimizing their nearness to busier turbine fields and turbines with faster tip speeds and larger rotor diameters. Also, red-tailed hawks and American kestrels appear to attempt to avoid end-of-row wind turbines, which happen to be where they get killed more often.

Raptors were more likely to fly close to wind turbines with slower-moving rotor blades and mounted on tubular towers, as well as to vertical axis turbines. They also were more likely to fly close by wind turbines that are more widely spaced apart.

These results indicate that wind turbines may be able to reduce mortality if they were more closely spaced and if they appeared "busier" on the landscape. They could also be flanked by inert structures that raptors can see and attempt to avoid by flying wide around them, thereby reducing the frequency of flying into the rotor zone of the end-of-row turbines.

In conclusion, behavior observation studies and studies of bird activity levels should precede the installation of wind turbines at new wind farms. Bird flight patterns could help guide the design of the wind farm, including the appropriate heights of wind turbines, the spatial arrangement of wind turbines, and the specific locations of wind turbines relative to the topography and land use practices. Additionally, pre-project behavior observation studies enable the measurement of the contributions of species susceptibility and project-induced vulnerability in leading to impacts after the wind farm is installed and operating. Our study supported the findings of Smallwood and Thelander (in review) that bird behaviors were likely changed by the ongoing activities of the wind farm, as exemplified by the apparent strong attraction of most bird species for the vicinity of wind turbines. However, the only way to know for certain whether birds are attracted to the vicinity of wind turbines is to perform behavior studies with a before-after control impact (BACI) design.

Typical of scientific investigations, ours left many new questions and unsatisfactory answers, even though much was learned. To satisfactorily answer many of the remaining questions, future behavioral studies at wind energy generating facilities will require much greater sampling effort and therefore much more funding. It will also require a BACI design.

One promising technology that could to be applied to the APWRA and other wind energy facilities is radar sampling with three-dimensional resolution. Radar would allow for more data to be collected over the study period and generate data representative of nighttime conditions, as well—a representation that we did not address. Radar, in combination with point counts, could inform us more effectively about the flight patterns of various groups of species in the APWRA and at other new wind farms, and information of the new wind turbines could be combined to forecast bird impacts under various wind farm design scenarios.

### 8.4.6 Flight Heights Relative to Existing and Proposed Future Rotor Planes

One of the most useful results of our behavior study may be the comparison of the frequencies of flight height above ground to the rotor planes of existing wind turbines, and what may imply for the rotor plane heights of wind turbines proposed for the APWRA repowering program. These comparisons reveal that for raptors most flights occur at heights that are within the rotor planes of currently operating wind turbines. This strongly suggests that the rotor plane heights contribute substantially to raptor mortality.

The heights of rotor blades on turbines proposed for repowering the APWRA overlap considerably with the rotor plane heights on wind turbines currently operating in the APWRA. While fewer raptor flights would be made within the proposed rotor plane heights, the difference would probably fail to substantially reduce raptor mortality. The wind turbines with the tallest towers being proposed for repowering will, however, operate at heights well above the majority of raptor flights we recorded. This difference in flight frequency at the tallest proposed rotor height is substantial and may have significant implications.

Flight behavior data we collected indicate that the frequency that golden eagles will fly at the tallest rotor plane heights being proposed for repowering is 50% less than the frequency they currently fly within the rotor plane heights of the smaller turbines now in use. American kestrels will fly at the heights of the tallest rotor plane only 15% as frequently as they do at the heights of the current rotor planes. Overall, raptors would fly at the heights of the proposed tallest wind turbines at only 21% of the frequency as they fly at the heights of the current rotor planes. If the frequency of raptor flights at rotor plane heights contributes significantly to raptor mortality, then a potential ~80% reduction in frequency of flights at rotor plane height (assuming the tallest turbines being proposed are installed) could reduce raptor mortality significantly. This can be achieved if the new towers used for repowering have rotor planes greater than 29 m from the ground.

Combining rigorous turbine siting guidelines, based on research findings presented herein, with the installation of turbines with rotor planes greater than 29 m above the ground may result in a substantial reduction in raptor mortality.