# BEHAVIOR OF RED-TAILED HAWKS IN A WIND TURBINE DEVELOPMENT

STACIA L. HOOVER,[1,2] Department of Biological Sciences, California State University, Sacramento, CA 95819, USA
MICHAEL L. MORRISON,[3,4] Department of Biological Sciences, California State University, Sacramento, CA 95819, USA

***Abstract:*** Birds flying within windfarms can be killed when they collide with wind turbines. Raptors, especially red-tailed hawks (*Buteo jamaicensis*), are more susceptible to collisions than other birds, which may be attributable to their specific foraging and flight behavior. To more fully understand the problem, and to reduce raptor mortality, it is necessary to acquire more information on habitat use and flight behavior by raptors inhabiting windfarms. Between June 1999 and June 2000, we watched raptors for 346 hours in the Altamont Pass Wind Resource Area, the largest windfarm in North America. We recorded flight behavior in relation to characteristics of the topography such as slope aspect, elevation, and inclination and in relation to various weather variables including wind speed and wind direction. We found that red-tailed hawk behavior and their use of slope aspect differed according to wind speed. Hawks perched more often in weak winds than in strong. Red-tailed hawks were more likely to soar during low wind conditions and kite during strong wind, particularly on hillsides that faced into the wind as opposed to hillsides shielded from the wind. This is likely a result of their use of deflection updrafts for lift during flight. During our study, when winds were strong and from the south–southwest, kiting behavior occurred on south–southwestern facing slopes with inclines of greater than 20% and peak elevations greater than adjacent slopes. Accordingly, mitigation measures to decrease red-tailed hawk fatalities should be directed specifically to these areas and others fitting this general model. Wind farm managers can power down turbines at the top of these hazardous slopes when they pose the greatest danger—when winds are strong and facing perpendicularly to the slope.

***JOURNAL OF WILDLIFE MANAGEMENT 69(1):150–159; 2005***

***Key words:*** Altamont Pass Wind Resource Area, *Buteo jamaicensis*, flight behavior, habitat use, red-tailed hawk, wind turbine.

Commercial wind energy plants have been constructed in 22 states, and additional projects are planned in others. Until recently, most windpower development in the United States occurred in California; however, a group of 12 states in the midsection of the country have enough wind energy potential to produce nearly 4 times the amount of electricity consumed by the nation in 1990 (M. N. Schwartz, American Wind Energy Association's Windpower '92 Conference, Seattle, Washington, USA).

Although generally considered environmentally friendly, wind power has been associated with the death of birds from colliding with turbines and other windplant structures, especially in California (Erickson et al. 2001). Early wind energy facilities in the United States often were constructed in areas without an understanding of the level of avian use at those locations. Consequently, some of these facilities are located where birds are abundant and the risk of turbine collisions is relatively high (American Wind Energy Association 1995). High raptor mortality has been documented at the Altamont Pass Wind Resource Area (AWRA), California, which has resulted in a great deal of scrutiny of other windplant developments (Orloff and Flannery 1992). Wind projects have been delayed and sometimes stopped at new wind sites across the country due to avian collision concerns (Erickson et al. 2001).

Of the bird species inhabiting the hills of the AWRA, red-tailed hawks appear to be particularly susceptible to wind turbine related fatalities (Orloff and Flannery 1992, Rugge 2001). Between 1998 and 2000 at AWRA, Rugge (2001) found 316 fatalities, 55% (174) of which were raptors. Of the recorded raptor fatalities, more than half were red-tailed hawks (96).

Furthermore, although bird fatalities occur at other windfarms, documentation of such high raptor mortality, particularly for red-tailed hawks, appears unique to the AWRA. At wind facilities such as the Buffalo Ridge and Tehachapi Wind Resource Areas (in Minnesota and southern California, respectively) low raptor mortality apparently is due to low raptor activity (Orloff and Flannery 1992; Osborn et al. 1998, 1999; Johnson 2002; Anderson et al. 2004). Low raptor activity at Tehachapi may be a result of an unsuitable prey

[1] Present address: 3253 Cambridge Road, Cameron Park, CA 95682.
[2] E-mail: shoover@ecorpconsulting.com
[3] Present address: Great Basin Institute, University of Nevada, Reno, NV 89557-0031.
[4] E-mail: morrison@unr.edu

base. At Buffalo Ridge, the lack of rolling hills and canyons may deter activity by raptors that prefer sites with some topographic relief.

However, there are data suggesting that where raptors do occur, their specific flight behavior may contribute to turbine-related fatalities (Barrios and Rodriquez 2004). Giffon vultures (*Gyps fulvus*) within wind facilities located in the Campo de Gibraltar region of Spain appear to use wind currents off ridges (and near turbines), which increase their vulnerability to collisions.

Thus, specific foraging and flight characteristics of raptors make them susceptible to collisions with rotating turbine blades (Orloff and Flannery 1992). Rugge (2001) documented red-tailed hawks displaying high-risk flight behavior, measured as the time spent in close proximity to rotating turbine blades, significantly more often than medium and low-risk flight behavior.

Raptors forage in sites where specific habitat features make prey more vulnerable or hunting more energy efficient (Smith and Murphy 1973, Stinson 1980, Baker and Brooks 1981, Bechard 1982, Janes 1985). Among such habitat features are weather conditions and topography, the combination of which determines the pattern of wind currents used during raptor flight. Raptor species often soar using thermals or exploit updrafts off of ridges for lift, which allows for energy-efficient flight (Janes 1985, Dunne et. al 1988). Our goal was to understand what features attract red-tailed hawks disproportionately to some areas over others. This knowledge will assist windfarm operators to manage their facilities and decrease the incidence of raptor–turbine collisions.

