Subcontractor Report

The Response of Red-Tailed Hawks and Golden Eagles to Topographical Features, Weather, and Abundance of a Dominant Prey Species at the Altamont Pass Wind Resource Area, California

April 1999—December 2000

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Sacramento, California

NREL

National Renewable Energy Laboratory

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Introduction

Wind energy has been promoted as a low-cost, clean, and reliable option for power production in the United States and abroad (NREL 1999). However, wind energy does have environmental costs. Studies have shown that birds flying through wind resource areas can be killed by collisions with turbines (Orloff and Flannery 1992; Musters, Noordervliet, and Ter keurs 1996; Howell 1997; Hunt 1997). These studies have spurred concern over the possible negative impacts such power plants may have on avian populations.

The Altamont Pass Wind Resource Area (WRA) (Figure 1), located approximately 70 km (43.5 mi) east of San Francisco, California, is 189 km^2 (73 mi^2) in size and contains roughly 5,000 turbines with a total capacity of 672 Megawatts. Studies of avian mortality have shown that a significant number of birds are killed within this facility, perhaps more than in any other WRA (Orloff 1992; Orloff and Flannery 1992).
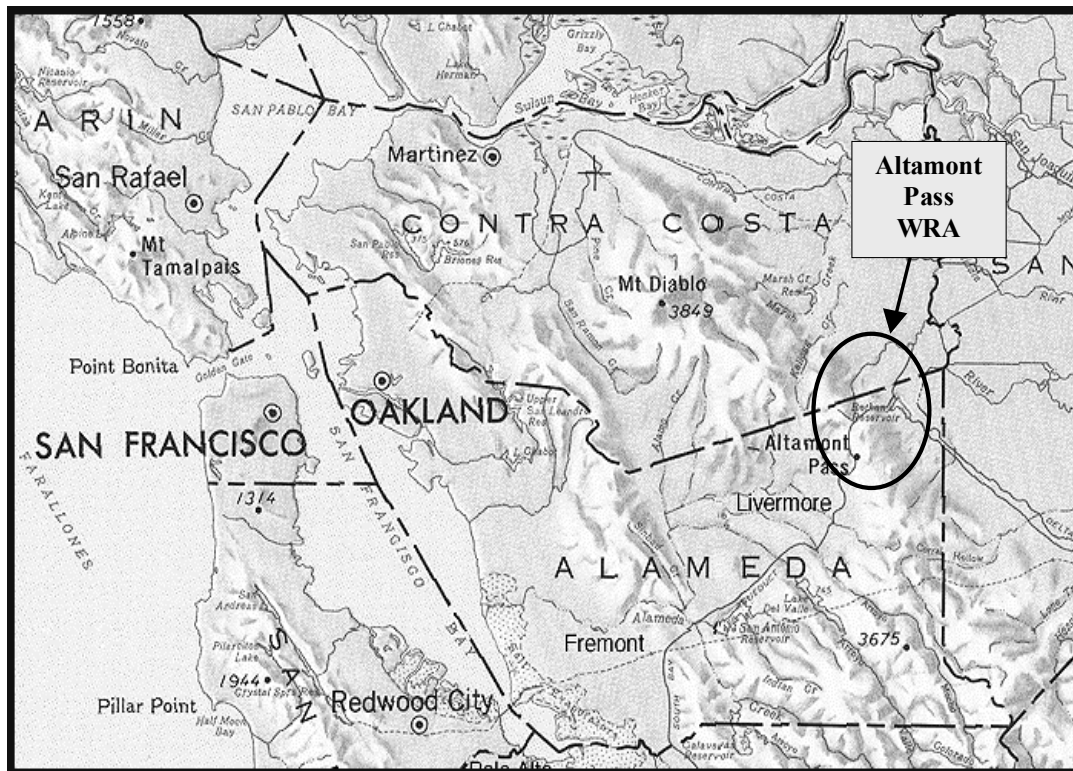
Figure 1. Map of Altamont Pass Wind Resource Area, California

Raptors are the type of bird most commonly killed within the Altamont Pass WRA. Orloff and Flannery (1992) estimated annual wind-farm-related raptor deaths to be 403 the first year of their study and 164 the second year. Golden eagle (*Aquila chrysaetos*), red-tailed hawk (*Buteo jamaicensis*), and American kestrel (*Falco sparverius*) fatalities were much higher than predicted from their abundance in the area. Turkey vultures (*Carthartes aura*) and nonraptor species, such as common ravens (*Corvus corax*), rock doves (*Columbia livea*), and passerines, showed relatively high activity yet few fatalities. One hypothesis for this disparity is that the specific

foraging behavior and flight characteristics of raptors make them more susceptible to accidental death (Orloff and Flannery 1992).

Two facets to consider when addressing the issue of raptor-turbine collisions is whether mortality is linked to where the turbines are placed or to specific characteristics of the turbines themselves. For example, Orloff and Flannery (1996) found that turbines with three blades, rather than two, and turbines with faster blade tip speed correlate with higher incidences of raptor collision. Most data, however, indicate that raptor mortality is more a consequence of turbine placement, rather than turbine type, particularly in relation to the topography. Orloff and Flannery (1992) found turbines placed on high-altitude hills or close to canyons pose the greatest risk for raptor collision.

Additionally, the most recent study to address raptor collisions at the Altamont Pass WRA (Rugge 2001) found a definite link between where raptor activity occurred and where raptors collided with turbines. In other words, when turbines, regardless of type, are placed in areas where raptors spend a great deal of time, the incidence of collision goes up. Rugge (2001) found that raptors, particularly red-tailed hawks, tended to spend more flight time in hilly, or high-complexity areas, than in areas with less topographic complexity. Accordingly, their mortality rates in these areas were also higher than in other areas.

This relationship between topography and collision rates may also explain why the WRA in Tehachapi, California (southeast of Bakersfield) has significantly lower raptor mortality rates when compared to the Altamont Pass WRA. Even though the two facilities have many turbine-related characteristics in common, raptor abundance is much greater at Altamont Pass than at Tehachapi (Orloff 1992).

If turbine placement in areas of high raptor activity is key in predicting raptor collisions, then elucidating what characteristics attract raptors disproportionately to some areas over others will provide information necessary to decrease raptor mortality. As previously mentioned, topography appears to be an important variable (Orloff and Flannery 1992; Rugge 2001). However, the Tehachapi site, like Altamont Pass, has variable topographic relief but rlatively low raptor activity. The two sites differ significantly in regard to prey base. The Tehachapi WRA has far fewer California ground squirrels (*Spermophilus beecheyi*) than the Altamont Pass facility (Orloff 1992). This indicates that prey abundance may also serve as an attractant to foraging raptors.

Raptor activity within the Altamont Pass WRA is concentrated in some regions more than in others, indicating active selection by raptors (Orloff and Flannery 1992; Rugge 2001; personal observation). California ground squirrels and desert cottontails (*Sylvilagus audubonii*) are relatively common; thus prey abundance is apt to affect the distribution of raptor activity. Optimal foraging theory predicts that animals should maximize their net rate of energy intake; therefore, an animal is expected to spend more time foraging in those areas yielding the greatest net gain (Krebs and Davies 1993). If prey occurs in discrete sites, or patches, within the Altamont Pass WRA, then there may be a correlation between the degree of raptor activity and prey activity.

Raptor foraging can be influenced by characteristics other than prey density. Raptors have been shown to choose foraging sites based, in part, on factors that make prey more vulnerable or make hunting more energy efficient. Some specific variables that appear to affect habitat selection by foraging raptors are vegetative ground cover, weather conditions, tree density, and perch availability (Stinson 1980; Baker and Brooks 1981; Bechard 1982; Janes 1985).

Topography also plays a part in a raptor's choice to forage in a particular area (Smith and Murphy 1973). Altamont Pass consists of rolling hills with significant elevation changes. For this reason, raptor use of the topography is of particular interest. Animals typically are expected to be adapted to certain modes of foraging and thereby efficiently exploit specific substrates (Morrison, Marcot, and Mannan 1998, 220). For example, golden eagles often use an aerial foraging tactic known as contour hunting. In hilly terrain they will glide within 1–3 m (3–10 ft) of the ground, following the contour of the land. This can be used as a surprise attack strategy whereby the eagle passes low over a hill crest then quickly descends the slope undetected to approach areas of high prey abundance (Carnie 1954; Collopy 1983; Dekker 1985). Thus, characteristics of the terrain may make prey more vulnerable to foraging eagles.

Further, the combination of topography and weather form a meaningful association because they determine the pattern of wind currents. Raptors are well known for being adept at using wind currents. They soar frequently by using thermals for lift and are known to exploit the updraft off a ridge on cloudy days when thermals are few (Dunne, Sibley, and Sutton 1988). Declivity winds (the winds deflected off hills) and thermals produced in hilly terrain during warm, windy weather conditions allow for more energy-efficient flight (Janes 1985). As a result, both red-tailed hawks and golden eagles, for example, will vary their mode of hunting in different weather conditions. During calm, overcast, or rainy days, they tend to perch more frequently than on sunny, windy days when they will primarily glide low over slopes (Preston 1981; Dekker 1985). Likewise, although red-tailed hawks are known primarily as perch hunters, tending to scan for prey from tall perches, they will exhibit aerial hunting if conditions are favorable (Janes 1985).

The topographic relief within Altamont Pass is highly variable and the weather is often extreme, especially in regard to high winds. Therefore, aspects of the topography and weather are likely to be variables in habitat selection by raptors foraging in this region. Although abundance of prey is undoubtedly important, a raptor may choose to hunt in an area with a relatively smaller food base because the area contains topographical elements that make foraging more efficient. I studied the topographical elements of slope aspect, peak elevation, and slope inclination to ascertain why some areas within the Altamont Pass WRA are used disproportionately by raptors. Variation in weather conditions, such as wind velocity, ambient temperature, cloudiness, and precipitation were also of interest because of their effect on the flight activity of open habitat raptors (Schnell 1968).

Goals of the Study

The overall goal of my study was to determine which characteristics of the landscape influence hawk and eagle habitat selection within the Altamont Pass WRA. Knowledge of features that attract raptors disproportionately to some areas will allow wind plant personnel to better manage specific high-use areas to decrease raptor-turbine collisions.

My specific objectives were to:

- Explore the relationship between hawk and eagle flight behavior and weather factors

- Determine whether hawks and eagles randomly use the topographical features of slope aspect, slope incline, and slope elevation

- Determine the relationship between relative squirrel abundance and hawk and eagle flight behavior.

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Study Area

As mentioned, the Altamont Pass WRA occupies approximately 189 km^2 (73 mi^2) amidst the rolling hills of Altamont Pass in central California (Figure 1). It is roughly 70 km (43.5 mi) east of San Francisco Bay and spans the county borders of Contra Costa and Alameda. My study area was roughly 10 km (6.2 mi) northeast of Livermore and ran parallel to, and 3 km (1.8 mi) west of, the California Aqueduct. The study area was bordered on the south by Interstate 580 and extended approximately 6 km (3.7 mi) to the north.

Altamont Pass is hilly with slope inclinations that range from mild to steep. Hill elevations are from 230 m (755 ft) to 375 m (1,230 ft) above sea level. Valleys range from 78 m (256 ft) to 188 m (617 ft) above sea level. Livestock grazing is the main form of land use, and vegetation growing in the compact soil is sparse (Hunt 1995). Vegetative cover reaches its highest biomass during the winter months and consists primarily of annual European grasses. Some scattered wildflowers exist, especially along roadsides where native and non-native thistles predominate. No shrubs and very few trees exist in the area. The rare exceptions are small stands of trees belonging to the genus *Eucalyptus*. There were only five such stands within my study area. As a result, available perch sites for birds consisted primarily of man-made structures, such as turbines, anemometer and power poles, and fence posts.

The wind season usually ranges from April to October when air from the warm valley meets the cool marine air. This temperature differential creates strong southwestern winds that range from 25–61 km (15–38 mi) per hour. During the winter months, wind speeds drop considerably and can come from various directions. Average yearly precipitation is about 37 cm (14.5 in.), and the majority of rainfall occurs in the winter months (December–February).

The raptor prey base in the study area consists primarily of California ground squirrels (*Spermophilus beecheyi*), California voles (*Microtus californicus*), and desert cottontails (*Sylvilagus auduboni*). Squirrels can be observed moving about, often in large numbers, and their burrows and trails are obvious in many regions. In other regions there are few signs of ground squirrel activity. Squirrel-control programs are used by ranchers throughout my study area to decrease the population size (Orloff and Flannery 1996; Hunt 1997; Smith 2001; personal observation). After yearly poisoning, populations are temporarily reduced, but within a couple of months they appear to rebound. This is presumably the result of neighboring animals moving into the vacated burrow systems (Smith 2001; personal observation).

Methods

Plot Selection

Selection of my study plots was based on the study by Lourdes Rugge of raptor activity and mortality within the Altamont Pass WRA (Rugge 2001). Within her study area, Rugge systematically searched for avian fatalities around turbines every six weeks during the same time period as my study was conducted. My intention in using the same study area was to combine the Rugge results of raptor fatalities with my data on raptor habitat use. Rugge was granted access to an area of roughly 20 km^2 (7.7 mi^2), which contained 15% of the total number of turbines at the Altamont Pass WRA. The 21 plots used during her study represented 100% of the area in which her research team was granted access (Rugge 2001).

I used only 15 of the 21 plots from the Rugge study because some were not appropriate for my research. The criteria I used to select these 15 plots were: (1) each plot was accessible (i.e., I had

access to the property in order to map burrows), (2) the entire plot had unobstructed visibility from the observation point, and (3) the plot was a minimum of 500 x 500 m (0.3 x 0.3 mi). The total area of all plots was approximately 375 ha (1.4 mi^2).

I subdivided each plot into smaller units at an average of seven subdivisions per plot. These smaller units, referred to as *slopes*, were distinguished from one another when there was a permanent change in aspect or when areas had distinctly different peak elevations. Each slope was given an identification number that was used during all phases of the study. I measured topographical features, mapped prey burrows, and recorded raptor behavior all with reference to the slope identification number (described in following paragraphs).

Topography Measurements

Slope Aspect

To describe the topography of a slope, aspect was recorded as N, NE, E, SE, S, SW, W, or NW. Some slopes and small hills formed a radius that resulted in aspects of multiple directions, one grading into the other without definitive breaks. An example of this was a slope that started at one end with an eastern aspect and curved to end with a western aspect. In such cases, the aspect representing the center of the range was used.

Slope aspects that were north, south, east, or west were rare; they made up less than 9% of the total area. Therefore, for data analysis, I combined the cardinal directions with the other directions to form four categories (and one nondirectional category). This yielded the following slope aspects: (1) north-northwest, (2) northeast-east, (3) southeast-south, (4) southwest-west, and (5) flat regions or areas without defined aspects. The percentages of the total area represented by aspect categories 1 through 5 are 21%, 38%, 17%, 20%, and 5%, respectively.

I also recorded the location of a raptor on a slope during the behavior portion of the study. The instantaneous aspect was the precise aspect of the land directly under the raptor at the time a behavior was recorded.

Slope Inclination

I measured slope inclination as the average percent grade, or the ratio of the total amount of elevation change to the total horizontal length. The average percent grade was obtained with the use of TOPO! (interactive topographical map software from Wildflower Productions, San Francisco, CA). The spread of incline values ranged from 0% to 37% average percent grade; however, not all values within this range were represented. I used these breaks in the distribution of incline values to create four categories that were, more or less, equally represented within my study area. The categories consisted of (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 are 16%, 28%, 31%, and 25%, respectively.

Slope Elevation

Peak elevation for each slope was obtained from 7.5-minute topographical maps at 1:24,000 scale with contour intervals of (6 m) 20 ft. The high point of the slope was recorded as the last contour line. I attempted to create equally represented categories without dividing the data into too many groups. I chose to use the following four divisions: (1) 128–183 m (420–600 ft), (2) 189–219 m (620–718 ft), (3) 226–256 m (741–840 ft), and (4) 262–347 m (860–1,138 ft). The total area represented by elevation categories 1 through 4 are as follows: 19%, 31%, 22%, and 14%, respectively.

Behavioral Observations

I conducted weekly observations of raptor behavior for each plot from June 9, 1999 to June 20, 2000. The recording session was 30 minutes in duration and instantaneous sampling was used (Martin and Bateson 1986). At 1.5-minute intervals I scanned the plot with 8x40 binoculars and recorded data on the location and behavior of all raptors. This interval size was sufficient to accurately record all raptor activity.

At the onset of each behavioral observation, I collected the data on the following variables: season, time of day, wind direction, wind speed, cloud cover, ambient temperature, precipitation, and fog.

Season fell into four categories in accordance with the four calendar seasons (Crystal 1997). After exploring my data set, a very clear seasonal pattern emerged whereby the amount of red-tailed hawk activity increased rapidly during the fall and winter and decreased during the spring and summer. Thus, during analysis, I used a two-season designation— peak (fall and winter) and non-peak (spring and summer).

The time of day was divided into the following three categories: (1) morning: dawn to 9:59 a.m., (2) midday: 10:00 a.m. to 2:00 p.m., and (3) late afternoon: 2:01 p.m. to sunset. Each plot was observed in a different time period than it had been the week prior so that observations were distributed equally over all time periods throughout the year.

Wind direction was recorded as N, NE, E, SE, S, SW, W, or NW. Wind speed was measured on the Beaufort scale as ordinal data, i.e., from 0 [< 1 km/h (0.62 mph)] to 8 [62–74 km/h (38.5–46 mph)] (Crystal 1997). When the average wind speed differed from periodic gusts, the gust speed was used. For the purpose of some analysis, wind speed was categorized as weak [Beaufort scale 0–4, 0–28 km/h (17.4 mph)] or strong [Beaufort scale 5–7, 29–61 km/h (16–38 mph)]. Cloud cover was recorded as (1) 0%–25%, (2) 26%–50%, (3) 51%–75%, or (4) 76%–100%. Temperature was measured in degrees centigrade.

Precipitation was measured as (1) none or (2) light drizzle. Light drizzle was recorded if it occurred at any point during the observation, even if it was for only a brief moment. I did not conduct observations during rainfall heavier than light drizzle because visibility was poor when using binoculars, and because raptor activity usually does not occur during heavy rain (Craighead and Craighead 1956; Schnell 1968; Preston 1981). Fog was measured as (1) none or (2) light fog with visibility at least 500 m (0.3 mi). Observations were not conducted if fog obscured any portion of the plot.

I laminated topographic maps for all plots to aid in recording raptor location. Slopes were numbered on the maps so that at the end of each 1.5-minute interval I could record the exact location (the specific slope number) of all raptors active in the plot at that moment (Figure 2). The same slope identification numbers were used throughout the study to collate prey data and topographical data (Table 1).
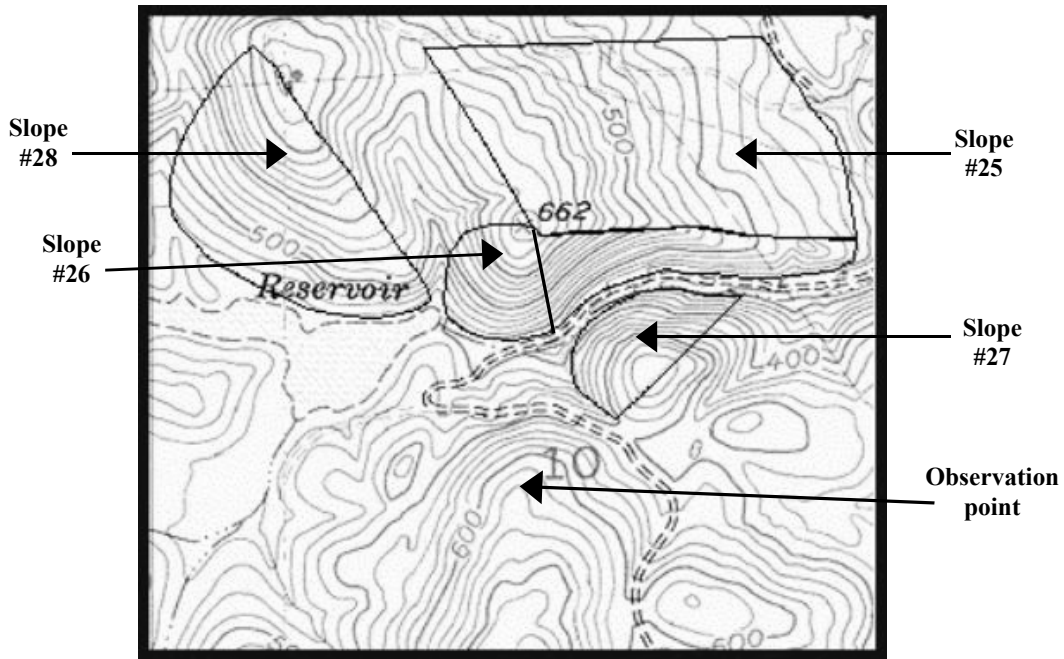
Figure 2. Topographic map used during behavioral observations

Table 1. Summary of topographical characteristics, squirrel burrow entrances, and squirrel sightings and vocalizations for 81 slopes. Altamont Pass WRA, California, June 1999–June 2000.