## STUDY AREA

We worked at the AWRA in the hills of Altamont Pass in central California. About 70 km east of San Francisco Bay, AWRA spans the county borders of Contra Costa and Alameda. Our study area was located about 10 km northeast of Livermore and was bordered on the south by Interstate 580 and on the west by the California Aqueduct.

Hill elevations ranged from 230 m to 375 m above sea level, and valley elevations ranged from 78 m to 188 m above sea level. Livestock grazing is the main form of land use in the area, and vegetation growing in the compact soil is sparse. Vegetation reaches its highest biomass during the winter months and consists primarily of annual European grasses. No shrubs and very few trees exist in the area. As a result, available perch sites for birds consist primarily of human-made structures, such as turbines, anemometer and power poles, and fence posts.

The season of strongest winds typically ranges from April to September when air from the warm valley meets the cool marine air. The temperature differential creates strong south and southwestern winds that range from 25 to 61 km/hr. During the winter months, wind speeds drop considerably and can come from various directions (Orloff and Flannery 1992). Average yearly precipitation was about 37 cm, occurring primarily in the winter months (Dec–Feb; USGS Water Resources of California, accessed 12 July 2004. U.S. Geological Service, http://ca.water.usgs.gov/archive/waterdata/).

## METHODS

We established 15 study plots within the AWRA for data recording. Our criteria in selecting these plots were (1) each plot was accessible and we were granted access to the property by the landowner or wind facility manager, (2) the plot was a minimum of 500 × 500 m, and (3) we had an unobstructed view of the entire plot from the observation point. The total area of all plots was approximately 375 ha.

Each plot was subdivided into smaller units (mean = 7) and each was given a unique identification number. These smaller units, referred to as slopes, were distinguished from one another by a change in slope aspect or by different peak elevations. Topography and raptor behavior were recorded in reference to the slope identification number.

### Behavioral Observations

Between June 1999 and June 2000, we recorded raptor behavior during weekly 30-minute observations of each plot using an instantaneous sampling rule with 1.5-min intervals (Martin and Bateson 1986). At the end of an interval, we recorded each bird's behavior and location (i.e., which slope it was flying over) within the plot. We also visually estimated the distance from the ground for each raptor sighting as (1) 1–10 m, (2) 11–50 m, (3) 51–75 m, (4) 76–100 m, or (5) >100 m. Most of the turbine towers within our study area stand approximately 24 m tall and have a rotor diameter of about 20 m. Thus we chose height intervals that related to the height of the rotating blades, which spans the distance from 14 m to 34 m from the ground. Flight performed less than 10 m from the ground was below the rotor swept area. Flight performed

between 11 and 50 m from the ground usually included an undulating pattern and so was judged to be within the rotor swept area even though the bird occasionally flew above the blade height. The remaining categories were in increments of 25 m, which simplified estimating height in the field since the turbines could be used as references (i.e., a known height).

We defined behavior as thermal soaring, flapping, gliding, kiting, or perching. The term thermal soaring referred specifically to instances where a bird circled within a thermal without wing beats (Cone 1962). Kiting is the relatively motionless, flapless flight of a bird within a deflection updraft. Gliding is flight in a straight path without wing beats, and flapping is flight powered by wing beats. The structure used by perching birds was categorized as (1) ground or rock, (2) wind turbine, (3) power line or power pole, (4) tree, or (5) other structure.

## Topography

Each plot contained sloped areas, which were measured and described in terms of peak elevation, inclination, and aspect. Slope incline, or the steepness of the hillside, was measured as the average percent grade (i.e., the ratio of elevation change to horizontal length). Average percent grade was obtained with the use of TOPO! (©1998 Wildflower Productions, San Francisco, California, USA). The incline values ranged from 0 to 37% average percent grade; not all values within this range were represented. We used these breaks in the distribution of incline values to create 4 categories: (1) 0–13% average grade, (2) 14–18% average grade, (3) 19–23% average grade, and (4) >23% average grade. The percentages of the total area represented by incline categories 1 through 4 was 16%, 28%, 31%, and 25%, respectively.

Peak elevation, or the highest point of each slope, was obtained from 7.5-min topographical maps at 1:24,000 scale with contour intervals of 20 ft (6 m). The elevation values ranged from 128 m (420 ft) to 347 m (1,140 ft), with most values located in the middle. We attempted to develop 4 equal-sized categories to which we assigned each slope. Categories were (1) 128–183 m, (2) 189–219 m, (3) 226–256 m, and (4) 262–347 m, which represented 19%, 31%, 22%, and 29% of the total project area, respectively.

Slope aspect was recorded during the behavioral portion of the study, as the aspect of the land directly under the hawk at the time a behavior was recorded. The location of the hawk was determined to be on a windward slope if the slope aspect faced into the wind and on a protected slope if it was not facing into the wind.

## Season and Weather

To account for differences in red-tailed hawk behavior that may be attributable to season and general weather conditions, such as migratory and breeding activities, data were recorded by calendar season between 1999 to 2000. Summer was recorded from 21 June to 22 September, fall from 23 September to 20 December, winter from 21 December to 21 March, and spring from 22 March to 20 June.

We recorded wind direction to the nearest 45°. Wind conditions were categorized as weak if they were between 0 and 4 (0–28 km/h) on the Beaufort scale and strong if they were between 5 and 7 (29–61 km/h). Cloud cover was visually estimated as 0–25%, 26–50%, 51–75%, or 76–100%.