Slope identification number	Percent average grade	Slope aspect	Peak elevation in meters	Average number of squirrel sightings and vocalizations/ hectare	Average number of active entrances/ hectare
1	13	NE	206	3.85	379
2	13	NE	230	3.43	439
3	25	SE	212	25.63	1045
4	27	SW	206	6.08	466
5	28	SE	176	16.04	363
6	19	NE	206	30.61	663
7	19	NE	206	6.32	433
8	20	SW	206	17.25	225
9	16	NE	164	23.08	274
9.1	25	SW	164	3.25	323
10	17	NE	212	17.83	342
11	25	SW	212	18.49	190
12	20	NW	212	13.21	68
12.1	5	valley, other	170	15.79	213
13	13	NE	255	7.78	511
14	23	E	224	6.64	335
15	19	NE	164	.92	79
16	14	SE	164	6.01	273

17	17	NE	164	3.06	53
18	7	valley, other	127	2.14	229
19	12	SW	164	7.18	265
20	30	NE	170	4.25	87
21	6	SE	158	3.82	201
22	20	NE	212	10.39	231
23	30	N	158	4.61	250
24	27	S	200	14.90	211
25	17	E	200	8.55	224
26	37	S	200	5.42	405
27	26	W	164	3.47	26
28	17	SW	224	1.86	120
29	8	valley, other	164	21.97	548
30	24	NW	194	Not mapped	Not mapped
31	18	SW	194	46.56	572
32	17	SE	224	6.99	472
33	24	NW	242	5.01	393
34	19	NE	218	3.56	140
35	17	NW	181	5.33	140
36	15	NE	181	6.89	190
37	22	W	224	14.53	382
38	25	SW	224	13.37	499
39	25	SE	255	4.25	325
40	15	NE	194	6.00	201
41	26	SW	255	0	176
42	26	SW	194	8.82	416
43	17	SW	194	22.22	317
44	17	SW	158	29.31	438
45	17	SE	194	21.72	645
46	28	W	164	23.94	290
47	25	NW	212	2.75	116
48	13	NE	164	15.6	422
49	26	S	224	1.19	137
50	9	W	164	6.20	226
51	24	NW	194	0	29
52	17	SW	188	11.33	23
53	19	NE	236	0	22
54	18	SE	200	2.91	89
55	16	NE	182	5.59	148
56	0	valley, other	145	17.51	114
57	21	SW	236	3.92	185
58	16	SE	212	10.00	553
59	22	NW	224	.66	65
60	16	N	236	10.60	207
61	18	E	261	3.70	42
62	22	SE	297	0	13
63	19	SE	315	.39	27
64	18	NE	345	1.00	53
66	18	NW	315	0	1
67	19	NW	345	0	0

68	17	SE	309	0	3
69	15	NW	309	0	0
70	21	NW	285	0	0
71	22	NE	333	.73	25
72	31	NE	303	0	4
73	26	NE	333	0	15
74	22	SW	333	.26	54
75	21	NW	345	1.1	2
76	9	valley, other	267	0	14
77	23	SE	315	0	0
78	22	NE	327	0	0
79	26	W	327	0	0

All raptor species were recorded with the exception of burrowing owls (*Athene cunicularia*). Burrowing owls were usually observed perched on the ground, at the opening of their burrows. This behavior was not recorded during the first three seasons of the study. However, data on burrowing owl activity was recorded during the burrow-mapping portion of the study.

When a raptor was observed, the sex was recorded as (1) unknown, (2) female, or (3) male. Age was recorded as (1) unknown, (2) immature (includes subadult golden eagles), or (3) adult. The flight direction of the bird was recorded as N, NE, E, SE, S, SW, W, or NW.

Flight behavior was categorized as soaring, flapping, gliding, kiting, or perching. Throughout the study, the term *soaring* refers specifically to thermal soaring, whereby a bird flies in a circular pattern within a thermal (Cone 1962). Kiting refers to the relatively motionless flight of a bird within an updraft. Gliding is flight in a straight path without wing beats, and flapping is flight powered by wing beats.

When raptors were seen perching, the exact perch structure was recorded. Each structure was placed into one of the following five categories: (1) ground or rock, (2) wind turbine, (3) power line or power pole, (4) tree, or (5) other structure.

I recorded the distance from the ground that the raptor was flying as (1) 1–10 m (3–33 ft), (2) 11–50 m (36–164 ft), (3) 51–75 m (167–246 ft), (4) 76–100 m (249–328 ft), or (5) >100 m (328 ft). The distance from nearest turbine that the raptor was flying was measured using the same scale. The instantaneous aspect of a slope where a sighting occurred was recorded as N, NE, E, SE, S, SW, W, or NW. Also, each bird sighting was determined to be on a slope whose aspect was either the same or different than the direction of the wind.

Squirrel Activity Measurements

The California ground squirrel is thought to be an important prey species for foraging raptors at Altamont Pass, and perhaps the primary species for golden eagles (Orloff and Flannery 1996; Hunt 1997). Red-tailed hawks are believed to be opportunistic with respect to prey and will often choose prey species that are in high abundance (Steenhof and Kochert 1988). They forage primarily on ground squirrels in many locations (Janes 1985), so, given that Altamont Pass has a significant ground squirrel population, they are likely to be a common prey item for red-tailed hawks as well. For these reasons, methods for estimating prey abundance were chosen based primarily on their appropriateness for sampling squirrels.

My study design included two methods to obtain information on relative squirrel abundance: active burrow entrance counts and squirrel activity determined by aboveground counts and alarm calls.

Active Burrow Counts

Assessing animal activity by counting active burrows is a cost-effective technique that makes it possible to sample large tracts of land. Several studies have provided data suggesting that it can be a reliable index to ground squirrel densities (Owings and Borchert 1975; Weddell 1989). For example, Nydegger and Smith (1986) showed that the number of active Townsend ground squirrel (*Spermophilus townsendii*) burrows in *Artemisia* and related vegetation in southwestern Idaho was highly correlated with estimates obtained by mark-recapture methods on the same plots (r = 0.94).

In contrast, Van Horne et al. (1997) pointed out that the application of this method is not suitable for all studies. In their study of Townsend's ground squirrels, burrow counts in shrub steppe habitats did not reveal a consistent relation to live-trapping estimates. Van Horne et al. (1997) suggested a number of possible reasons for this weak relationship. The assignment of active-inactive status by observers can be inconsistent. Also, the persistence of burrow entrances can be variable; erosion occurs more quickly in some habitats or weather conditions than in others. Finally, it can be difficult to determine the species of the burrow inhabitant. Burrows of various semifossorial animals can look similar, and different species may adopt abandoned squirrel burrows for their own.

Potential sampling problems were reduced by two means. First, I compared squirrel burrow densities of slopes only during the same season to eliminate the confounding variability of different weather conditions and burrow erosion rates. Second, I was the only person who collected burrow data, thus eliminating bias between observers and ensuring consistency in assigning activity status to burrows.

Each plot was subdivided into slopes. For each slope, all squirrel burrow entrances encountered along belt transects 5 m (16.5 ft) wide were mapped onto enlarged portions of a topographical map. Parallel transects were spaced roughly 20 m (65.5 ft) apart and the total number of steps taken to traverse the slope was measured with a pedometer. The distance traveled was calculated as the number of steps taken multiplied by the size of each step in meters. Because this distance covered the area of a slope, it was converted into an approximate value in hectares. I calculated the active burrow entrance index as the number of active burrow entrances per hectare (2.5 acres).

Because the terrain was more difficult to traverse on some slopes than others, the length of my steps varied slightly. To resolve this bias, I measured the length of my stride by laying out a tape measure on slopes of varying difficulty, counting the number of steps in a 50-m (164-ft) span, and then dividing 50 m (164 ft) by the number of steps taken. I obtained a measurement of my stride length for three categories of terrain as follows: (1) difficult to walk [0.70 m (2.3 ft) per step], (2) medium difficulty [0.75 m (2.5 ft) per step], or (3) easy [0.80 m (2.6 ft) per step].

Recording the burrow entrances onto topographical maps allowed me to develop an overall value of squirrel activity as well as a map of the relative distribution and density within the study area. It also provided information on the relationship between squirrel burrows and topographical features, such as location on slope, slope aspect, slope inclination, etc.

Burrow entrances were determined to be in use by squirrels if they had any of the following characteristics: freshly excavated soil, the presence of squirrel droppings, clear pathways leading

to and from the opening, visual observation of individuals entering or leaving the hole, or vocalizations from within the hole. Alternatively, holes clogged with debris, containing spider webs, lacking squirrel pathways, or only possessing vole runways and vole latrines are all signs that squirrels have abandoned the burrow entrance (Schmutz and Hungle 1989).

Each slope was mapped for burrow entrances four times, about every three and a half months, throughout the study period. The first cycle, which corresponds approximately to spring 1999, began April 6, 1999 and ended June 29, 1999. It was used primarily as a trial run in an attempt to resolve the logistics of recording my data. I used codes in the beginning of this mapping session that were not used during the successive mapping sessions. This resulted in incompatible data sets. Hence, I did not use this first mapping session (spring 1999) during the analysis.

The second, or summer, cycle of burrow mapping was conducted between July 7, 1999 and October 7, 1999. The fall cycle was conducted between October 21, 1999 and January 13, 2000. Finally, the winter cycle lasted from January 1, 2000 to April 24, 2000.

Squirrel Activity

While mapping burrow entrances, I also kept count of the number of squirrels I observed and heard. Squirrel vocalizations emanating from within a burrow or from within deep grass were counted as sightings. The approximate location of the squirrel was mapped to decrease the chance of counting the same individual more than once. Visual counts have been used as population indices for whitetail prairie dogs (*Cynomys leucurus*) (Menkens, Biggins, and Anderson 1990) and blacktail prairie dogs (*Cynomys luovicianus*) (Knowles 1987). Powell et al. (1994) found maximum counts of prairie dogs were highest in areas with high burrow density. However, the association was weaker at the low and medium burrow density designations. Powell et al. (1994) suggested that this result may have been because the low, medium, and high burrow-entrance delineations were not refined enough to detect a linear relationship.

For this study, I used five density categories that were determined after data collection. I ordered my slopes from lowest average burrow entrance density to highest. I then determined breaks between categories every 20% of the total study area. The categories consisted of (1) 0–24 entrances/ha (2.5 acres), (2) 25–120 entrances/ha, (3) 121–229 entrances/ha, (4) 230–422 entrances/ha, and (5) > 423 entrances/ha.

Data Analysis

Golden eagles and red-tailed hawks displayed different behavioral patterns and seasonal frequencies. Therefore, they were analyzed separately.

Behavioral Data

Session refers to a 30-minute observation session, which is composed of twenty 1.5-minute intervals. Clearly sightings between intervals do not constitute independent samples, thus I used the mean number of sightings per session as my measurement of activity. I calculated the mean number of certain behaviors (perch, soaring, kiting, etc) per session and tested whether the mean number of sightings per session varied among weather factors and seasons.

Because I cannot state with assurance that sightings between observation sessions are truly independent, the statistical conclusions of this study should not be taken to imply how all hawks or eagles might behave in general. It is possible that observations on different plots and slopes, even different days, were of the same birds. Thus, this study is meant to characterize the patterns of behavior of raptors inhabiting the Altamont Pass WRA only.

Topography Data

Each plot contained a number of slopes, which were measured and described in terms of peak elevation, inclination, and aspect. Because the categories within each topographical factor were not the same size (i.e., 16% of the study area had an average grade of 0%–13%, while 27% had an average grade of 14%–18%), I divided the mean number of sightings/session/slope by the area of the slope (in hectares).

The topographical characteristics of each specific slope were used to determine the mean number of sightings/session/slope/hectare for different incline, elevation, and aspect categories.

Squirrel Activity and Burrow Entrance Data

The number and distribution of active squirrel burrow entrances of each slope was mapped approximately every four months between June 1999 and June 2000. The number of entrances was divided by the area of the slope (in hectares) and the number of total mapping sessions. The mean number of active burrow entrances/slope/hectare was used during analysis.

The total number of squirrels sightings and vocalizations recorded while mapping each slope was divided by the area of the slope (in hectares) and averaged over all mapping sessions. The sampling unit used during analysis was squirrel activity/slope/hectare.

Statistical Tests

I tested all data sets for normality and equality of variances. If the data did not satisfy the required assumptions for parametric tests, I transformed the data. Because my behavioral data contained many zeros, I used log $10(X +1)$ transformation (Zar 1996, 279). Transformation of my data did not lead to normality for the majority of the analyses. In these cases, I used nonparametric statistics.

If the data were normal, I used analysis of variance (ANOVA) to test whether there was a difference in mean values among three or more groups. If the data did not have a normal distribution, I used the Kruskal-Wallis test, also called *analysis of variance by ranks* (Zar 1996, 198).

Similarly, I used a t-test to detect a difference in mean values between two normally distributed samples. The Mann-Whitney nonparametric test was used when normality of data could not be achieved through transformation (Zar 1996, 147). I used the Wilcoxen paired sample test to determine whether the mean number of sightings on slope aspects facing the wind direction differed from the mean number not facing the wind for each observation session (Zar 1996, 167).

I performed Spearman's rho correlation test to determine whether the mean number of combined squirrel sightings and vocalizations (referred to as *squirrel activity*) was correlated with the mean number of active burrow entrances for each slope (Zar 1996, 389). I judged the strength of the correlation coefficient (r) based on four levels. A weak correlation is less than 25%, a moderate correlation is greater than 25% but less than 50%, a moderately strong correlation is greater than 50% but less than 75%, and a strong correlation is greater than 75%. I used linear regression to determine whether there was a relationship between the mean number of bird sightings/ha (for various behaviors) and the mean amount of squirrel activity/ha (Zar 1996, 319).

In cases in which ANOVA was used and a significant difference was found among the mean values among multiple samples, I used Tukey's multiple comparison test to determine where the difference was located. When the Kruskel-Wallis test was performed and a significant difference

between samples was found, I performed the Nemenyi test, which is a nonparametric analogue to the Tukey-type multiple comparison test (Zar 1996, 227).

Because the nature of this study was primarily to describe patterns of raptor habitat use, I determined Type II errors (failure to detect differences) to be more serious than Type I errors (incorrect rejection of the null hypothesis). Thus, for the analysis, I set alpha at 0.10, rather than at the commonly used 0.05, in order to increase the power of my tests (Ratti and Garton 1996, 11).

Results

Raptor Sightings

Between June 1999 and June 2000, I conducted 694 observational sessions, totaling 346.5 hours. The most common species observed during my study was the red-tailed hawk, which comprised 76% of the total raptor sightings. The American kestrel made up 9% of the total sightings, golden eagles and turkey vultures each made up only 5%, and northern harriers 3% (Figure 3).
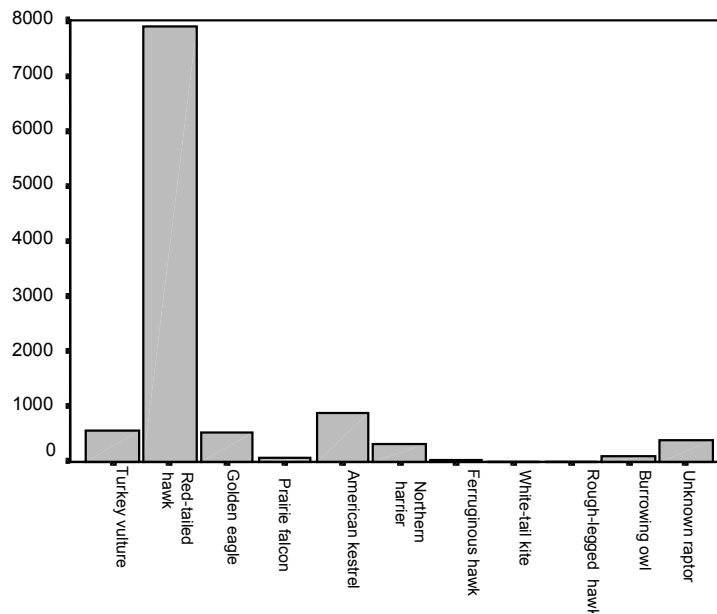
Figure 3. Total number of raptor sightings at the Altamont Pass WRA, California, from June 1999–June 2000.

Peak raptor activity occurred in the fall, during which time 69% of the sightings were made. The fall raptor sighting average was 39.5 per session. This high activity spilled into the winter season, which accounted for 23% of the year's total raptor activity with an average of 14 sightings per session (Table 2). These values were strongly affected by the abundance of red-tailed hawks. The average number of sightings per session and per season of other raptors was far fewer (Table 3).

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Table 2. Total number of 30-minute observations and the average number of raptor sightings per observation. Altamont Pass WRA, California, from June 1999–June 2000.

Season	Number of 30-minute observational sessions	Average raptor sightings per session
Summer 1999	180	5.5
Fall 1999	160	39.5
Winter 1999	180	14.0
Spring 2000	157	6.1

Table 3. Summary of raptor sightings in the Altamont Pass WRA, California, from June 1999 to June 2000. Values represent the average number of sightings of each species after 693 observation sessions for 15 study plots.

Species	Average number of sightings per session (N = 693)			
	Summer 1999	Fall 1999	Winter 1999	Spring 1999
Red-tailed hawk *Buteo jamaicensis*	2.95	31.5	9.8	3.60
American kestrel *Falco sparverius*	.34	3.01	1.70	.31
Turkey vulture *Cathartes aura*	.94	1.41	.41	.55
Northern harrier *Circus cyaneus*	.09	1.50	.33	.04
Golden eagle *Aquila chrysaetos*	.31	.83	1.08	.85
Prairie falcon *Falco mexicanus*	.26	.04	.01	.02
Burrowing owl *Athene cunicularia*	*	*	*	.73
Rough-legged hawk *Buteo lagopus*	0	0	.04	0
Ferruginous hawk *Buteo regalis*	0	.06	.11	0

*Burrowing owl activity was not recorded for the first three seasons.