## Statistical Analyses

We observed hawks in 694 observational sessions totaling 346.5 hours; the red-tailed hawk comprised 76% of the total raptor sightings. We used the mean number of observations per session as our measurement of activity to test whether the occurrence of behaviors (e.g., perching, soaring, kiting) differed by weather conditions, season, and time of day. To determine whether behavior differed among specific slopes and topographic categories we used, as our measurement of activity, the mean number of sightings per session per slope divided by the area of the slope.

We used both parametric and nonparametric statistics because some of our data were heteroscedastic and not normally distributed. To test for differences in mean values among groups, we employed either the Kruskal-Wallis (K-W) test followed by the multiple comparison Nemenyi test when a difference was located, or analysis of variance (ANOVA) followed by Tukey's multiple comparison test (Zar 1996). For comparisons between 2 independent samples, we used the Mann-Whitney nonparametric test and the *t*-test (Zar 1996). The Wilcoxon paired sample test was used to detect differences between 2 related samples (i.e., to determine whether mean number of sightings within an observation session differed between slope aspects facing the wind direction and slope aspects not facing the wind; Zar 1996:167). Proportional data were examined using chi-square analysis (Zar 1996). Multivariate

analyses were not conducted because only 15 study plots were sampled.

Because our study was primarily exploratory, we set alpha at 0.10 (Ratti and Garton 1996:11). Since red-tailed hawk sightings between sessions may occasionally include repeated sightings of the same bird, the statistical conclusions of this study should not be taken to imply how all hawks behave in general. Our conclusions should be applicable, however, to birds in other wind developments because the turbines used in AWRA are typical of those used in developments throughout the United States.

## RESULTS

### Season

Red-tailed hawks sightings were most frequent during the fall season (average = 31.5 sightings/session), and less common during the remaining seasons (average sightings/session: winter = 9.8, spring 3.6, summer 3.0).

The amount of flight behavior versus perching behavior differed seasonally (Fig. 1). During summer, the number of sightings of flying hawks was 40% greater than the number of sightings of perched hawks (Wilcoxon: $P = 0.002$, $Z = -3.117$, $n = 180$). During the remaining seasons, observations of perching hawks were 2.3 to 5.3 more common than observations of hawks in flight (fall – Wilcoxon: $P = <0.001$, $Z = -5.141$, $n = 160$, winter – Wilcoxon: $P = <0.001$, $Z = -6.185$, $n = 180$, and spring – Wilcoxon: $P = 0.028$, $Z = -2.201$, $n = 157$).

### Cloud Cover

During the summer and spring, the most common cloud cover level was 0–25% (71% of sightings); however, red-tailed hawk activity was greatest during cloud cover of 51–75%. Flight activity was significantly higher in 51–75% cloud cover than in cloud cover of 0–25% (ANOVA: $P = 0.042$, $F = 2.763$, df = 3, 352; Tukey multiple comparison: $P = 0.027$). Similarly, red-tailed hawks perched during cloud cover of 51–75% roughly 4.5 times more often than during cloud cover of 0–25%, and 3 times more frequently during cloud cover of 26–50% (ANOVA: $P = 0.031$, $F = 2.985$, df = 3, 352, Tukey: $P = 0.024$ and 0.036, respectively). Red-tailed hawk flight and perch activity did not differ between cloud cover levels during the fall and winter (ANOVA: $P = 0.295$, $F = 1.240$, df = 3, 333 and $P = 0.600$, $F = 0.624$, df = 3, 333, respectively).

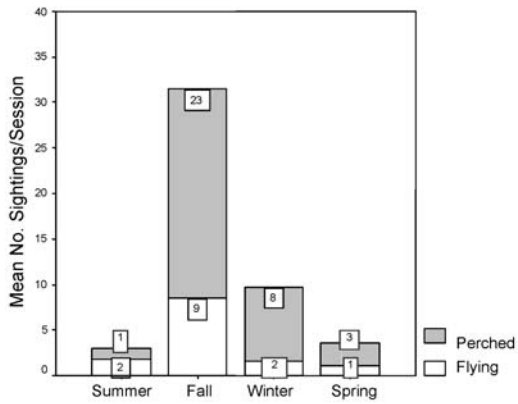


Fig. 1. Flight and perch activity of red-tailed hawks by season at the Altamont Pass Wind Resource Area, California, USA, summer 1999 to spring 2000.

### Wind Speed

Red-tailed hawks were seen perched 2.8 times more frequently when winds were weak than when they were strong (14.0 sightings/session/ha vs. 5.3 sightings/session/ha, *t*-test: $P < 0.001$, $t = 25.14$, df = 692). In addition, the primary perch structure used by red-tailed hawks in weak winds differed from perch structures used in strong winds (chi-square: $P = 0.000$, $\chi^2 = 240.748$, df = 4; Fig. 2). Hawks perched on low-lying objects, such as on boulders, or on the ground more often in strong winds than in weak winds (54% of perch sightings vs. 32%, respectively). In contrast, they used taller structures more often in weak wind conditions than in strong winds (power line/pole = 39% vs. 26%, turbine = 22% vs. 14%, tree = 0.05% vs. 0.0%).

Although the total amount of flight activity of red-tailed hawks did not differ by wind speed (*t*-test: $P =$

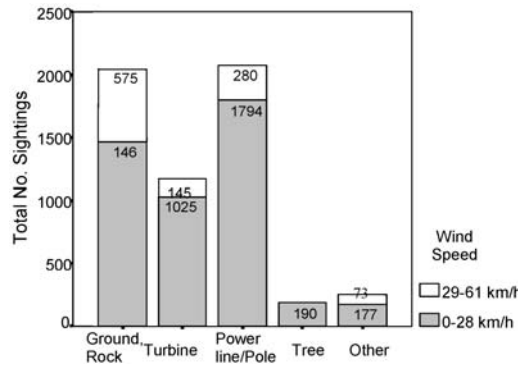


Fig. 2. Sightings of red-tailed hawk perch activity by structure type and wind speed at the Altamont Pass Wind Resource Area, California, USA, June 1999–June 2000.

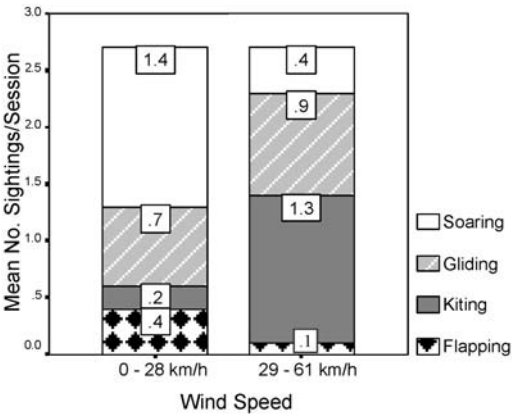


Fig. 3. Flight behavior of red-tailed hawks by wind speed at the Altamont Pass Wind Resource Area, California, USA, June 1999–June 2000.

0.96, $t$ = 0.04, df = 691), there was a difference in the relative use of 2 primary styles of flight (Fig. 3). Kiting behavior was 6.5 times more common when winds were strong than when winds were weak ($t$-test: $P$ = 0.041, $t$ = –2.08, df = 79). Conversely, soaring behavior was 3.5 times greater during weak wind than strong wind ($t$-test: $P$ = 0 .002, $t$ = 3.282, df = 79). Red-tailed hawk flapping behavior ($t$-test: $P$ = 0.870, $t$ = 1.291, df = 79) and gliding behavior ($t$-test: $P$ = 0.222, $t$ = –1.631, df = 79) did not differ significantly between wind speed categories.

## Distance from the Ground

Overall, red-tailed hawks flew at a distance of 11 to 50 m above the ground about 5 times more frequently than at any other height level (K-W: $P$ < 0.001, $\chi^2$ = 241.311, df = 3; Nemenyi test: $P$ < 0.05). This was the case regardless of flight style (i.e., kiting, flapping, soaring, gliding). However, when hawks used flapping flight, they were equally likely to be 1–10 m from the ground as they were to be 11–50 m from the ground (K-W: $P$ < 0.001, $\chi^2$ = 153.054, df = 4; Nemenyi test: $P$ < 0.05; Fig. 4).

## Aspect

Overall, red-tailed hawks were more often seen perching on slopes protected from the wind (i.e, whose aspect did not face into prevailing winds) than windward slopes (Wilcoxon: $P$ = 0.000, $Z$ = –6.593, $n$ = 213). This was particularly true during strong winds, when 86% of perch sightings were on protected slopes, as opposed to 72% during weak winds.

In both strong and weak wind conditions, red-tailed hawks displayed kiting behavior 3.8 times more often on windward slopes than on protected slopes (Wilcoxon: $P$ = 0.020, $Z$ = –2.333, df = 133 for wind speeds 0–28 km/h; $P$ < 0.001, $Z$ = –5.022, df = 190 for wind speeds 29–61 km/h; Fig. 5).

In contrast, flapping behavior was displayed approximately 3.5 times more frequently on protected slopes than on windward slopes (Wilcoxon: $P$ = 0.006, $Z$ = –2.758, df = 133 for wind speeds 0–28 km/h; $P$ < 0.001, $Z$ = –3.530, df = 190 for wind speeds 29–61 km/h).

Gliding and thermal soaring behavior were equally likely to be seen on windward and protected slopes (Wilcoxon: gliding in wind 0–28 km/h, $P$ = 0.700, $Z$ = –0.386, df = 133; soaring in wind 0–28 km/h, $P$ = 0.956, $Z$ = –0.055, df = 133; gliding in winds 29–61 km/h, $P$ = 0.184, $Z$ = –1.329, df = 190; soaring in wind 29–61 km/h, $P$ = 0.817, $Z$ = –0.232, df = 190).

## Inclination

The mean number of total red-tailed hawk sightings (perching and flying) did not differ among slope incline levels when analyzed by activity season, perch versus flight behavior, or wind speed. When behavior was divided into the primary styles of flight, only gliding behavior differed between incline levels (Fig. 6). Red-tailed hawks glided almost 3 times more frequently on the steepest slopes than on slopes of other incline levels (K-W: $P$ = 0.005, $\chi^2$ = 12.970, df = 3; Nemenyi: $P$ < 0.05).

There was no significant difference in activity by slope incline level for flapping flight (K-W: $P$ = 0.436, $\chi^2$ = 2.724, df = 3), soaring flight (K-W: $P$ = 0.183, $\chi^2$ = 4.847, df = 3), or kiting flight (K-W: $P$ = 0.492, $\chi^2$ = 2.410, df = 3).