Red-tailed Hawk Activity by Season and Weather

Season

The mean number of red-tailed hawk sightings across seasons was significantly different for both perching behavior (Kruskal-Wallis: P = 0.000, X^2 = 106.9, df = 3) and flight behavior (Kruskal-Wallis: P= 0.000, X^2 = 57.93, df = 3) (Figure 4). Specifically, the mean red-tailed hawk flight sightings during the summer was 40% greater than the mean number of perch sightings (Wilcoxen: P = 0.002, Z = -3.117, N = 180). The mean number of perch sightings was 2.7 times greater than the mean number of flight sightings during the fall (Wilcoxen: P = 0.000, Z= -5.141, N = 160), 5.3 times greater during the winter (Wilcoxen: P = 0.000, Z = -6.185, N = 180), and 2.3 times greater during the spring (Wilcoxen: P = 0.028, Z = -2.201, N = 157).
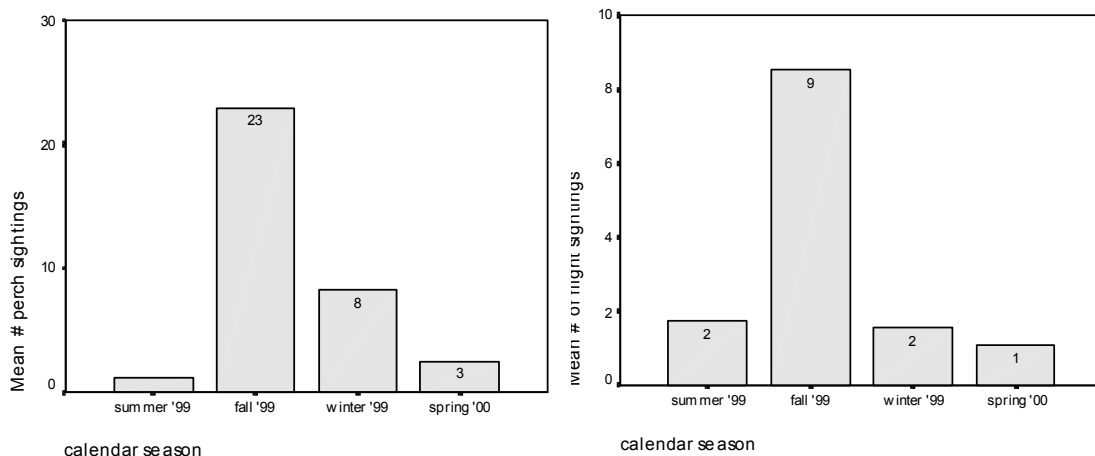
Figure 4. Mean number of red-tailed hawk perch and flight sightings/session at the Altamont Pass WRA, California, for summer 1999 (n = 180), fall 1999 (n = 160), winter 1999 (n = 180), and spring 2000 (n = 157).

Wind Speed

Red-tailed hawks perched 2.8 times more when winds were weak than when they were strong (T-test: $P < 0.001$, $F = 25.14$, $df = 692$) (Figure 5). Also, the primary perch structure used by red-tailed hawks in weak winds differed significantly from perch structures used in strong winds (Chi square: $X^2 = 0.000$, $df = 4$) (Figure 6). Ground and rock perches were used as primary perch structures in strong wind but not in weak wind (54% of perch sightings versus 32%, respectively). However, taller structures were used more often in weak winds than in strong winds (power line/pole = 39% vs. 26%, turbine = 22% vs. 14%, tree = 0.05% vs. 0.0%).
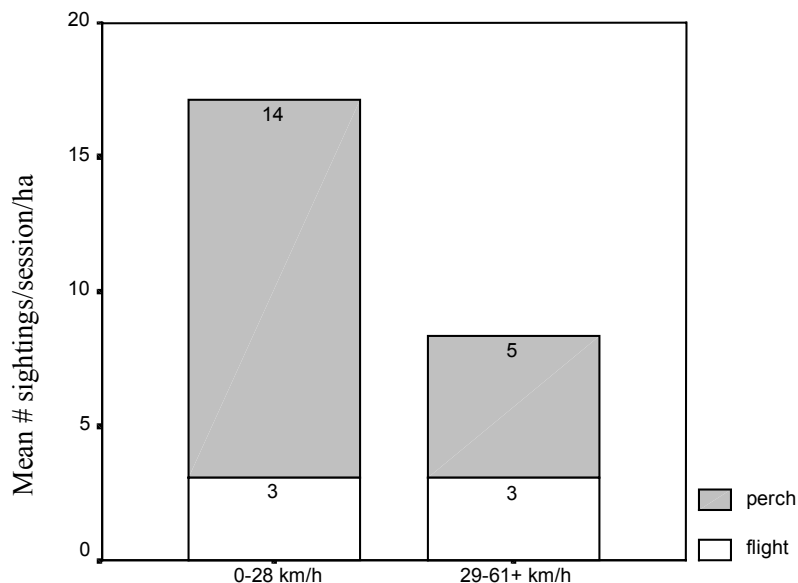
Figure 5. Mean number of red-tailed hawk perch and flight sightings/session by wind speed category at the Altamont Pass WRA, California, June 1999–June 2000.
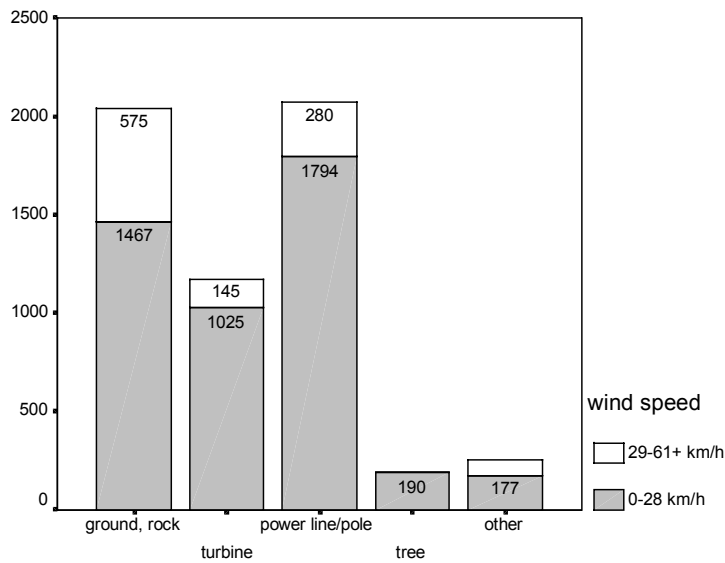
Figure 6. Total number of sightings of red-tailed hawk perch activity by structure type and wind speed at the Altamont Pass WRA, California, June 1999─June 2000.

Overall, red-tailed hawks were more often seen perching on slopes whose aspect did not face into prevailing winds (Wilcoxen: P = 0.000, Z = -6.593, N = 213). However, perch sightings on slopes facing into the wind account for more of the sightings in weak wind [28% of sightings in wind 0–28 km/h (17.4 mph)] than in strong wind [14% of sightings in wind 29–61 km/h (18–38 mph)] (Figure 7).
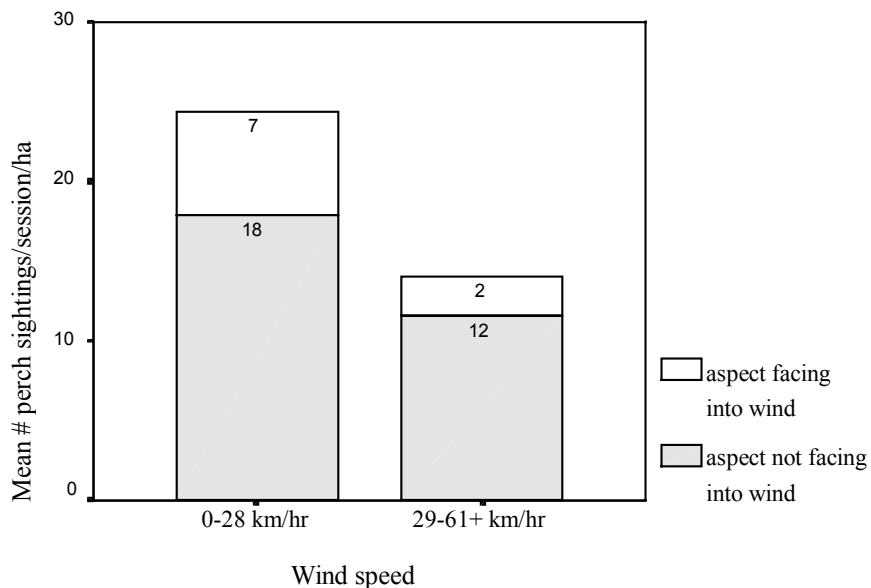
Figure 7. Mean number of sightings/session/slope/ha, for two wind speed categories, of red-tailed hawks perched on slopes facing into winds and perched on slopes not facing into wind. Altamont Pass WRA, California, June 1999–June 2000.

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Although the amount of flight activity displayed by red-tailed hawks in weak wind did not differ significantly from that displayed in strong wind (T-test: P = 0.96, F = 0 .002, df = 691) (Figure 5), the relative use of two primary styles of flight differed depending on wind speed (Figures 8 and 9). The mean number of sightings of kiting behavior was 0.2 in weak wind and 1.3 in strong wind; an increase of 6.5 times (P = 0.041, T = -2.08, df = 79). Conversely, the average number sightings per session of soaring behavior was 3.5 times greater during weak wind (mean = 1.4) than strong wind (mean = 0.4) (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) were not significantly different between wind speed categories.
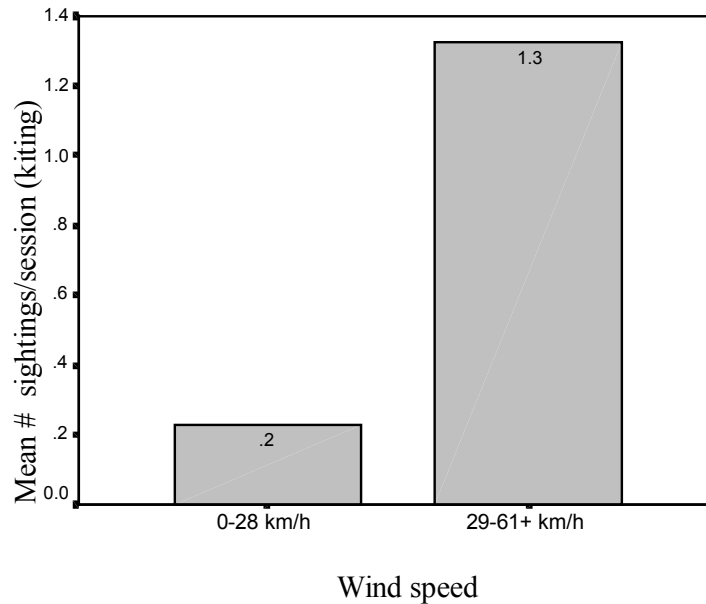
Figure 8. Mean number of sightings/session of red-tailed hawk kiting behavior for two wind speed categories. Altamont Pass WRA, California, June 1999–June 2000.
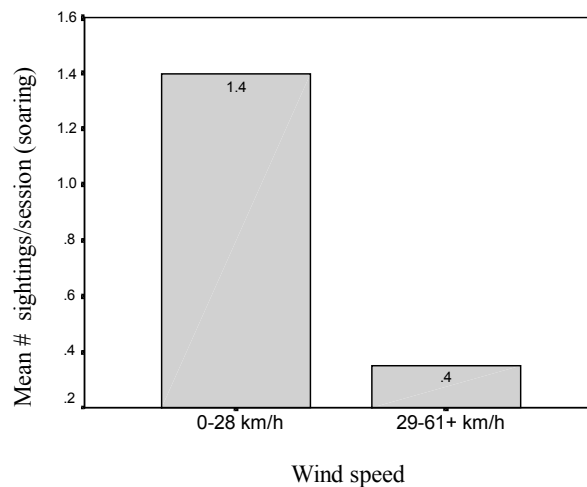
Figure 9. Mean number of red-tailed hawk sightings/session of soaring behavior for two wind speed categories. Altamont Pass WRA, California, June 1999–June 2000.

Cloud Cover

During the summer and spring season, there were 3.1 sightings of red-tailed hawks per session in 51%–75% cloud cover, but only 1.1 sightings/session/ha when cloud cover was 0%–25%, a decrease of 2.8 times (ANOVA: P = 0.042, F = 2.763, df = 352, Tukey multiple comparison: P = 0.027). Similarly, they perched during 51%–75% cloud cover 4.5 times more often than during 0%–25% cover and 3 times more frequently than during 26%–50% cover (ANOVA: P = 0.031, F = 2.985, df = 352, Tukey: P = 0.024 and 0.036 respectively) (Figure 10). The average number of flight sightings and perch sightings did not differ significantly among cloud cover levels during the peak of red-tailed hawk activity, i.e., the fall and winter season (ANOVA: P = 0.295, F = 1.240, df = 333 and P = 0.600, F = 0.624, df = 333, respectively) (Figure 11).
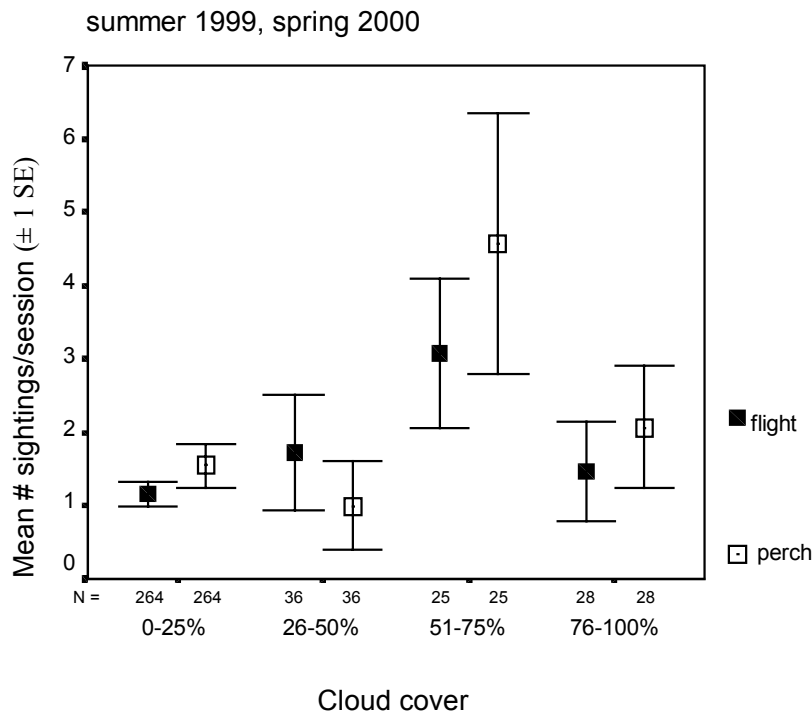
Figure 10. Mean number of red-tailed hawk flight and perch sightings/session (± 1 SE) in different amounts of cloud cover. Observations conducted during summer (21 June–22 September 1999) and spring (21 March–20 June 2000) at Altamont Pass WRA, California.

fall 1999, winter 1999-2000
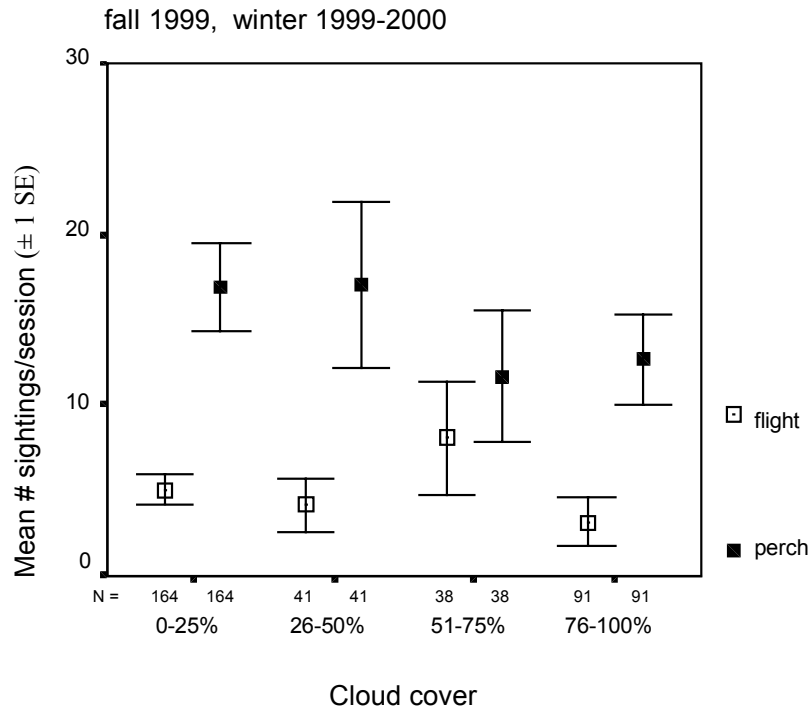
Figure 11. Mean number of red-tailed hawk flight and perch sightings/session (± 1 SE) in different levels of cloud cover. Observations conducted during fall (23 September–20 December 1999) and winter (21 December 1999–20 March 2000) at Altamont Pass WRA, California.

Time of day

The mean number of perch sightings did not differ by time of day during the summer, fall, or winter seasons (Figures 12, 13, and 14). However, during the spring, average red-tailed hawk perch sightings were 2.9 times greater during the afternoon than during the evening (Kruskal-Wallis: $P = 0.040$, $X^2 = 6.456$, df = 2) (Figure 15).

summer 1999
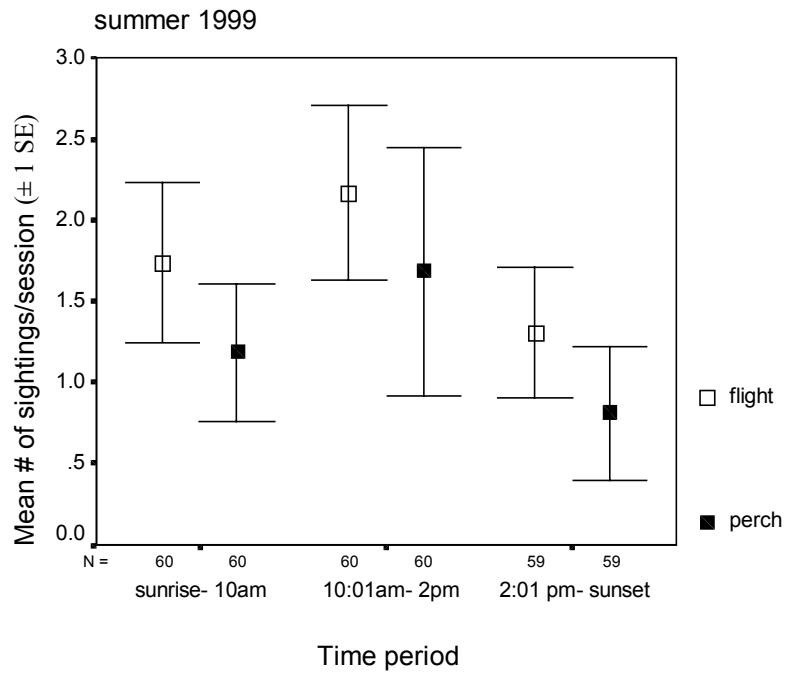
Figure 12. Mean number of red-tailed hawk flight and perch sightings/session (± 1 SE) for different time periods during the summer season (June 21–September 22, 1999) at Altamont Pass WRA, California.

fall 1999
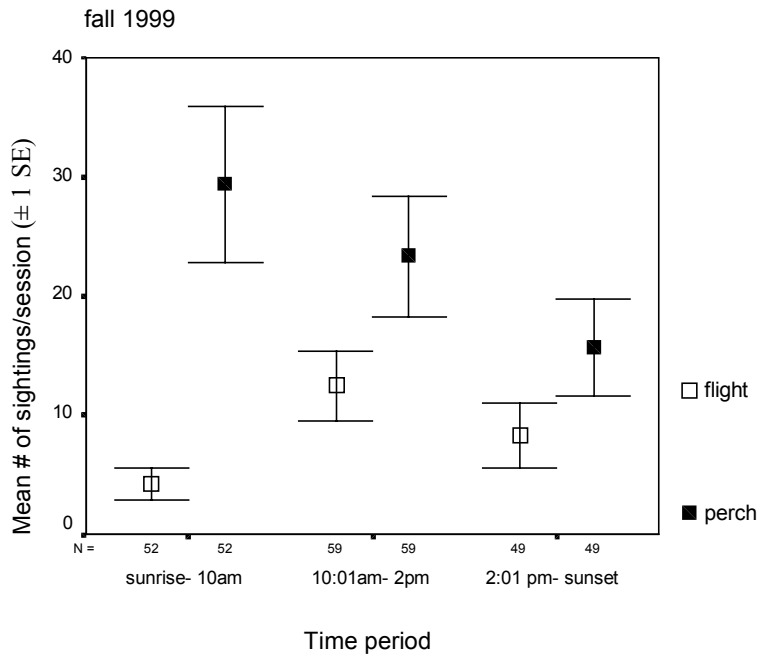
Figure 13. Mean number of red-tailed hawk flight and perch sightings/session (± 1 SE) for different time periods during the fall season (September 23 – December 20, 1999) at Altamont Pass WRA, California.