## Elevation

Red-tailed hawks were 5.5 times more likely to be seen flying on slopes with a peak elevation of 226–256 m than on slopes of other elevation ranges (K-W: $P$ = 0.002, $\chi^2$ = 15.224, df = 3; Fig. 7). Perching activity was 1.7 times greater on slopes with peak elevations of 226–256 m than on slopes with elevations of 262–347 m (K-W: $P$ < 0.001, $\chi^2$ = 19.368, df = 3; Nemenyi: $P$ < 0.05).

All flight styles were more common on slopes falling into the 226–256 m peak elevation category. However, differences were only found for kiting and gliding activity, which were 6 times and 2.4 times greater, respectively, at 226–256 m than at other elevation levels (K-W: $P$ = 0.072, $\chi^2$ = 6.992, df = 3; Nemenyi: $P$ < 0.05 and K-W: $P$ < 0.001, $\chi^2$ = 28.537, df = 3; Nemenyi: $P$ < 0.05, respectively).

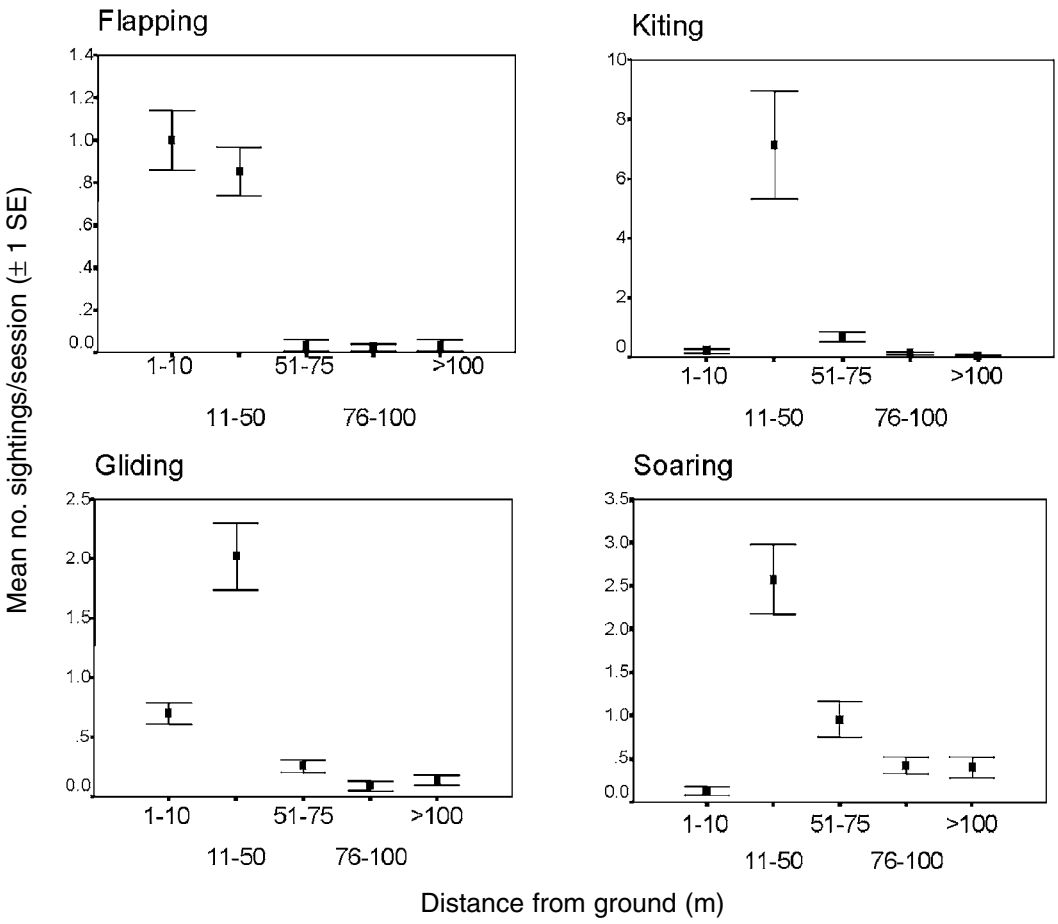


Fig. 4. Flight activity of red-tailed hawks at various height levels from the ground. Number of sightings documented for each behavior type was flapping = 83, kiting = 74, gliding = 162, and soaring = 107. Altamont Pass Wind Resource Area, California, USA, June 1999–June 2000.

## Activity on Specific Slopes

At 3 out of 80 total slopes (4%), we observed 90% of red-tailed hawk kiting behavior, averaging 8.5, 4.0, and 3.9 sightings per session. These 3 slopes had inclines of 26%, 26%, and 21% average grade, respectively. They were all south/southwest-facing slopes with the highest peak elevation (226–256 m) relative to surrounding peaks.

## DISCUSSION

Our results indicate that red-tailed hawk behavior is strongly influenced by the combination of wind conditions and topography. This is consistent with numerous studies describing raptors' skillful use of wind currents during flight (Cone 1962, Janes 1985, Haugh 1986, Dunne et al. 1988).

During our study, the 2 most common flight patterns displayed by red-tailed hawks were thermal soaring and kiting. The use of each flight type was dependent on wind conditions. Thermal soaring occurred more frequently in weak winds than in strong winds. This is presumably because soaring depends on rising masses of warm air, or thermals, which can be disrupted when wind velocities are too high. Once disrupted they no longer provide adequate lifting power (Preston 1981, Dunne et al. 1988).