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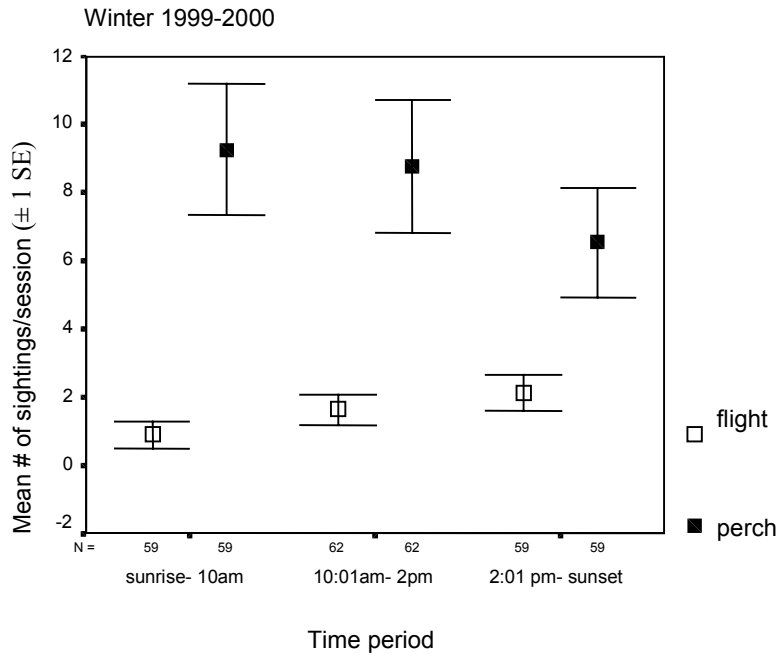
Figure 14. Mean number of red-tailed hawk flight and perch sightings/session (± 1 SE) for different time periods during the winter season (December 21, 1999–March 20, 2000) at Altamont Pass WRA, California.
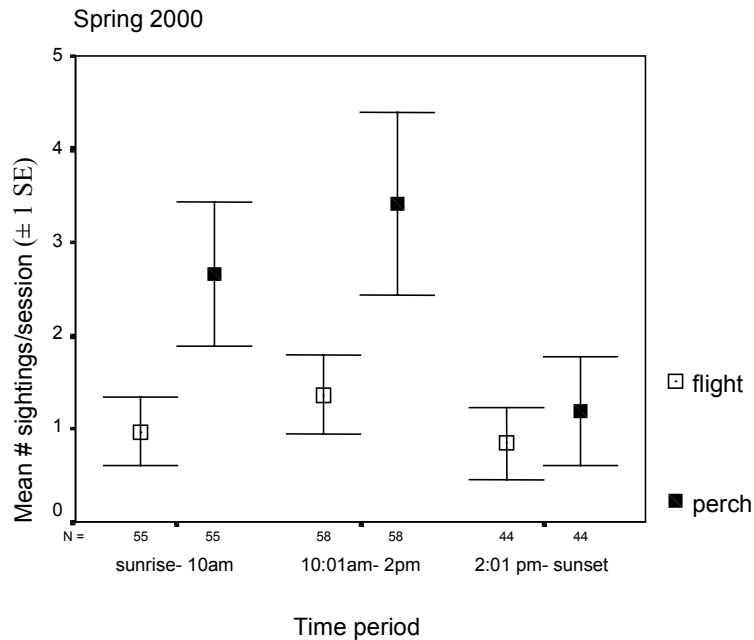
Figure 15. Mean number of red-tailed hawk flight and perch sightings/session (± 1 SE) for different time periods during the spring season (March 21–June 20, 2000) at Altamont Pass WRA, California.

During the summer and spring seasons, the mean number of flight sightings did not differ significantly by time of day (Figure 12 and 15). In the fall, the average number of red-tailed hawks flight sightings was 3 times greater in the afternoon than in the morning (Kruskal-Wallis: $P = 0.008$, $X^2 = 9.611$, $df = 2$, Nemenyi multiple comparison test: $P < 0.05$), and in the winter, the average number of flight sightings was 2.4 times greater in the evening than in the morning (Kruskal-Wallis: $P = 0.043$, $X^2 = 6.310$, $df = 2$, Nemenyi: $P < 0.10$) (Figure 13 and 14).

Red-tailed Hawk Activity and Topography

Distance from nearest turbine

Red-tailed hawk flight behavior at distances greater than 100 m (328 ft) from the nearest turbine averaged 7.1 sightings per session. This was 2 to 2.6 times more than the number of sightings observed within the other distance categories (Kruskal-Wallis: $P < 0.001$, $X^2 = 176.164$, $df = 4$, Nemenyi: $P < 0.05$). Flight activity was least common within 10 m (32.8 ft) from a turbine; averaging only 0.5 sightings per session (Nemenyi: $P < 0.05$).

In strong wind, flapping behavior occurred most commonly at distances of greater than 100 m (328 ft) from the nearest turbine, averaging 0.6 sightings per session. This was 4 times greater than the occurrence of flapping within 1–10 m (3.2–32.8 ft) of turbines and 3 times more frequent than for distances of 11–50 m (36–164 ft) and 76–100 m (249–328 ft), respectively, from the nearest turbine (Kruskal-Wallis: $P = 0.036$, $X^2 = 10.294$, $df = 4$, Nemenyi: $P < 0.05$). Similarly, flapping in weak wind was most frequent at distances greater than 100 m (328 ft) from turbines and differed significantly from distances 1–10 m (3.2 –32.8 ft) and 76–100 m (249–328 ft) (Kruskal-Wallis: $P = 0.012$, $X^2 = 12.926$, $df = 4$, Nemenyi: $P < 0.10$) (Figure 16).
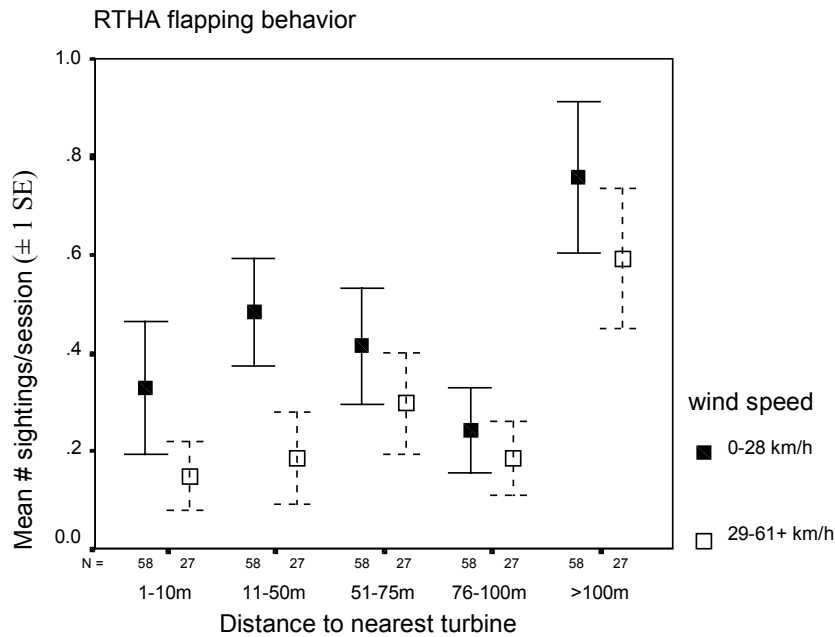
Figure 16. Mean number of red-tailed hawk sightings/session (± 1 SE) of flapping behavior for five distance categories from the nearest turbine, in two wind speed levels. Altamont Pass WRA, California, June 1999–June 2000.

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In weak wind, kiting behavior did not differ between distance levels from nearest turbine (Kruskal-Wallis: P = 0.236, X^2 = 5.541, df = 4) (Figure 17). However, when winds were strong, kiting 11–50 m (36–164 ft) from the nearest turbine averaged 3.5 sightings per session. This was significantly greater than kiting within 10 m (32.8 ft) of turbines, which was extremely rare; approximately 0.1 sightings per session. (Kruskal-Wallis: P < 0.001, X^2 = 39.903, df = 4, Nemenyi: P < 0.05).
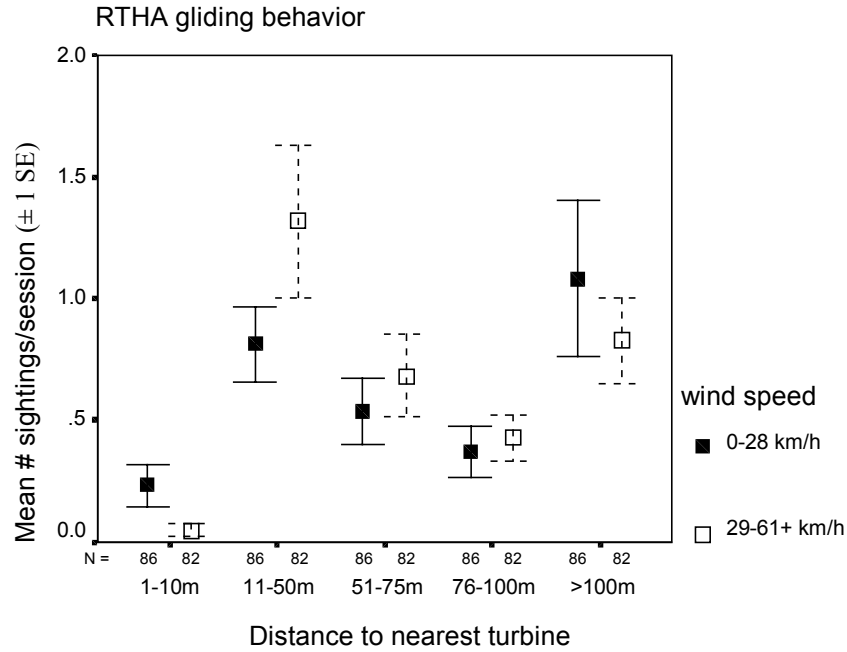
Figure 17. Mean number of red-tailed hawk sightings/session (± 1 SE) of kiting behavior at five distance categories from the nearest turbine, for two wind speed levels. Altamont Pass WRA, California, June 1999–June 2000.

In weak wind, gliding activity at distances greater than 100 m (328 ft) from the nearest turbine was 5.5 times more common than from distances of 1–10 m (3.2 –32.8 ft), and 2.8 times more common than from distances of 76–100 m (249–328 ft) (Kruskal-Wallis: P < 0.001, 33.829, df = 4, Nemenyi: P < 0.05) (Figure 18).
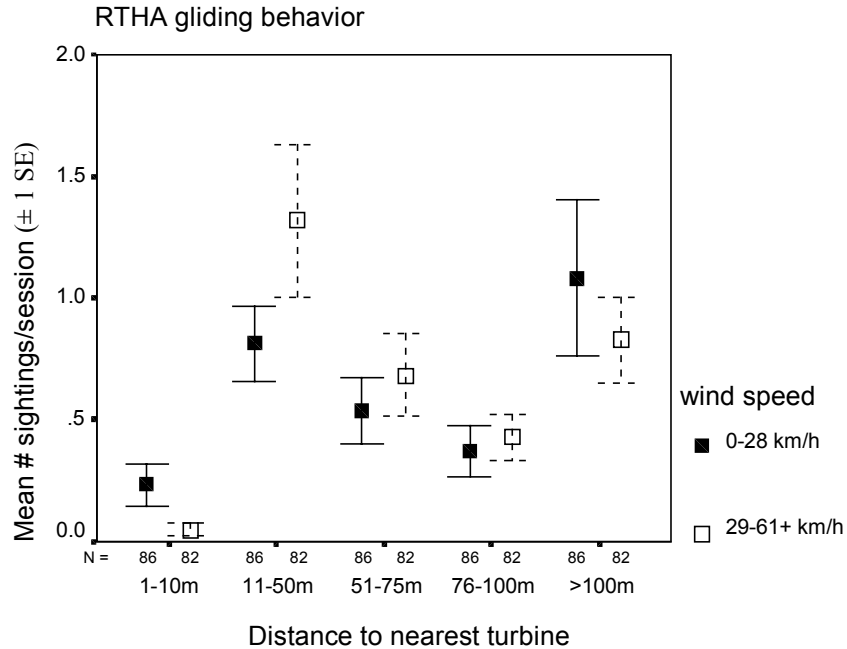
Figure 18. Mean number of red-tailed hawk sightings/session (± 1 SE) of gliding behavior at five distance categories from the nearest turbine, for two wind speed levels. Altamont Pass WRA, California, June 1999–June 2000.

In strong winds, red-tailed hawks gliding within 1–10 m (3.2 –32.8 ft) of a turbine were rare, averaging less than 0.1 sightings per session. This was considerably less than gliding within 11–50 m (36–164 ft) from a turbine (1.3 sightings per session) and gliding at distances more than 100 m (328 ft) of a turbine (0.8 sightings per session). The most common distance from a turbine that gliding activity was observed was 11–50 m (36–164 ft), which was twice as common as distances of 76–100 m (249–328 ft) (Kruskal-Wallis: P < 0.001, X^2 = 44.431, df = 4, Nemenyi: P < 0.05). Finally, in weak wind, soaring activity at distances greater than 100 m (328 ft) from the nearest turbine averaged 2.3 sightings per session, which was at least 1.8 times greater than for any other distance level (Kruskal-Wallis: P < 0.001, X^2 = 50.116, df = 4, Nemenyi: P < 0.05) (Figure 19). The second most common distance from turbines was 11–50 m (36–164 ft), which was significantly more common than 76–100 m (249–328 ft) (mean =1.3 sightings per session versus mean = 0.5 sightings per session) (Nemenyi: P < 0.05).

When winds were strong, soaring activity was greater 11–50 m (36–164 ft) from turbines (mean = 1.1 sightings per session) than from 1–10 m (3.2 –32.8 ft) or 51–76 m (167–328 ft) (mean = 0.3 sightings per session and mean = 0.2 sightings per session, respectively) (Nemenyi: P < 0.05).
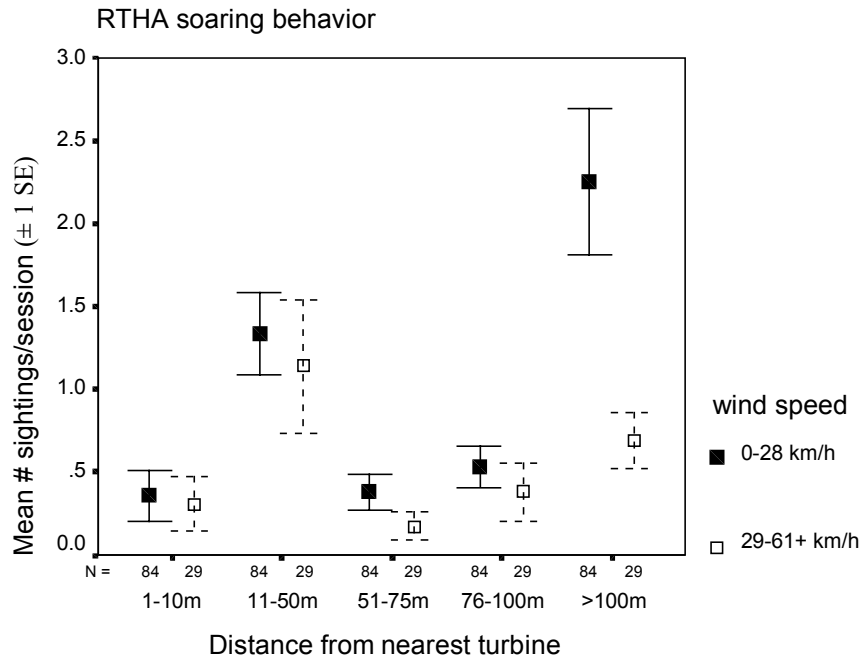
Figure 19. Mean number of red-tailed hawk sightings/session (± 1 SE) of soaring behavior at five distance categories from the nearest turbine, for two wind speed levels. Altamont Pass WRA, California, June 1999–June 2000.

Distance from the ground

Overall, red-tailed hawks were at least 5 times more likely to fly at 11–50 m (36–164 ft) above the ground than at other height levels (Kruskal-Wallis: $P < 0.001$, $X^2 = 241.311$, df = 3, Nemenyi test: $P < 0.05$).

Specifically, the mean number of sightings of kiting behavior observed 11–50 m (36–164 ft) from the ground was at least 7 times greater than the mean at other distance levels (Kruskal-Wallis: $P < 0.001$, $X^2 = 188.938$, df = 4, Nemenyi test: $P < 0.05$) (Figure 20).
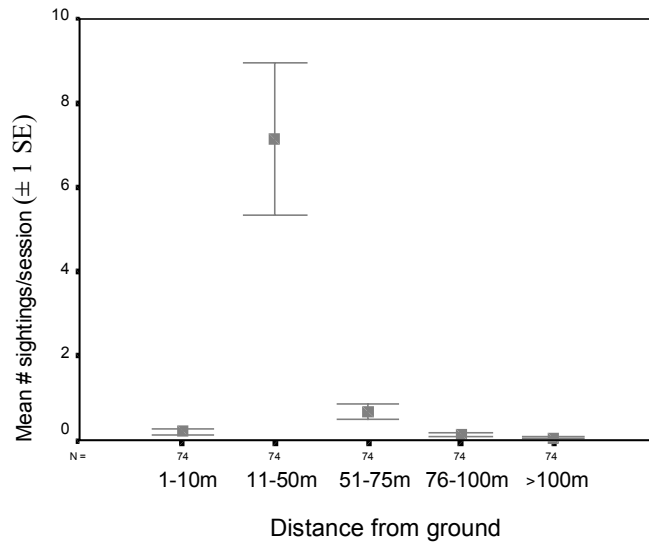
Figure 20. Mean number of red-tailed hawk sightings/session (±1SE) of kiting behavior at various height levels from the ground. Altamont Pass WRA, California, June 1999–June 2000.

Flapping behavior occurred significantly more often 1–10 m (3.2 –32.8 ft) and 11–50 m (36–164 ft) from the ground (mean = 1 sighting per session and mean = 0.85 sightings per session, respectively). Both differed significantly from the mean number of sightings at other levels (remaining levels all have means < 0.1) (Kruskal-Wallis: P < 0.001, X^2 = 153.054, df = 4, Nemenyi test: P < 0.05) (Figure 21).
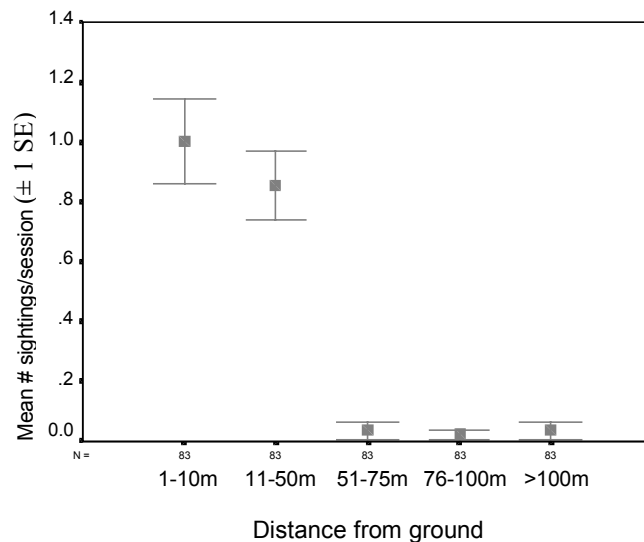
Figure 21. Mean number of red-tailed hawk sightings/session (± 1 SE) of flapping flight at various height levels from the ground. Altamont Pass WRA, California, June 1999–June 2000.

Similarly, gliding behavior was exhibited most commonly 11–50 m (36–164 ft) from the ground with an average of 2 sightings per session. This was at least 2.8 to 20 times greater than other distance levels (Kruskal-Wallis: $P = 0.000$, $X^2 = 254.879$, df = 4; Nemenyi multiple comparison $P < 0.10$) (Figure 22). The second most frequent distance level was 1–10 m (3.2 –32.8 ft), which averaged 0.7 sightings per session and differed from distances 76–100 m (249–328 ft) from the ground (mean = 0.1 sightings per session) and distances of more than 100 m (328 ft) from the ground (mean = 0.2 sightings per session) (Nemenyi multiple comparison: $P < 0.10$).
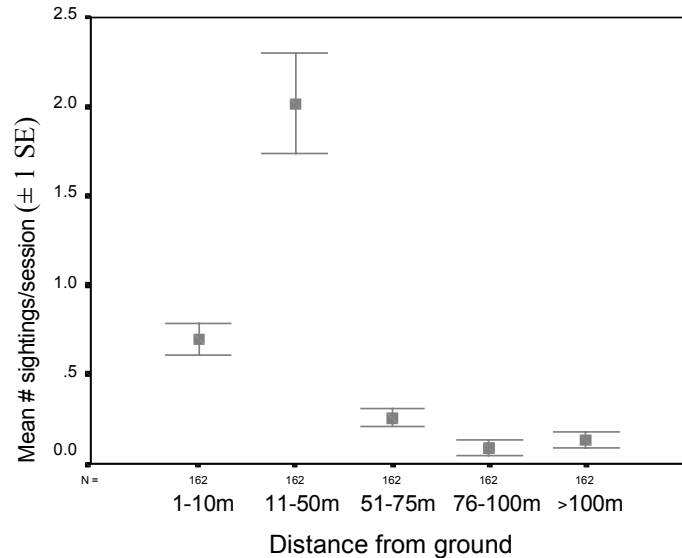
Figure 22. Mean number of red-tailed hawk sightings/session (± 1 SE) of gliding behavior at various height levels from the ground. Altamont Pass WRA, California, June 1999–June 2000.

Lastly, soaring behavior was also most common 11–50 m (36–164 ft) from the ground, averaging 2.5 sightings per session (Kruskal-Wallis: $P < 0.001$, $X^2 = 118.291$, df = 4, Nemenyi multiple comparison: $P < 0.05$) (Figure 23). However, this mode of flight was less common 1–10 m (3.2 – 32.8 ft) from the ground (mean = 0.2 sightings per session) than it was 51–75 m (167–246 ft) from the ground (mean = 1 sighting per session) (Nemenyi multiple comparison: $P < 0.05$).
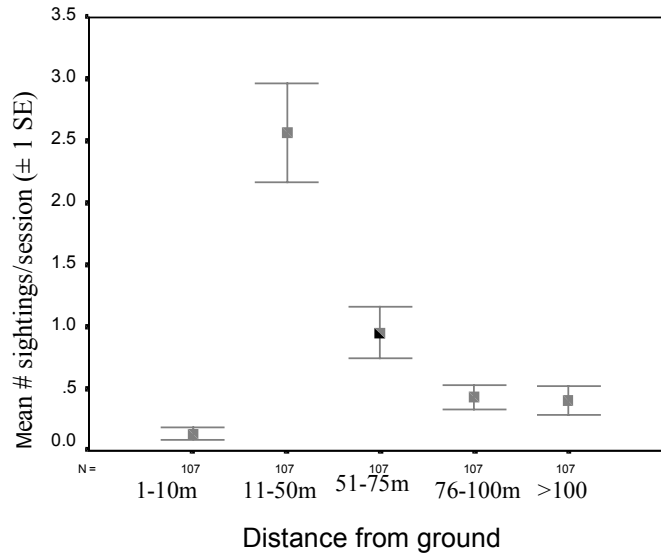
Figure 23. Mean number of red-tailed hawk sightings (± 1 SE) of soaring behavior at various height levels from the ground. Altamont Pass WRA, California, June 1999–June 2000.

When wind speed was added as a factor (weak wind, strong wind), flight within height levels did not differ significantly among the two wind speed ranges (Table 4).

Table 4. Wilcoxen paired sample test results comparing red-tailed hawk flight distance from ground in weak (0–28 km/h) and strong (29–61 km/h) wind conditions. Altamont Pass WRA, California, June 1999–June 2000.

Distance from Ground	Wind speed	N	Mean # sightings/ session	SD	X^2, df	p-value
1-10 meters	Weak	108	.99	1.74	.006, 1	.939
	Strong	175	.93	1.76		
11-50 meters	Weak	108	3.88	10.34	.359, 1	.549
	Strong	175	5.16	12.67		
51-75 meters	Weak	108	1.03	2.29	2.593, 1	.107
	Strong	175	.55	1.33		
> 75 meters	Weak	108	.64	1.54	.162, 1	.688
	Strong	175	.50	1.33		

Aspect

In both strong and weak wind conditions, red-tailed hawks displayed kiting behavior 3.8 times more often on slopes whose aspect faced into the wind than on slopes that did not face into the wind [Wilcoxen paired-sample: P = 0.020, Z = -2.333, df = 133 for wind speeds 0–28 km/h (17 mph), P < 0.001, Z = -5.022, df = 190 for wind speeds 29–61 km/h (18–38 mph)] (Figures 24 and 25).
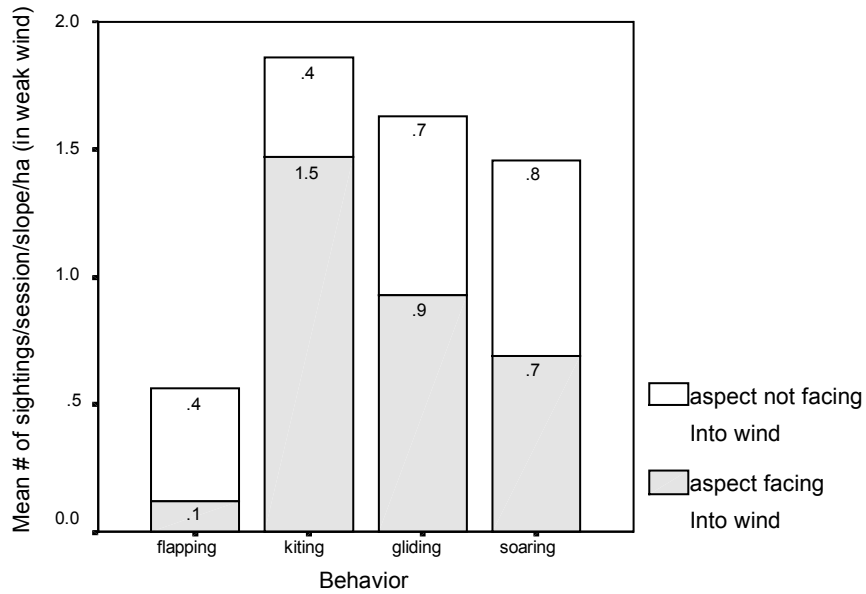
Figure 24. Mean number of red-tailed hawk sightings/session/slope/ha, by flight style, in weak wind (0–28 km/h) on hillsides facing into prevailing winds and hillsides not facing into wind. Altamont Pass WRA, California, June 1999–June 2000.
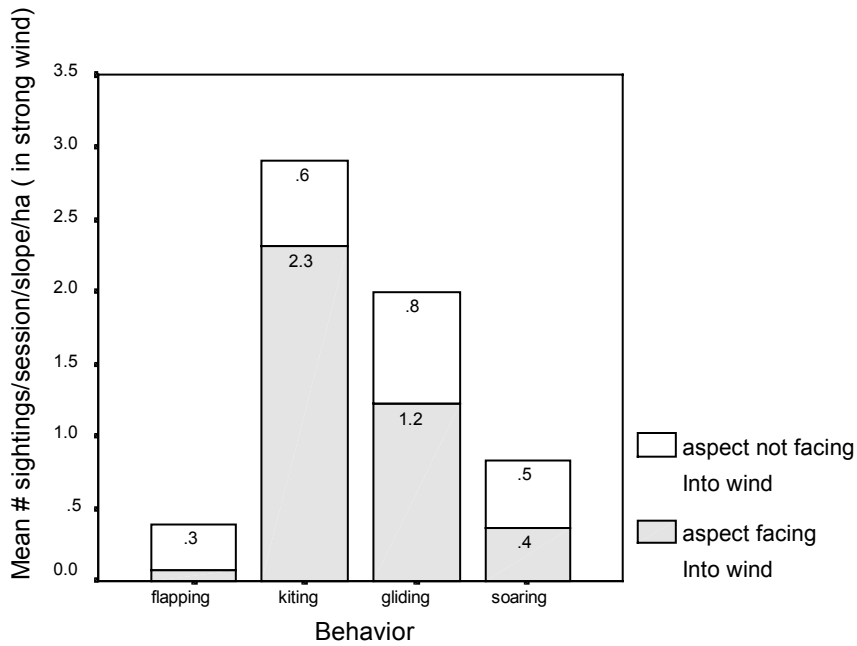
Figure 25. Mean number of red-tailed hawk sightings/session/slope/ha, by flight style, in strong wind (29–61 km/h) on hillsides facing into winds and hillsides not facing into wind. Altamont Pass WRA, California, June 1999–June 2000.

Flapping behavior was displayed approximately 3.5 times more frequently on hillsides whose aspect did not face into the wind than on those slopes that did [Wilcoxen paired-sample: P = 0.006, Z = -2.758, df = 133 for wind speeds 0–28 km/h (17 mph), P < 0.001, Z = -3.530, df = 190 for wind speeds 29–61 km/h (18–38 mph)] (Figure 24 and 25).

Gliding and soaring behavior were equally likely to be seen on slopes facing into the wind as those slopes whose aspect did not face into the wind [Wilcoxen paired-sample: gliding in wind 0–28 km/h (17 mph), P = 0.700, Z = -0.386, df = 133; soaring in wind 0–28 km/h (17 mph), P = 0.956, Z = -0.055, df = 133; gliding in winds 29–61 km/h (18–38 mph), P = 0.184, Z = -1.329, df = 190; soaring in wind 29–61 km/h (18–38 mph), P = 0.817, Z = -0.232, df = 190) (Figure 24 and 25).

Inclination

The mean number of total red-tailed hawks sightings (perching and flying) did not differ significantly among slope incline levels when analyzed by activity season, perch versus flight behavior, or wind speed (Table 5).

Table 5. Kruskal-Wallis test results comparing mean number of sightings/session/slope/ha of red-tailed hawk activity among four different slope incline levels by season, behavior, and wind speed level (see text). Altamont Pass WRA, California, June 1999–June 2000.

average % grade	Statistic	Flight during non-peak activity season activity	Flight during peak activity season	Flight in weak wind	Flight during strong wind	Perching during non-peak activity season	Perching during peak activity season	Perching during weak wind	Perching during strong wind
0-13%	Mean # sightings/session/ slope/hectare	.28609	.88035	.41437	.64004	.20529	3.78126	2.90928	1.56483
	N	12	12	12	12	12	12	12	12
	Std. Error of Mean	5.0157E-02	.26405	.10714	.18216	.12472	1.18328	1.17334	.46468
14-18%	Mean # sightings/session/ slope/hectare	.39071	.71626	.53091	.52413	.72370	11.12448	10.16013	2.79213
	N	24	24	24	24	24	24	24	24
	Std. Error of Mean	.17489	.17614	.16041	.15127	.21132	3.58954	3.26196	.93037
19-23%	Mean # sightings/session/ slope/hectare	.42374	1.47713	1.06853	.89372	.31983	4.17161	3.95903	.96812
	N	21	21	21	21	21	21	21	21
	Std. Error of Mean	.11950	.60551	.25061	.44750	.13086	1.29271	1.36969	.28245
>24%	Mean # sightings/session/ slope/hectare	.46058	2.81894	1.08345	1.85221	.98367	3.83614	2.53030	2.03143
	N	23	23	23	23	23	23	23	23
	Std. Error of Mean	.10967	1.16400	.30072	.96035	.41535	.89549	.59759	.57423
Kruskal -Wallis test results	X^2, df	5.731, 3	4.131, 3	5.634, 3	2.463, 3	4.415, 3	4.504, 3	3.336, 3	1.517, 3
	p-value	.125	.248	.131	.482	.220	.212	.343	.678

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When red-tailed hawk behavior was divided into the primary styles of flight, only gliding behavior differed significantly between incline levels (Figure 26). Red-tailed hawks glided almost 3 times more frequently on the steepest slopes than on slopes of other incline levels (Kruskal-Wallis: $P = 0.005$, $X^2 = 12.970$, df = 3, Nemenyi: $P < 0.05$).
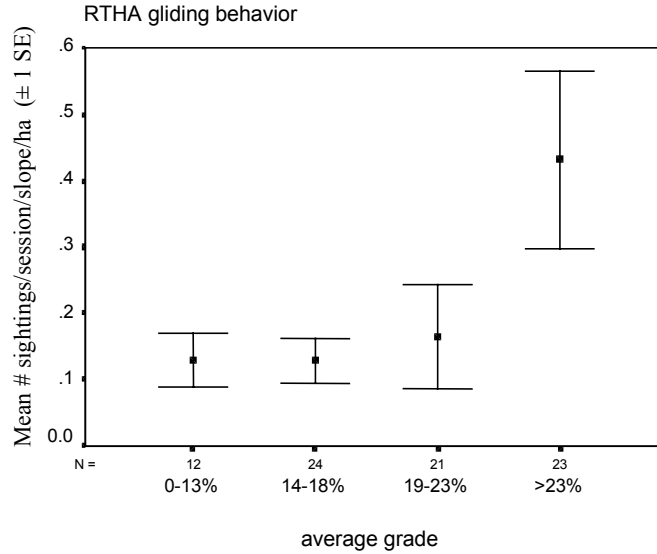
Figure 26. Mean number of sightings/session/slope/ha (± 1 SE) of red-tailed hawks gliding on slopes of different incline levels. Altamont Pass, California, June 1999–June 2000.

There was no significant difference in activity by slope incline level for flapping flight (Kruskal-Wallis: $P = 0.436$, $X^2 = 2.724$, df = 3) (Figure 27), soaring flight (Kruskal-Wallis: $P = 0.183$, $X^2 = 4.847$, df = 3) (Figure 28), or kiting flight (Kruskal-Wallis: $P = 0.492$, $X^2 = 2.410$, df = 3) (Figure 29).
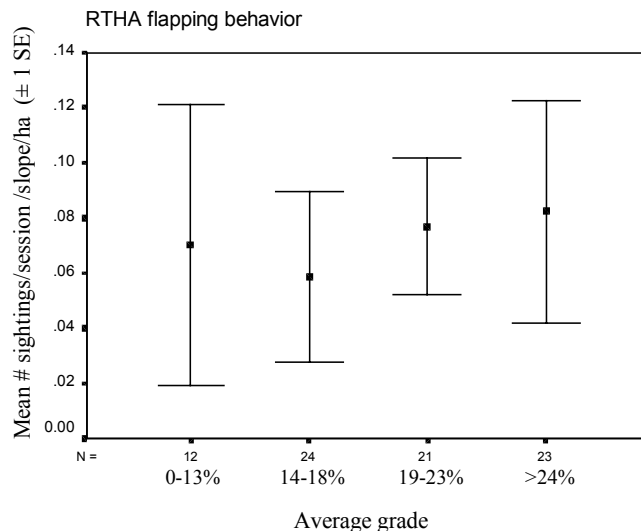
Figure 27. Mean number of sightings/session/slope/ha (± 1 SE) of red-tailed hawks using flapping flight on slopes of different incline levels. Altamont Pass, California, June 1999–June 2000.
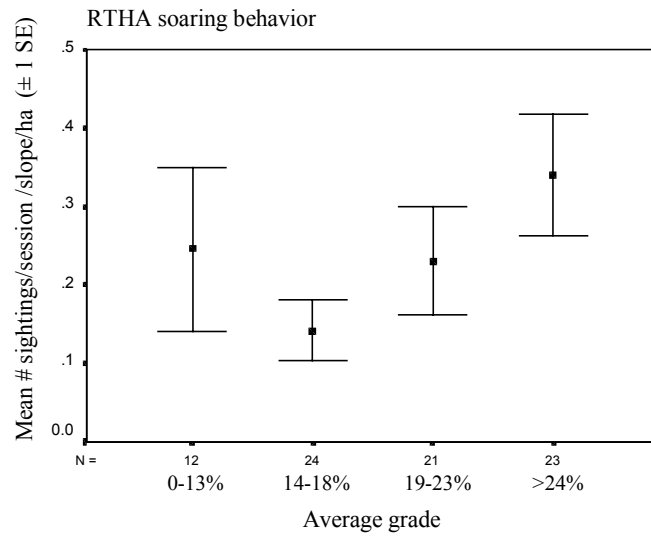
Figure 28. Mean number of sightings/session/slope/ha (± 1 SE) of red-tailed hawks using soaring flight on slopes of different incline levels. Altamont Pass, California, June 1999–June 2000.
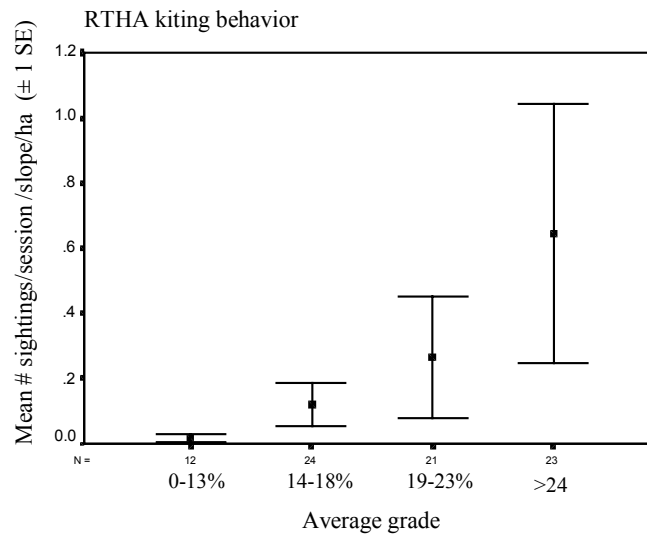
Figure 29. Mean number of sightings/session/slope/ha (± 1 SE) of red-tailed hawks using kiting flight on slopes of different incline levels. Altamont Pass, California, June 1999–June 2000.

Elevation

Red-tailed hawks were 5.5 times more likely to be seen flying on slopes with a peak elevation of 226–256 m (741–840 ft) than on slopes of other elevation ranges (Kruskal-Wallis: P = 0.002, X^2 = 15.224, df = 3) (Figure 30). Perching activity was 1.7 times greater on slopes with peak elevations of 226–256 m (741–840 ft) than on slopes with elevations of 262–347 m (860–1,138 ft) (Kruskal-Wallis: P < 0.001, X^2 = 19.368, df = 3; Nemenyi: P < 0.05).
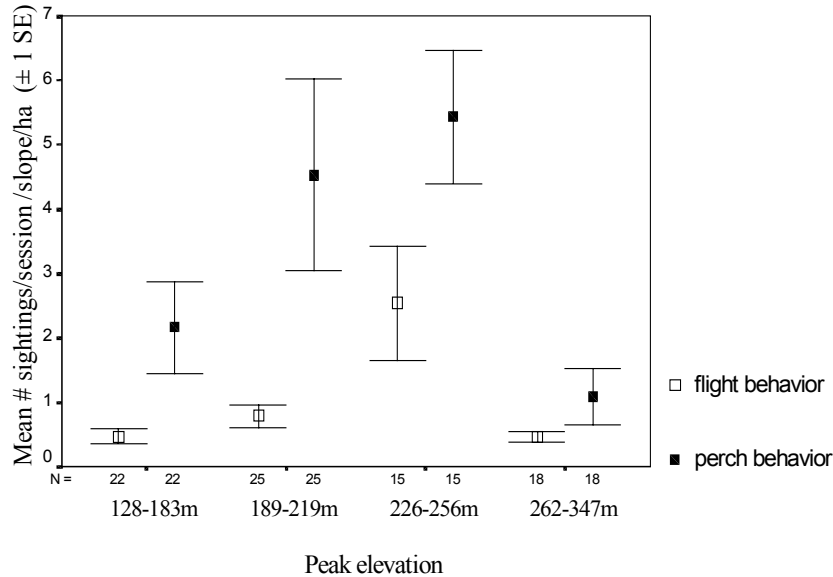
Figure 30. Mean number of red-tailed hawk sightings/session/slope/ha (± 1 SE) on slopes for four peak elevation levels. Altamont Pass WRA, California, June 1999–June 2000).