In contrast, hawks exhibited kiting activity almost exclusively in strong winds and on windward slopes. In these situations, deflection updrafts are created by the deflection of wind up over a hillside. Studies have shown raptor use of updrafts for lift to be positively correlated with increasing wind velocities, especially for red-tailed hawks (Schnell 1968, Pennycuick 1972, Preston 1981). On the rare occasions that we observed

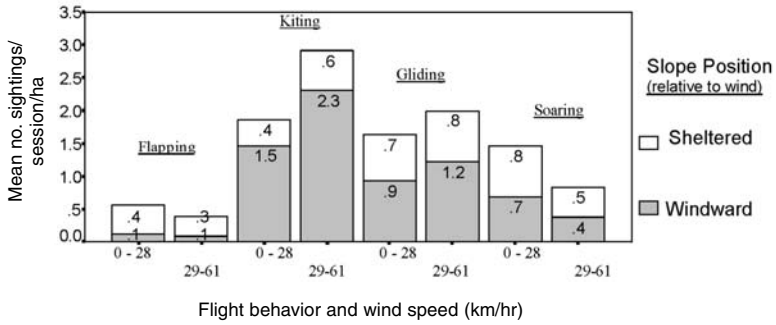


Fig. 5. Flight activity of red-tailed hawks by wind speed on sheltered (protected) slopes and windward slopes. Wind speeds between 0 and 28 km/hr were categorized as weak. Wind speeds between 29 and 61 km/hr were categorized as strong. Altamont Pass Wind Resource Area, California, USA, June 1999–June 2000.

flapping behavior, it was used by hawks to cross slopes that were protected from prevailing winds. Apparently, they needed to generate their own lift to traverse areas lacking favorable wind currents.

In addition to slope aspect, slope incline and elevation are also related to the formation of updrafts used by foraging hawks. Most red-tailed hawk kiting activity occurred on a small fraction of the slopes studied, all of which had similar topographic features. They had steep inclines, which produces deflected wind with more vertical force spread over a larger area (Cone 1962). The heavily used slopes also had the highest peaks relative to surrounding hills. High-elevation slopes will not be blocked by surrounding slopes, and will receive the full force of prevailing winds.

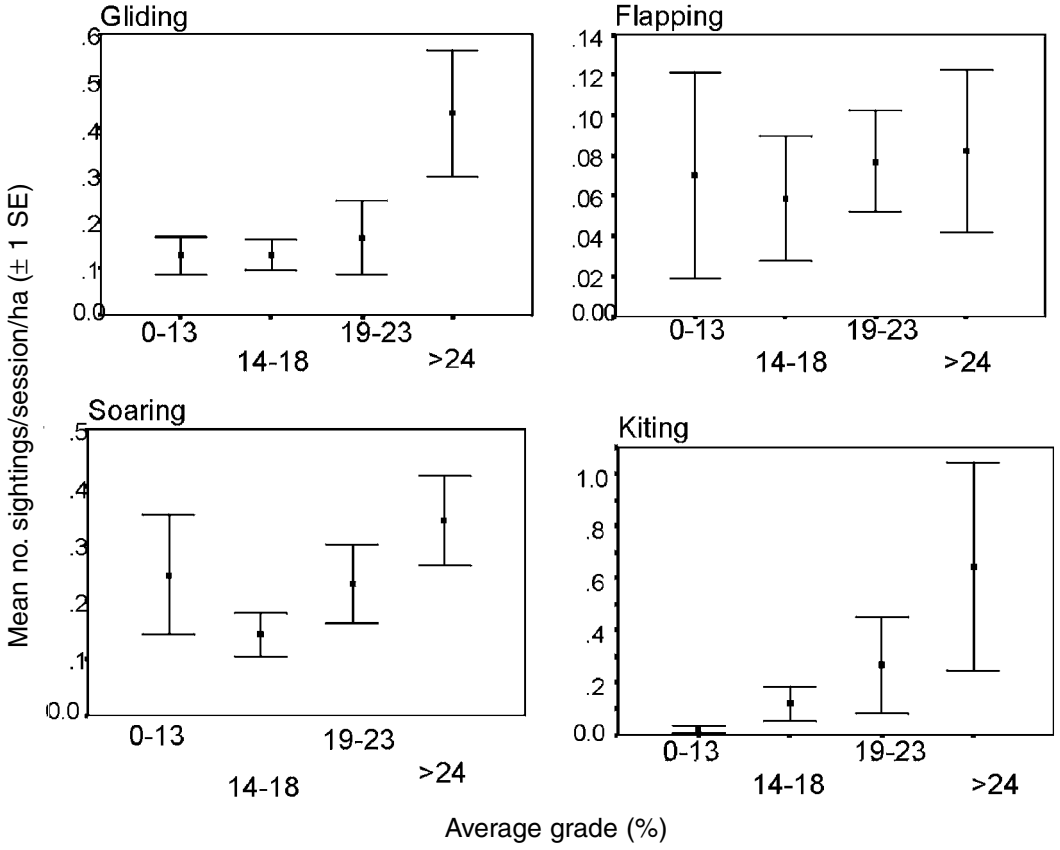


Fig. 6. Activity of red-tailed hawks, by flight style, over slopes with different incline levels. Number of slopes observed for each incline level was 0–13% = 12, 14–18% = 24, 19–23% = 21, and >24% = 23. Altamont Pass Wind Resource Area, California, USA, June 1999–June 2000.

The reason red-tailed kiting activity was lower on the highest peak elevation slopes relative to the second highest elevation category may be a result of differences in land management among areas. Eighty-seven percent of the slopes in the highest elevation category also had low squirrel burrow density (Hoover 2001). These areas routinely underwent a rigorous squirrel control regimen not used elsewhere in our study area. Thus, red-tailed hawks may be choosing the tallest peaked slopes in a region, provided there is a minimum of squirrel activity.

The seasonal differences we observed in red-tailed hawk activity can also be explained by wind currents within the study area. Although red-tailed hawks are thought to be primarily perch hunters, they are known to hunt aerially during favorable conditions (Janes 1985). During the summer months, when wind speeds were greatest and updrafts most abundant, we observed hawks aerial hunting more than perch hunting. In contrast, during the remaining seasons, when wind speeds were lower and less consistent, hawks were more frequently perched on hillsides than in flight. When perched hawks hunted, they usually faced downhill on slopes that were protected from prevailing winds. This may be to avoid having to fight strong updrafts when swooping for a kill.

Our study documented red-tailed hawk foraging behavior that may be used in addressing their vulnerability to turbine collisions. For red-tailed hawks inhabiting windfarms, kiting constitutes a common and potentially dangerous flight activity for several reasons. First, as our data revealed, kiting is used at a distance from the ground that puts red-tailed hawks at the height of rotating turbine blades (i.e., 15–35 m above ground level). In addition, kiting is used primarily in strong winds, which often produce unpredictable gusts. Since the position that a kiting hawk assumes within a deflection updraft is dependent upon wind velocity (Cone 1962), a significant change in velocity may suddenly change the hawk's position, essentially throwing it off-balance. Finally, kiting is a static style of flight. Thus, a hawk remains in a hazardous position adjacent to rotating blades for an extended time period, which increases the risk of turbine-related injury.

Carcass searches performed at the AWRA concurrently with our behavioral observations (Rugge 2001) revealed red-tailed hawks collided with turbines on the same slopes in which we observed most kiting behavior. Between February 1999 and March 2000, a disproportionate number of turbine-related red-tailed hawk fatalities occurred

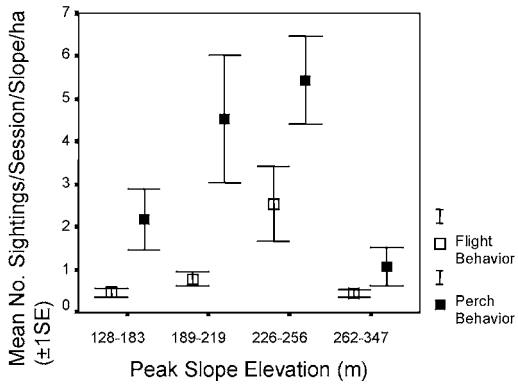


Fig. 7. Activity of red-tailed hawks on slopes with different peak elevations. Number of slopes observed for each elevation level was 128–183 m = 22, 189–219 m = 25, 226–256 m = 15, and 262–347 m = 18. Altamont Pass Wind Resource Area, California, USA, June 1999–June 2000.

on the few slopes where 90% of the kiting behavior took place (i.e., 14% of the total number of red-tailed hawk collisions were found on 4% of the slopes surveyed; Rugge 2001, personal observation). This suggests that red-tailed hawk collisions may be related to kiting activity, which in turn is related to slope-specific characteristics.

During the Rugge (2001) study, red-tailed hawk fatality rates during our study period were higher during the fall and winter than during the summer (there was no seasonal difference in fatality rate during 1998–1999). Although kiting behavior was less frequent during the fall, hawk abundance was much higher during these months than during the summer; we documented about 10 times more hawk sightings per session. Altamont Pass is located within the Pacific flyway and experiences an influx of migrant birds during the fall. The increased fatality rate during fall versus summer may be related to the increased abundance of raptors foraging within a confined area.

The issue of avian fatalities within windfarms is a species-specific and site-specific problem. For raptor species, the particular relationship among flight behavior, topography, and wind currents is central. Other wind facilities experiencing raptor mortality have identified similar trends. Barrios and Rodriquez (2004) found that the vulnerability and mortality of griffon vultures within wind facilities located in the Campo de Gibraltar region of Spain were related to wind-relief interactions. Researchers suggest that vultures experienced high mortality during fall and winter because the thermals that lift them out of the

area of rotating blades were lacking during these months. Instead, vultures used declivity winds created off hillsides for lift, which increased their exposure to turbines and mortality. In addition, Barrios and Rodriquez (2004) observed that the Eurasian kestrel (*Falco tinnunculus*), another frequent fatality, often hovered on windward slopes close to ridges (and turbines) while hunting.

## MANAGEMENT IMPLICATIONS

Our results illustrate the need to understand how raptors use features of the topography during flight activities. Red-tailed hawks are known to utilize favorable wind currents when possible during foraging, as they do at the AWRA; as such, our study is applicable to other windfarms that may experience red-tailed hawk mortality. Topographical features of the landscape (inclination, aspect, elevation) and weather variables (wind speed and direction) can predict the strength and location of deflection updrafts necessary for kiting behavior. Thus, red-tailed hawk activity can be predicted to some extent, by examining topographical and weather features of an area. It is essential that prior to installation of new windfarms, a detailed site assessment and behavioral study be conducted to identify locations where the topographical/weather interaction may produce dangerous conditions for foraging red-tailed hawks and other raptors.

For facilities already in place, such as the AWRA, mitigation measures to decrease red-tailed hawk fatalities can be directed specifically to areas fitting the general pattern described in our study. Windfarm managers can power down turbines at the top of these hazardous slopes when they pose the greatest danger; that is, when winds are strong and facing perpendicularly to the slope. Alternatively, bird-deterring methods to discourage raptor activity near turbines may be used on these slopes. One such method, presently being researched and developed, is to paint blades in such a way as to accentuate them (Hodos 2003). With knowledge of high-activity/high-risk areas, such as that provided by our study, expensive turbine modifications might be specifically applied where they will be most effective.