All flight styles were more common on slopes falling into the 226–256m (741–840- ft) peak elevation category. However, significant differences were only found for kiting and gliding activity, which were at least 6 times greater and at least 2.4 times greater, respectively, at 226–256 m (741–840 ft) than other elevation levels (Kruskal-Wallis: P = 0.072, X^2 = 6.992, df = 3; Nemenyi: P < 0.05 and Kruskal-Wallis: P < 0.001, X^2 = 28.537, df = 3; Nemenyi: P < 0.05, respectively) (Figure 31 and 32).

Miscellaneous: Activity on Specific Slopes

Slope numbers 41, 49, and 57 contained 90% of red-tailed hawk kiting behavior, averaging 8.5, 4.0, and 3.9 sightings per session, respectively. These three slopes had inclines of 26%, 26%, and 21% average grade, respectively. They were south/southwest-facing slopes and each had the highest peak elevation [226–256m (741–840 ft)], relative to surrounding peaks. The only higher peaks were on the other side of the study area in an area devoid of squirrel activity. Finally, all three slopes had an average burrow entrance density falling in the middle size category (121–229/ha).
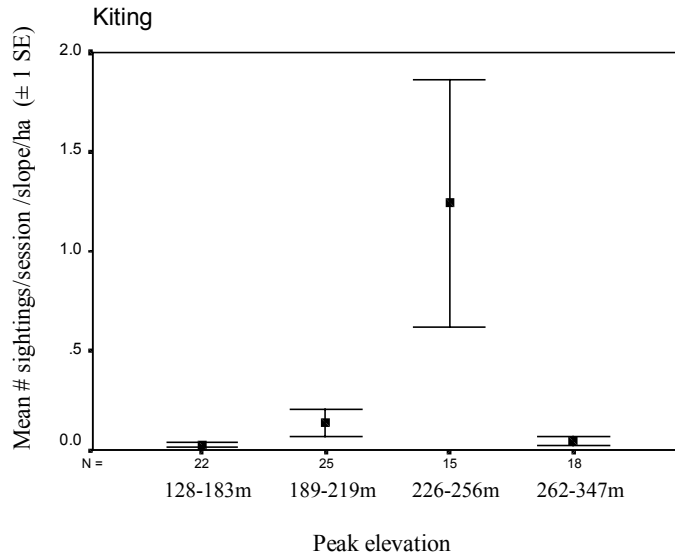
Figure 31. Mean number of red-tailed hawk sightings/session/slope/ha (± 1 SE) of kiting behavior for four peak elevation categories. Altamont Pass WRA, California, June 1999– June 2000.
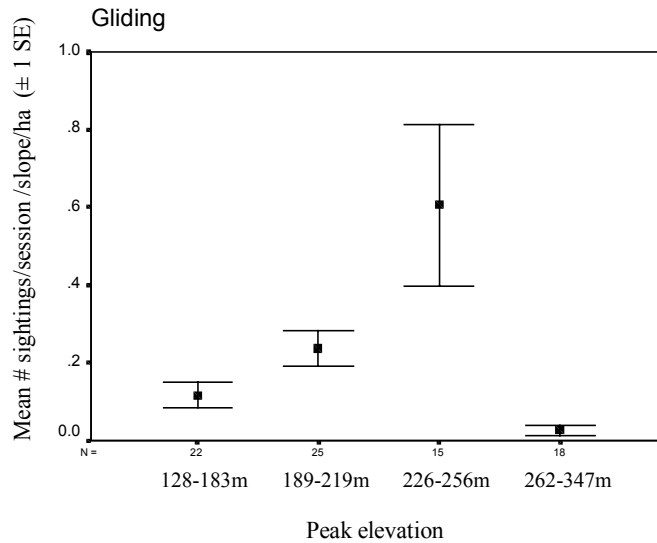
Figure 32. Mean number of red-tailed hawk sightings/session/slope/ha (± 1 SE) of gliding behavior for four peak elevation categories. Altamont Pass WRA, California, June 1999– June 2000.

Red-tailed Hawk Activity and Ground Squirrel Activity

Active burrow entrances

The mean number of active squirrel burrows per hectare did not differ significantly between seasons (Figure 33) (ANOVA: P = 0.143, F = 1.961, df = 2).
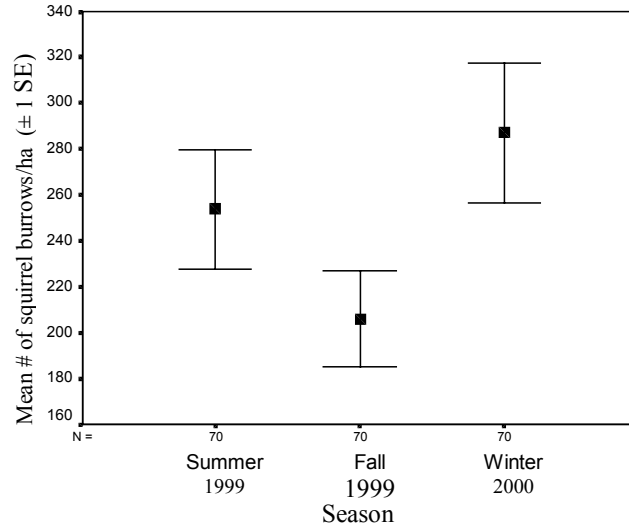
Figure 33. Mean number of active squirrel burrows entrances/ha (± 1 SE) for three seasons. Altamont Pass WRA, California, July 1999– May 2000.

During the nonpeak activity season, red-tailed hawks perched between 3 and 6 times more frequently on slopes that had the highest burrow entrance density than slopes with lower density (Kruskal-Wallis: P = 0.037, X^2 = 10.184, df = 4) (Nemenyi: P < 0.10) (Figure 34). During strong winds, they perched significantly more on slopes with the highest burrow density (> 423/ha), as well as on slopes with a density of 25–120 entrances/ha. Activity at both these densities differed significantly from perching activity in the lowest density of 0–24 entrances/ha (Kruskal-Wallis: P < 0.001, X^2 = 31.184, df = 4) (Nemenyi: P < 0.05) (Figure 35).
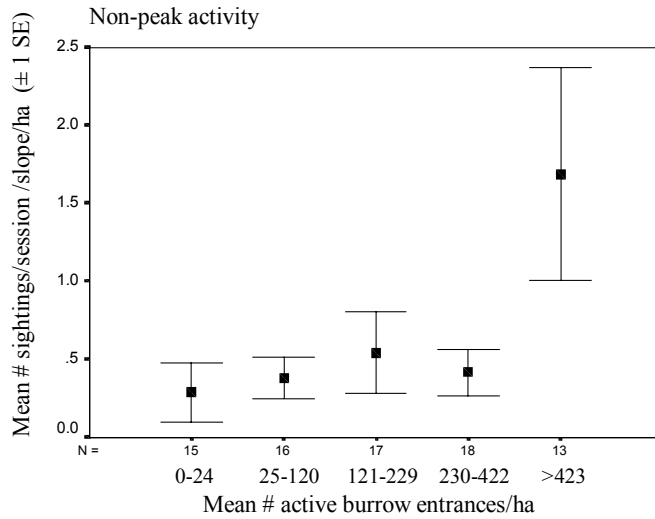
Figure 34. Mean number sightings/session/slope/ha (± 1 SE), during the non-peak activity season, of red-tailed hawks perching in areas with varying densities of active squirrel burrow entrances. Burrow densities are averages calculated over three mapping rotations. Altamont Pass WRA, California, June 1999–June 2000.
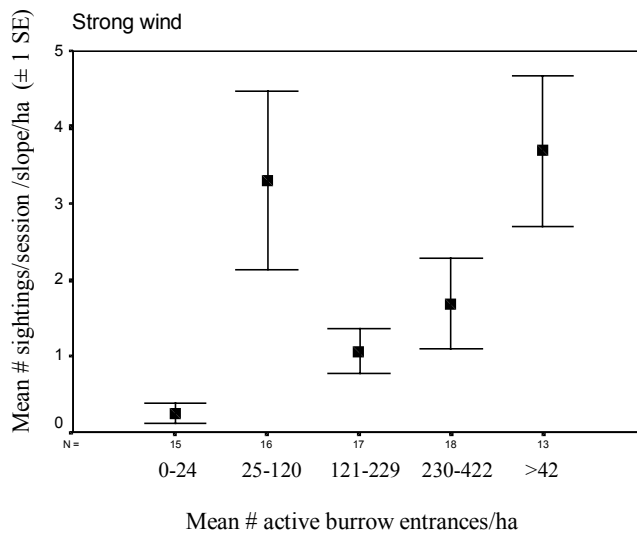
Figure 35. Mean number of red-tailed hawk perch sightings/session/slope/ha (± 1 SE) in strong wind (29–61 km/h) for areas with varying burrow entrance densities. Altamont Pass WRA, California, June 1999–June 2000.

During weak wind and the peak activity season, red-tailed hawk perching activity did not differ among burrow entrance densities (Table 6). Additionally, red-tailed hawks showed no difference in flight activity by burrow entrance density when tested by season or wind speed (Table 6).

Table 6. Kruskal-Wallis test results comparing mean number of sightings/session/slope/ha of red-tailed hawk activity among five different burrow entrance density levels by season, behavior, and wind speed level. Altamont Pass WRA, California, June 1999–June 2000

Ave. # entrances/ hectare	Statistic	Flight during non-peak activity season	Flight during peak activity season	Flight during weak wind	Flight during strong wind	Perching during non-peak activity season	Perching during peak activity season	Perching in weak wind	Perching in strong wind
0-50	Mean # sightings/session/ slope/hectare	.26023	.68567	.68571	.36112	.37882	3.58364	2.65164	1.16182
	N	20	20	20	20	20	20	20	20
	Std. Error of Mean	7.19E-02	.15708	.23848	8.76E-02	.15700	1.33737	1.25556	.56076
51-150	Mean # sightings/session/ slope/hectare	.62705	1.58967	1.20329	.89798	.50478	10.03375	8.95140	2.51444
	N	15	15	15	15	15	15	15	15
	Std. Error of Mean	.24094	.59256	.32167	.30364	.25343	5.35798	4.34529	1.14657
151-250	Mean # sightings/session/ slope/hectare	.39223	3.44153	.78980	2.55326	.32478	6.42276	6.65348	.96745
	N	14	14	14	14	14	14	14	14
	Std. Error of Mean	.14278	1.97489	.27102	1.65199	.20822	2.15946	2.55694	.32627
251-400	Mean # sightings/session/ slope/hectare	.26740	.73263	.41264	.54262	.46148	5.51862	5.73666	1.40497
	N	14	14	14	14	14	14	14	14
	Std. Error of Mean	6.79E-02	.22688	.12703	.18324	.18125	2.08075	2.79101	.55445
>400	Mean # sightings/session/ slope/hectare	.51396	1.61932	1.00052	1.02966	1.43860	6.17745	3.70783	3.66721
	N	16	16	16	16	16	16	16	16
	Std. Error of Mean	.19583	.44852	.35081	.29991	.56892	1.47757	1.04983	.88766

Kruskal -Wallis test results	X^2, df	1.932,4	4.572,4	3.855,4	5.480,4	7.800,4	7.538,4	3.658,4	17.663,4
	p-value	.748	.334	.426	.241	.099	.110	.454	.001

Squirrel Activity

There was a strong positive correlation between the mean number of active burrow entrances in an area and the mean amount of squirrel activity (number of sightings and vocalizations) (r = 0.75, P < 0.001) (Figure 36).
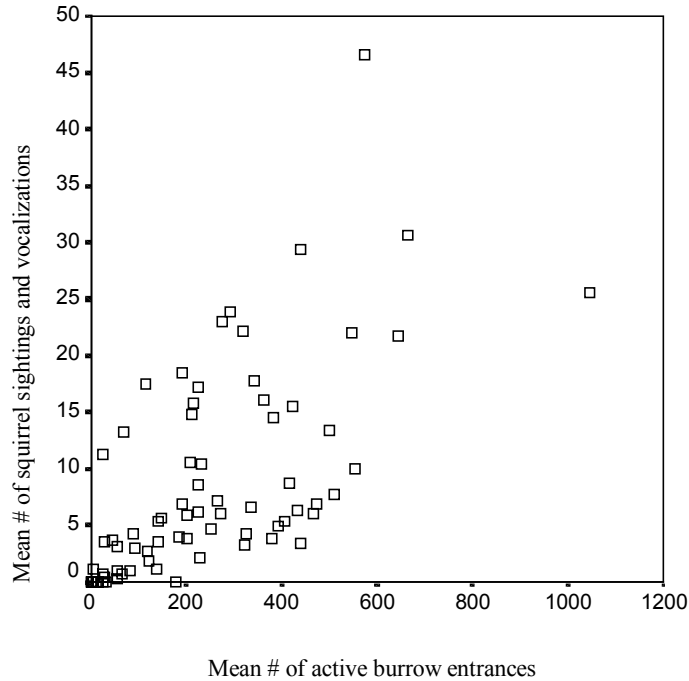
Figure 36. Mean number of active squirrel burrow entrances by mean number of squirrel sightings and vocalizations for each slope (N = 77). Altamont Pass WRA, California, from June 1999–June 2000.

There was no relationship detected between the mean amount of red-tailed hawk flight activity and the mean amount of squirrel activity (model significance P = 0.564, R^2 = 0.009). Similarly, there was no relationship between the mean amount of perch activity and the mean amount of squirrel activity (model significance P = 0.434, R^2 = 0.005).

Golden Eagle Activity by Season and Weather

Season

Of the 693 observations conducted between June 1999–June 2000, only 100 sessions included eagle sightings (Table 7). Of those sessions with golden eagle activity, the fewest number (16%) were in the summer. Summer also showed the fewest sightings per session (mean = 3.6). The winter season was responsible for 29% of the sessions with eagle activity and had more than twice the number of sightings per session than the summer and spring (mean = 6.7). The fall season was responsible for only 19% of the sessions with golden eagle activity, yet it had the highest number of sightings per session (mean = 7). Finally, the highest number of sessions showing eagle activity occurred during the spring (36%), yet spring had relatively few sightings per session (mean = 3.7).

Table 7. Summary of total golden eagle sightings by season and session. Sighting per session is for only those sessions that had eagle activity. Observations conducted at the Altamont Pass WRA, California, June 1999–June 2000.

Season	Total sightings	Number of sessions with golden eagle sightings	Sightings per session
Summer 1999	57	16	3.6
Fall 1999	133	19	7.0
Winter 1999	195	29	6.7
Spring 2000	133	36	3.7
Total	518	100	5.2

Winter and spring showed roughly 3 times more golden eagle activity (flight and perch) than summer (ANOVA: $P < 0.001$, $F = 6.351$, $df = 675$, Tukey multiple comparison: $P = 0.022$ and $P = 0.011$, respectively) (Figure 37). The mean amount of flight activity per session during the spring was 4.6 times greater than during the summer and twice as great as during the fall (Tukey: $P < 0.001$ and $P = 0.045$, respectively) (Figure 38). There was no significant difference in perch sightings between seasons (ANOVA: $P = 0.157$, $F = 1.741$, $df = 675$).
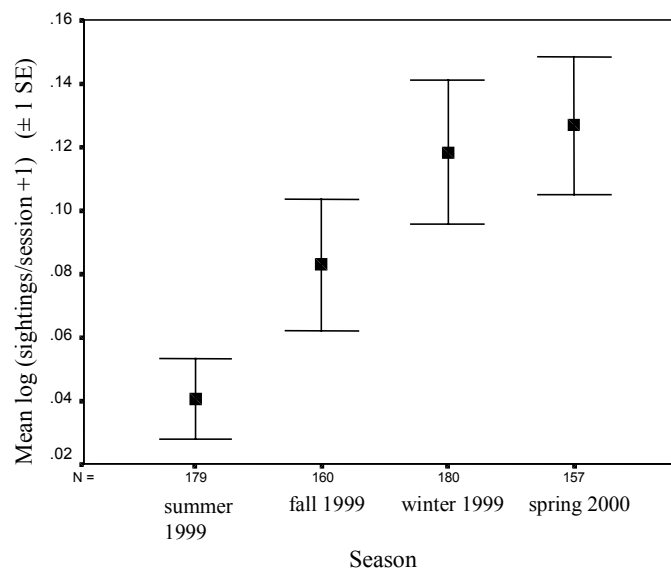
Figure 37. Mean of Log (X+1) transformation of total golden eagle sightings/session (± 1 SE) for four seasons from June 1999–June 2000 at the Altamont Pass WRA, California.
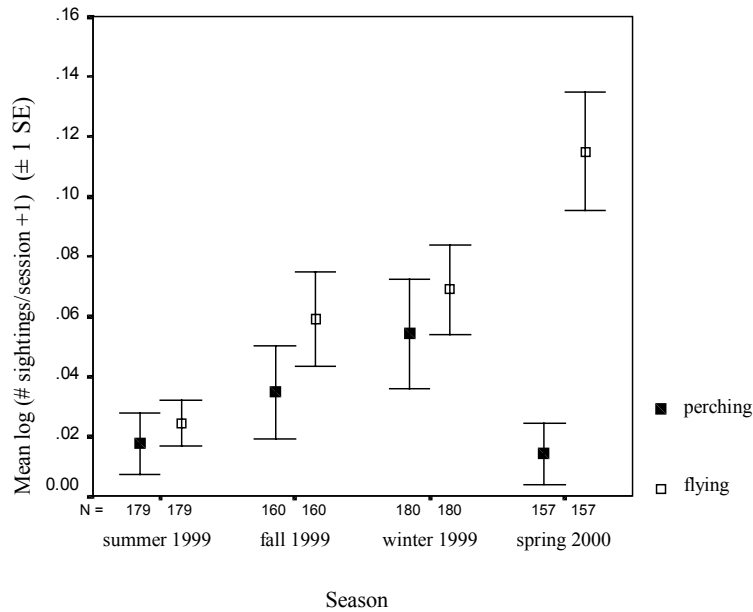
Figure 38. Mean Log (X+1) transformation of golden eagle perch and flight sightings/session (± 1 SE) by season from June 1999 to June 2000 at the Altamont Pass WRA, California.

The relative amount of flight activity versus perch, within seasons, differed significantly for summer and spring (Figure 39). Summer showed twice the amount of perching activity as flight activity (Wilcoxen: $P = 0.094$, $Z = 1.676$). In contrast, springtime showed 3 times the amount of flight activity as perching activity (Wilcoxen: $P < 0.001$, $Z = -4.234$). The difference between flying and perching was not significant during fall and winter.
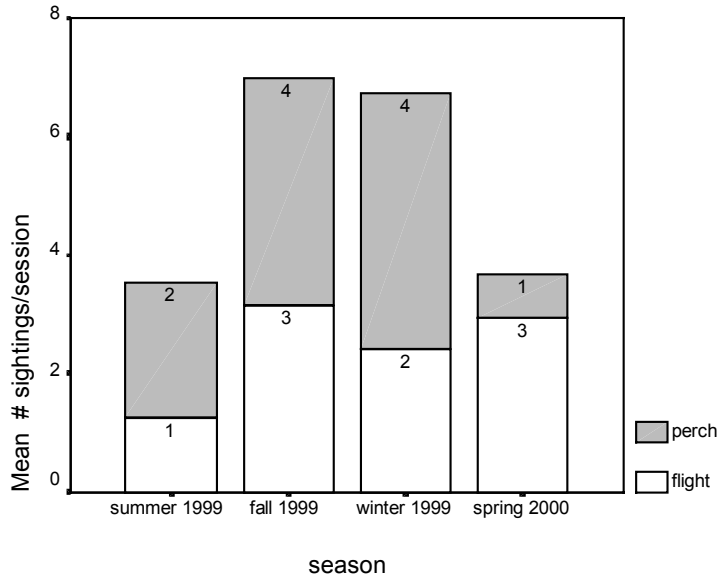
Figure 39. Mean number of golden eagles perch and flight sightings/session for only those observation sessions that contained eagle activity (summer: n = 14, fall: n = 19, winter: n = 29, spring: n = 36). Altamont Pass WRA California, June 1999–June 2000.

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The style of flight used by golden eagles consisted primarily of gliding flight (36%) and soaring flight (42%). Flapping flight made up 7% of the total sightings, interactions with other birds (black birds, corvids, and red-tailed hawks) made up 6%, and the remaining 9% were nondefined or rare behaviors (diving, kiting, etc).

Cloud cover

There was no significant difference in the amount of golden eagle flight activity among cloud cover levels (ANOVA: P = 0.773, F = 0.372, df = 686) (Figure 40). However, eagles were observed perching in cloud cover of 76%–100% more than twice as often as in 0%–25% cloud cover and 65 times as often as in 51%–75% cover, the latter of which was very rare (ANOVA: P = 0.050, F = 2.624, df = 686) (Figure 41).
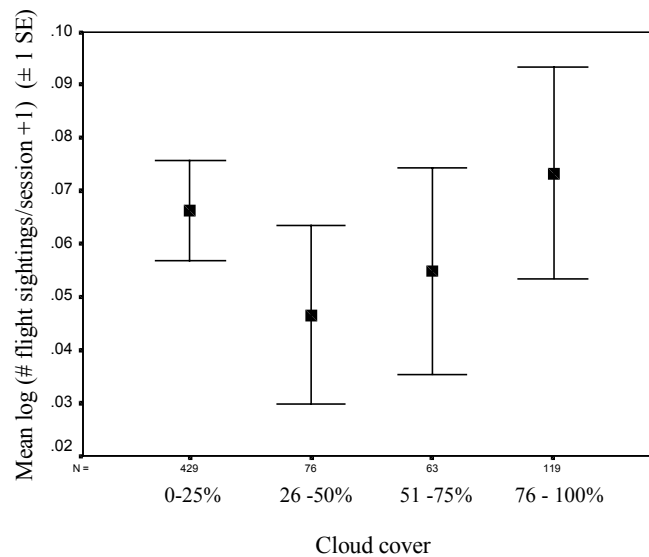
Figure 40. Mean log (X+1) transformation of number of golden eagle flight sightings/session (± 1 SE) by cloud cover level at Altamont Pass WRA, California, from June 1999 to June 2000.

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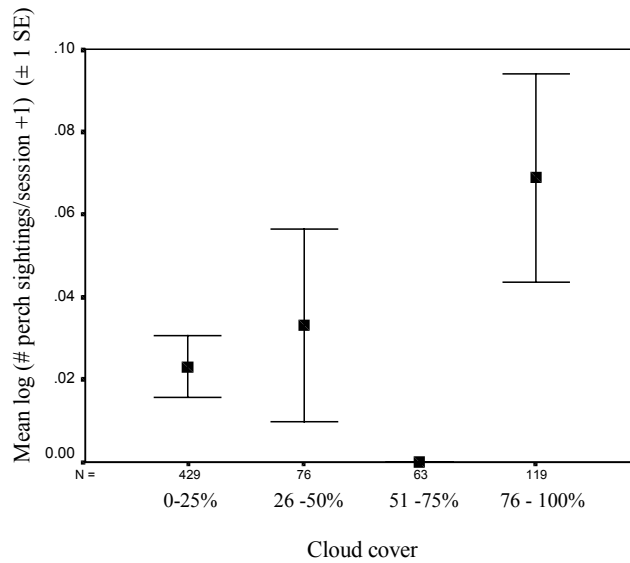
Figure 41. Mean log (X+1) transformation of number of golden eagle perch sightings/session (± 1 SE) by cloud cover level at Altamont Pass WRA, California, from June 1999 to June 2000.

Time of day

Golden eagles did not show a preference for perching at a specific time of day for any of the four seasons (ANOVA: summer P = 0.213, F = 1.558, df = 178; fall P = 0.671, F = 0.400, df = 159; winter P = 0.304, F = 1.198, df = 179; spring P = 0.827, F = 0.190, df = 156) (Figure 42).
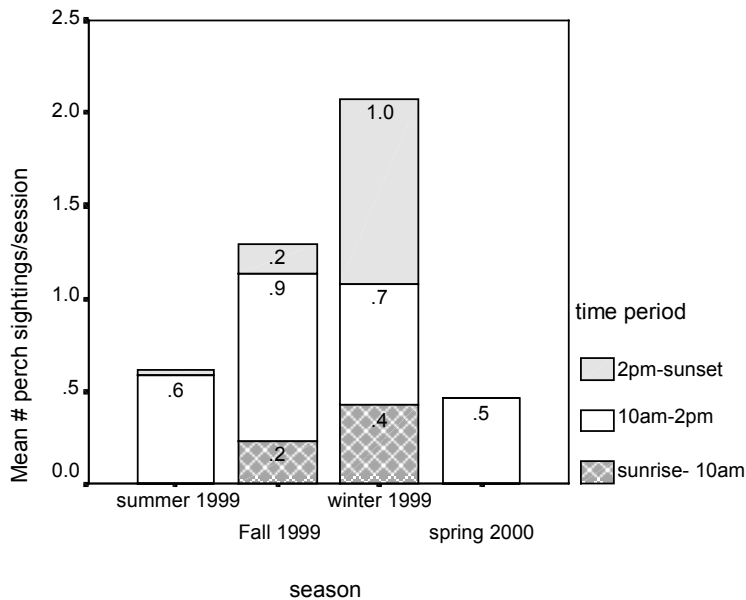
Figure 42. Mean number of golden eagle perch sightings/session by time period and season at the Altamont Pass WRA, California, from June 1999 to June 2000. The number of observation sessions for each season is: summer n = 180, fall n = 160, winter n = 180, spring n = 157.

In the summer, spring, and winter, flight did not differ significantly by time of day (ANOVA: P = 0.121, F = 2.137, df = 178, Tukey: P = 0.106) (Figure 43). During the fall, flight activity in the middle afternoon (10:00 a.m. – 2:00 p.m.) was 5 times more common than early morning flight (ANOVA: P = 0.077, F = 2.603, df = 159, Tukey: P = 0.060)
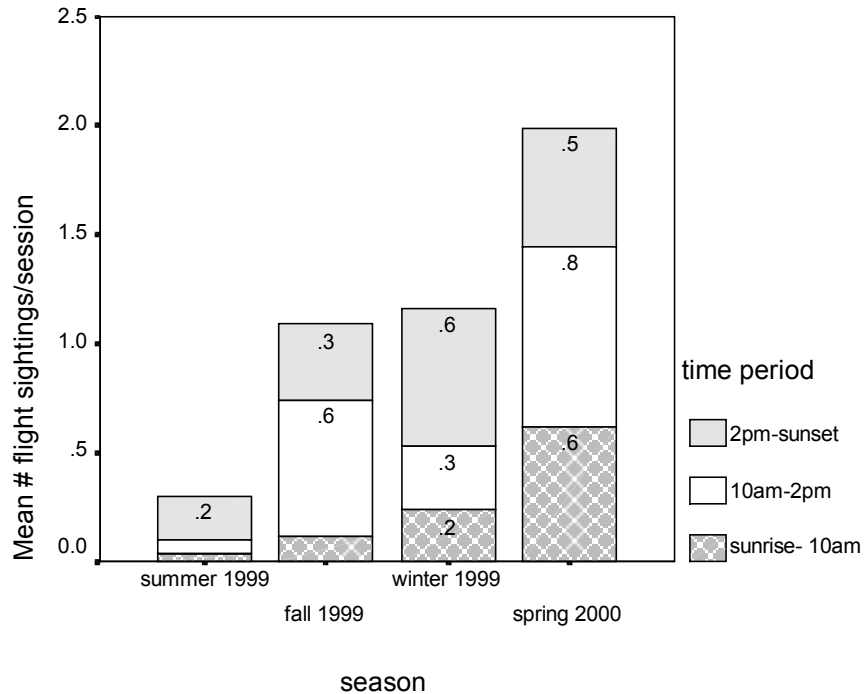
Figure 43. Mean number of golden eagle flight sightings/session by time period and season at the Altamont Pass WRA, CA, from June 1999–June 2000. The number of observation sessions for each season is: summer n = 180, fall n = 160, winter n = 180, spring n = 157.

Wind Speed

Golden eagles were observed perching far more often in weak wind than in strong wind (mean = 0.57 sightings per session versus mean = 0.10 sightings per session) (Mann-Whitney T-test: P = 0.007, t = 2.713, df = 607) (Figure 44). They most commonly perched on the ground (mean = 9.6 sightings/session/ha), followed by fence posts (mean = 3.6 sightings/session/ha), power poles (mean = 2.1 sightings/session/ha), trees (mean = 1.1), vertical axis turbines (mean = 0.9), and rocks (mean = 0.8) (Figure 45).

Although the total amount of flight sightings did not differ significantly between wind speed levels (Mann-Whitney T-test: P= 0.550 , t = -0.598, df = 557), golden eagles were observed using gliding flight more than 3 times as often in strong wind than in weak wind (Mann-Whitney T-test: P = 0.006, t = -2.756, df = 399) (Figure 46).
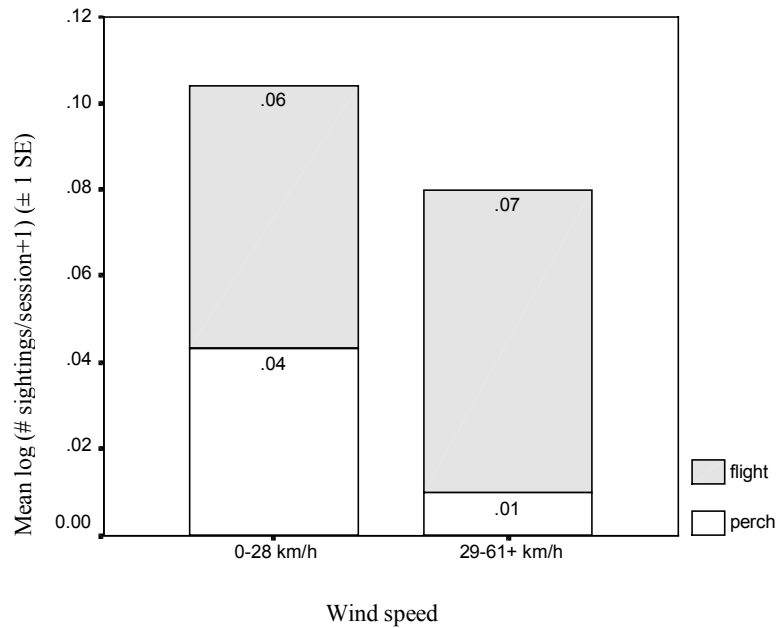
Figure 44. Mean log (X+1) transformation of number of golden eagle flight and perch sightings/session (± 1 SE) by wind speed category at the Altamont Pass WRA, California, from June 1999 to June 2000.
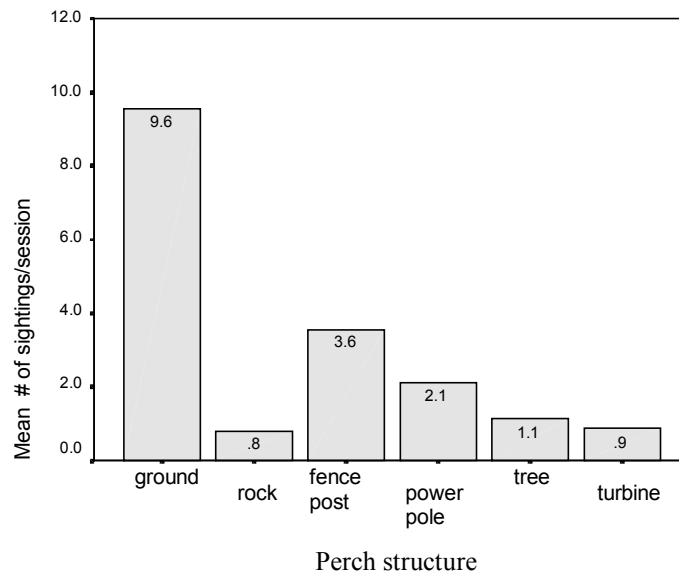
Figure 45. Mean number of golden eagle sightings/session by perch structure. Sessions included are only those that contained eagle perching activity (N = 23). Altamont Pass WRA, California, June 1999±June 2000.
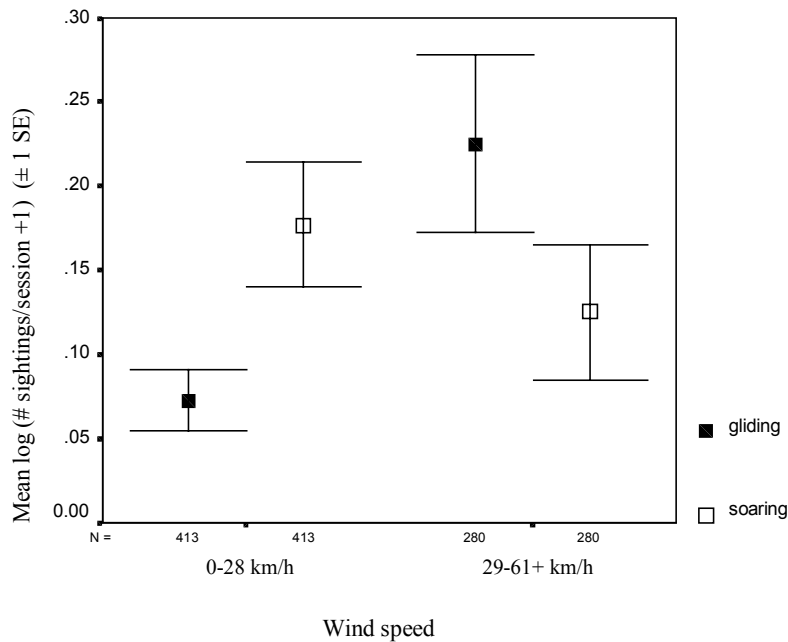
Figure 46. Mean log (X+1) transformation of golden eagle sightings/session (± 1 SE) for two flight styles (gliding and soaring) and two wind speed levels. Altamont Pass WRA, California, June 1999–June 2000.

Golden Eagle Activity and Topography

Distance from nearest turbine

In weak wind, golden eagles commonly flew more than 75 m (246 ft) from turbines towers, averaging 1.6 sightings per session. This was at least 2.6 times more often than the next most common distance [51–75 m (167–246 ft)] and 16 times more than the least common distance [0–10 m (32.8 ft)] (Kruskal-Wallis: $P < 0.001$, $X^2 = 39.207$, df = 4, Nemenyi multiple comparison: $P < 0.05$) (Figure 47). When winds were strong, they were more than 3 times more likely to fly at distance of more than 100 m (328 ft) from the wind turbines (Kruskal-Wallis: $P = 0.000$, $X^2 = 30.096$, df = 4, Nemenyi multiple comparison: $P < 0.05$) (Figure 48).

Distance from ground

On average, golden eagles were most often found flying in the range of 11–50 m (36–164 ft) from the ground, with an average of 2.4 sightings per session (Figure 49). The occurrence of flight at this height level was twice that of flight at 76–100 m (249–328 ft) from the ground, but did not differ significantly from other height levels (Kruskal-Wallis: $P = 0.043$, $X^2 = 9.844$, df = 4, Nemenyi: $P < 0.05$).

Gliding behavior was 4 times more common than soaring behavior at distances of 1–10 m (3.2–32.8 ft) from the ground (Mann-Whitney: $P = 0.003$, $Z = -2.964$) (Figure 50). In contrast, soaring behavior occurred 3 times more frequently than gliding behavior at distances over 100 m (328 ft) from the ground (Mann-Whitney: $P = 0.036$, $Z = -2.096$).

Weak wind (0-28 km/h)

Distance from nearest turbine
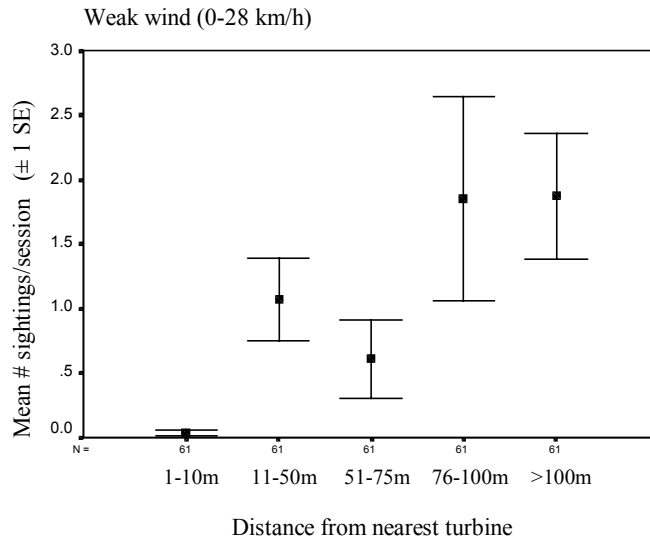
Figure 47. Mean number of sightings/session (± 1 SE) of golden eagles flying in weak wind (0–28 km/h) within five distance categories from the nearest turbine. Altamont Pass WRA, California, June 1999–June 2000.

Strong wind (29-61 km/h)

Distance from the nearest turbine
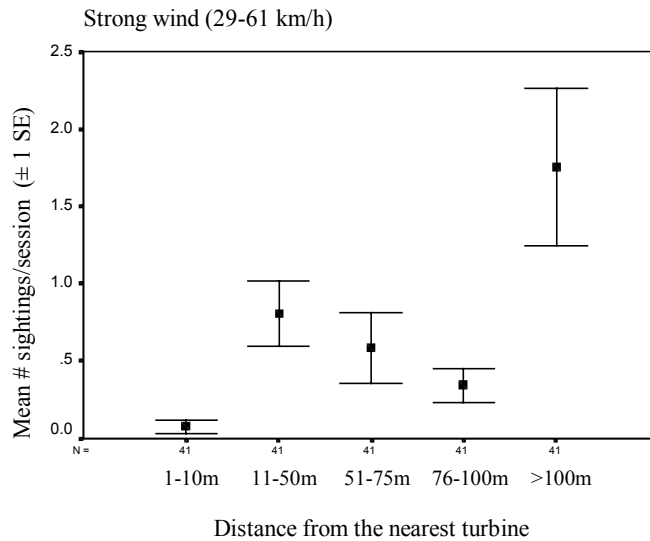
Figure 48. Mean number of sightings/session (± 1 SE) of golden eagles flying in strong wind (29–61 km/h) within five distance categories from the nearest turbine. Altamont Pass WRA, California, June 1999–June 2000.
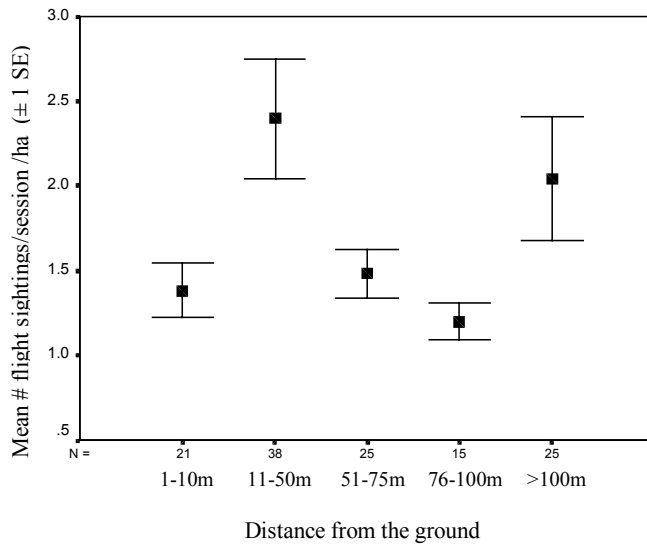
Figure 49. Mean number of golden eagle sightings/session (± 1 SE) flying at various height levels from the ground. Altamont Pass WRA, California, June 1999–June 2000.
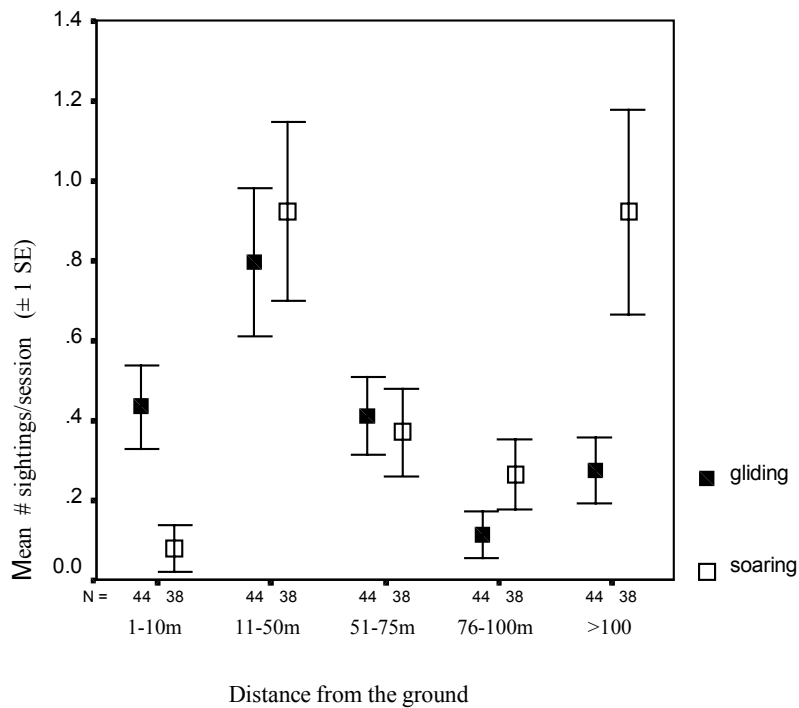
Figure 50. Mean number of golden eagle sightings/session (± SE) by distance from the ground for gliding behavior and soaring behavior. Altamont Pass WRA, California, June 1999–June 2000.