## ACKNOWLEDGMENTS

We thank the National Renewable Energy Laboratory, for funding this project, and Karin Sinclair for assisting with project logistics. Additionally, we thank Lourdes Rugge for her useful suggestions and assistance in the field.

## LITERATURE CITED

AMERICAN WIND ENERGY ASSOCIATION. 1995. Avian interactions with wind energy facilities: a summary. American Wind Energy Association, Washington, D.C., USA.

ANDERSON, R., W. P. ERICKSON, M. D. STRICKLAND, M. BOURASSA, K. J. BAY, K. J. SERNKA, J. TOM, AND N. NEWMANN. 2004. Avian monitoring and risk assessment at the Tehachapi Pass Wind Resource Area. National Renewable Energy Laboratory, Golden, Colorado, USA.

BAKER, J. A., AND R. J. BROOKS. 1981. Distribution patterns of raptors in relation to density of meadow voles. Condor 83:42–47.

BARRIOS, L., AND A. RODRIQUEZ. 2004. Behavioral and environmental correlates of soaring-bird mortality at on-shore wind turbines. Journal of Applied Ecology 41:72–81.

BECHARD, M. J. 1982. Effect of vegetative cover on foraging site selection by Swainson's hawk. Condor 84:153–159.

CONE, C. D. 1962. Thermal soaring of birds. American Scientist 50:180–209.

DUNNE, P., D. SIBLEY, AND C. SUTTON. 1988. Hawks in flight. Houghton Mifflin, Boston, Massachusetts, USA.

ERICKSON, W. P., G. D. JOHNSON, M. D. STRICKLAND, D. P. YOUNG, JR., K. J. SERNKA, AND R. E. GOOD. 2001. Avian collisions with wind turbines: a summary of existing studies and comparisons to other sources of avian collision mortality in the United States. National Wind Coordinating Committee, Washington, D.C., USA.

HAUGH, J. R. 1986. Raptors in migration. Pages 35–48 *in* Raptor conservation in the next 50 years. Raptor Research Report Number 5. The Raptor Research Foundation.

HODOS, W. 2003. Minimization of motion smear: reducing avian collision with wind turbines; period of performance: July 12, 1999–August 31, 2002. Report Number SR-500-33249. National Renewable Energy Laboratory, Golden, Colorado, USA.

HOOVER, S. 2001. The response of raptors and their prey to topographical features of the Altamont Pass Wind Resource Area, California. Thesis, California State University, Sacramento, USA.

JANES, W. S. 1985. Habitat selection in raptorial birds. Pages 159–188 *in* M. L. Cody, editor. Habitat selection in birds. Academic Press, London, United Kingdom.

JOHNSON, G. D., W. P. ERICKSON, M. D. STRICKLAND, M. F. SHEPARD, D. A. SHEPARD, AND J. W. KERN. 2002. Collision mortality of local and migrant birds at a large-scale wind power development on Buffalo Ridge, Minnesota. Wildlife Society Bulletin 30:879–887.

MARTIN, P., AND P. BATESON. 1986. Measuring behaviour: an introductory guide. Cambridge University Press, Cambridge, Massachusetts, USA.

ORLOFF, S., AND A. FLANNERY. 1992. Wind turbine effects on avian activity, habitat use and mortality in Altamont Pass and Solano County Wind Resource Areas. Report to the Planning Departments of Alameda, Contra Costa, and Solano counties and the California Energy Commission. Grant Number 990-89-003. BioSystems Analysis, Tiburon, California, USA.

OSBORN, R. G., C. D. DIETER, K. F. HIGGINS, AND R. E. USGAARD. 1998. Bird flight characteristics near wind turbines in Minnesota. American Midland Naturalist 139:29–38.

———, K. F. HIGGINS, R. E. USGAARD, C. D. DIETER, AND R. D. NEIGER. 1999. Bird mortality associated with wind

turbines at the Buffalo Ridge Wind Resource Area, Minnesota. American Midland Naturalist 141:41–51.

PENNYCUICK, C. J. 1972. Animal flight. Edward Arnold, London, United Kingdom.

PRESTON, C. R. 1981. Environmental influence on soaring in wintering red-tailed hawks. Wilson Bulletin 93:350–356.

RATTI, J. T., AND E. O. GARTON. 1996. Research and experimental design. Pages 1–23 *in* T. A. Bookhout, editor. Research and management techniques for wildlife and habitats. Fifth edition, revised. The Wildlife Society, Bethesda, Maryland, USA.

RUGGE, L. 2001. An avian risk behavior and mortality assessment at the Altamont Wind Resource Area in Livermore, California. Thesis, California State University, Sacramento, USA.

SCHNELL, G. D. 1968. Differential habitat utilization by wintering rough-legged and red-tailed hawks. Condor 70:373–377.

SMITH, D. G., AND J. R. MURPHY. 1973. Breeding ecology of raptors in the eastern great basin of Utah. Scientific Bulletin Biological Service 18:1–76. Brigham Young University, Provo, Utah, USA.

STINSON, C. H. 1980. Weather-dependent foraging success and sibling aggression in red-tailed hawks in central Washington. Condor 82:76–80.

ZAR, J. H. 1996. Biostatistics. Third edition. Prentice-Hall, Upper Saddle River, New Jersey, USA.

*Acting Editor: Kuenzi.*