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Aspect and wind

When winds were weak, overall flight by golden eagles was equally likely to take place on slope aspects that faced into the wind as those that did not face into the wind (Wilcoxen signed ranks: P = 0.813, Z = -0.237) (Figure 51). In strong winds though, they were 3.4 times as likely to fly on slopes whose aspect faced into the wind than those that did not (Wilcoxen signed ranks: P = 0.005, Z = -2.786).
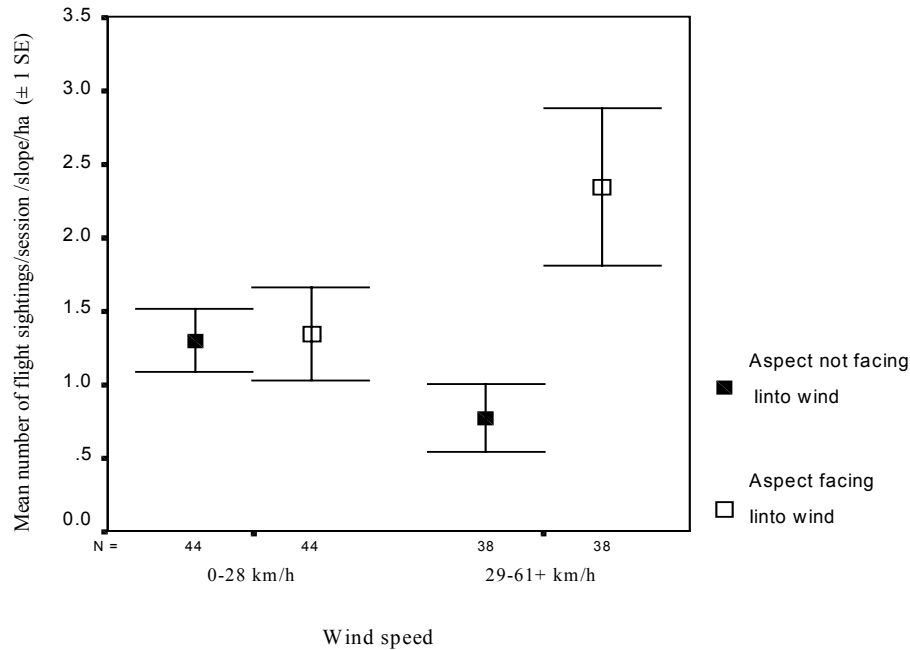
Figure 51. Mean number of sightings/session/slope/ha (± 1 SE), for two wind speed levels, of golden eagles flying over slopes with aspects equal to, and unequal to, the direction of the wind. Altamont Pass WRA, California, June 1999–June 2000.

Gliding behavior, in particular, was more than twice as common on slopes facing into the wind than on slopes not facing into the wind (Mann-Whitney: P = 0.007, Z = -2.717) (Figure 52). Flapping and soaring behavior was equally likely to occur on slopes facing and not facing into the wind (Mann-Whitney: P = 0.729, Z = -0.346 and P = 0.656, Z = 0.446, respectively).

There was no significant difference in golden eagle perch activity on slope aspects facing into the wind and slope aspects not facing into the wind (Wilcoxen signed ranks: P = 0.337, Z = -0.960) (Figure 53).
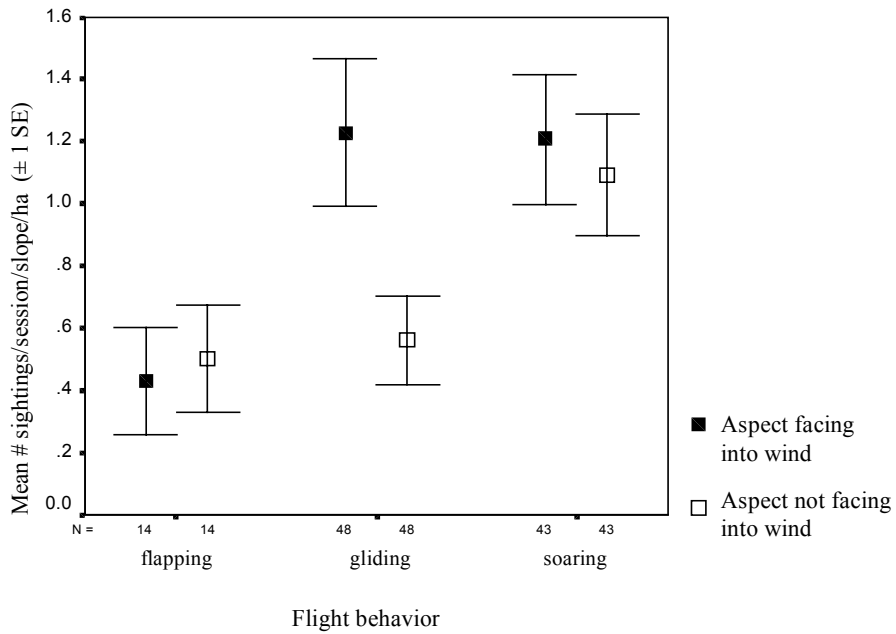
Figure 52. Mean number of sightings/session/slope/ha (± 1 SE) of golden eagle flight styles observed on slopes facing into the wind and on slopes not facing into the wind. Altamont Pass WRA, California, June 1999–June 2000.
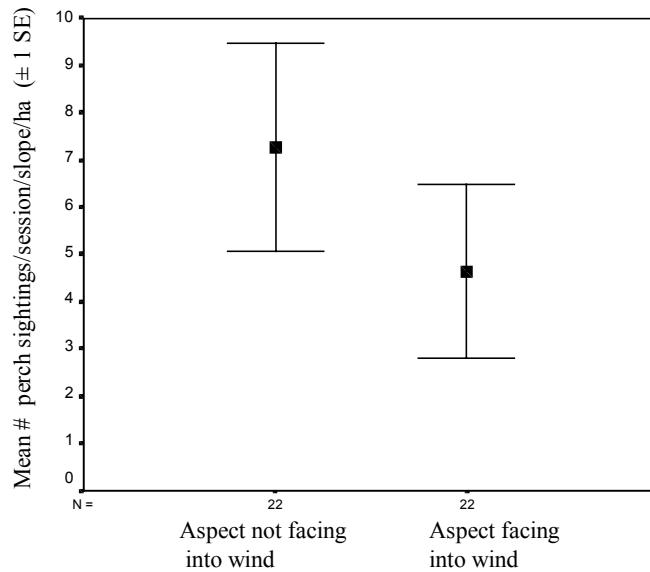
Figure 53. Mean number of sightings/session/slope/ha (± 1 SE) of golden eagles perching on slopes facing into the wind and on slopes not facing into the wind. Altamont Pass WRA, California, June 1999–June 2000.

Inclination

Out of a total of 693 observation sessions, only 73 sessions included golden eagle flight activity. There was no significant difference in the average amount of flight activity among slope incline levels for both strong wind and weak wind conditions (Kruskal-Wallis: P = 0.833, X^2 = 0.868, df = 3 and P = 0.932, X^2 = 0.441, df = 3, respectively) (Figure 54). Similarly, gliding and soaring behavior did not differ by incline level (Kruskal-Wallis: P = 0.555, X^2 = 2.083, df = 3 and P = 0.743, X^2 = 1.241, df = 3, respectively) (Figure 55).
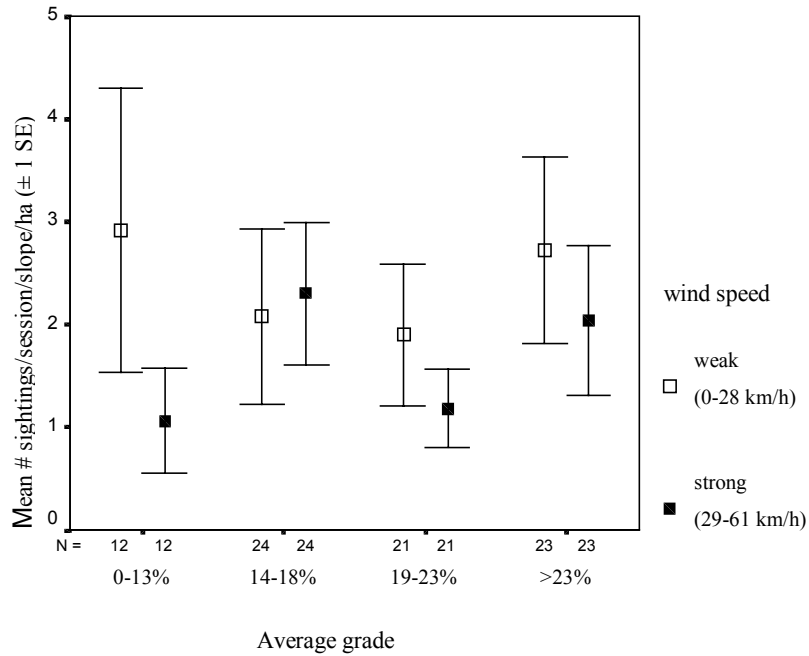
Figure 54. Mean number of sightings/session/slope/ha (± 1 SE) for two wind speed levels of golden eagles flying over slopes in four slope incline levels. Means are calculated from the 73 sessions in which golden eagle flight activity was observed. Altamont Pass WRA, California, from June 1999–June 2000.
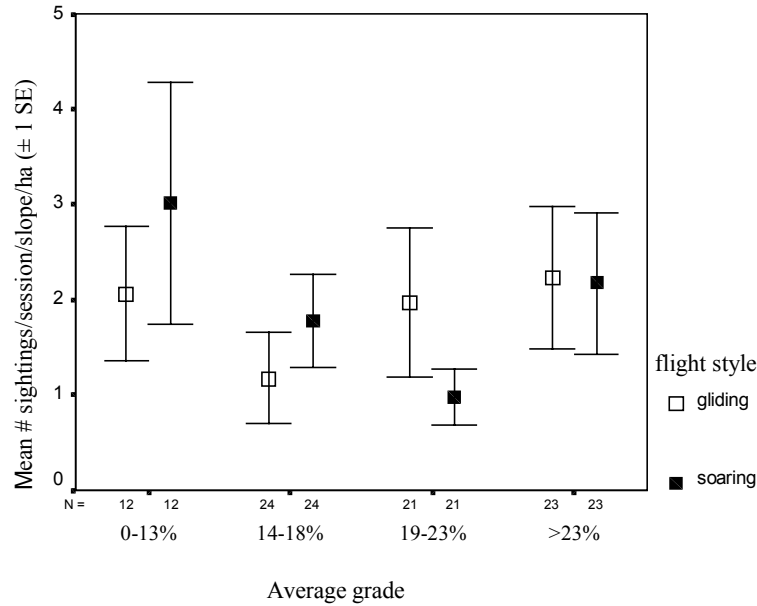
Figure 55. Mean number of golden eagle sightings/session/slope/ha (± 1 SE) for two common flight behaviors (gliding and soaring) and four slope incline categories. Means were calculated for only the 73 sessions in which golden eagle flight activity was observed. Altamont Pass WRA, California, June 1999–June 2000.

For the 20 sessions that had golden eagle perching behavior, 57% of the perch sightings were on seven slopes all with an average percent grade of greater than 23%. These seven slopes made up 8.8% of the total study area but 36% of the area in the steepest incline category (>23%). A single slope (S26), with a 26% grade, was responsible for 29% of the total perch sightings (Table 8).

Table 8. Summary of slopes showing golden eagle perching activity in terms of topographical and active squirrel burrow entrance density. Altamont Pass WRA, California, June 1999–June 2000.

Slope number	Number of sessions with activity	Total number of sightings	Mean # sightings/ session/ha	% average grade	Aspect	Peak elevation (m)	Average number of burrow entrances/ha
26	5	64	4.73	37	SW	200	405
3	3	53	5.63	25	SE	212	1045
41	2	16	2.34	26	SW	200	176
42	1	20	15.12	26	SW	194	416
25	1	20	12.87	17	E	200	224
45	1	18	6.63	17	SE	194	645
4	1	7	5.11	27	SW	206	466
6	1	14	4.57	19	NE	206	663

2	1	1	1.07	13	NE	230	436
20	1	2	0.63	30	NE	170	87
30	1	3	0.54	24	NW	194	not mapped
32	1	1	0.36	17	SE	224	472
29	1	1	0.24	8	FLAT	164	548

Peak slope elevation

When wind speeds were strong, golden eagles were significantly more likely to fly on slopes with peak elevations between 128 and 183 m (420 and 600 ft) (mean = 2.7 sightings per session) than on slopes with peak elevations between 262 and 347 m (860 and 1,138 ft) (mean = 0.5 sightings per session) (Kruskel-Wallis: P = 0.076, X^2 = 6.884, df = 3, Nemenyi: P < 0.05) (Figure 56). Although flight activity showed a similar pattern when winds were weak, the difference among peak elevation levels was not significant (Kruskal-Wallis: P = 0.174, X^2 = 4.965, df = 3).
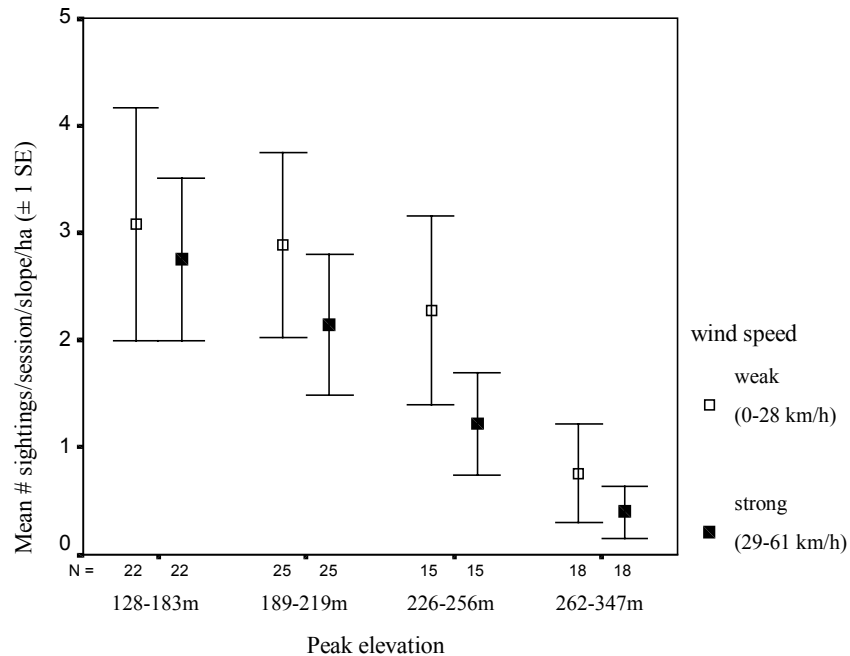
Figure 56. Mean number of golden eagle sightings/session/slope/ha (± 1 SE) for four slope peak elevations in two wind speed conditions. Means are calculated from sessions in which golden eagle flight activity was observed (N = 73). Altamont Pass WRA, California, from June 1999–June 2000.

There was no significant difference in gliding behavior among peak elevation categories (Kruskal-Wallis: P = 0.370, X^2 = 3.143, df = 3) (Figure 57). However, the 6.4-fold increase in soaring activity on slopes with peak elevation in the range of 128–183 m (420–600 ft) versus 262–347 m (860–1,138 ft) approached significance (Kruskal-Wallis: P = 0.102, X^2 = 6.204, df = 3).
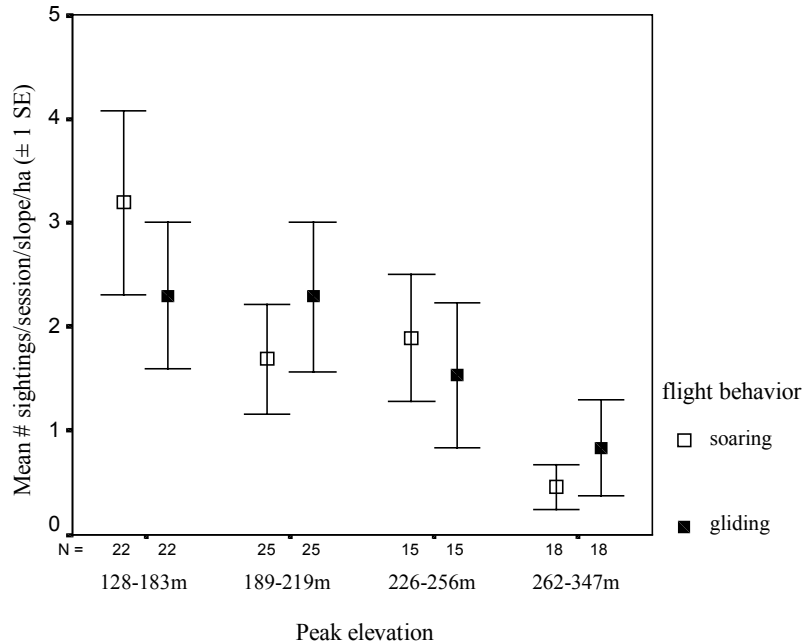
Figure 57. Mean number of golden eagle sightings/session/slope/ha (± 1 SE) for two common flight behaviors (gliding and soaring) and four slope peak elevation categories. Means were calculated for only the 73 sessions in which golden eagle flight activity was observed. Altamont Pass WRA, California, June 1999–June 2000.

Eight of the eleven slopes on which golden eagle perching was observed had peak elevations in the range of 189–219 m (620–719 ft). This accounted for 92% of the perch sightings (Table 8). The number of slopes in this range, however, accounted for only 32% of the total number of slopes under study.

Golden Eagle Activity and Squirrel Activity

Golden eagle flight activity did not differ by squirrel burrow entrance density for both weak wind and strong wind conditions (Kruskel-Wallis: P = 0.298, X^2 = 4.980, df = 4 and P = 0.160, X^2 = 6.569, df = 4, respectively). Also, no significant difference was detected in the mean amount of gliding behavior by burrow entrance density level (Kruskel-Wallis: P = 0.731, X^2 = 2.027, df = 4) (Figure 58).
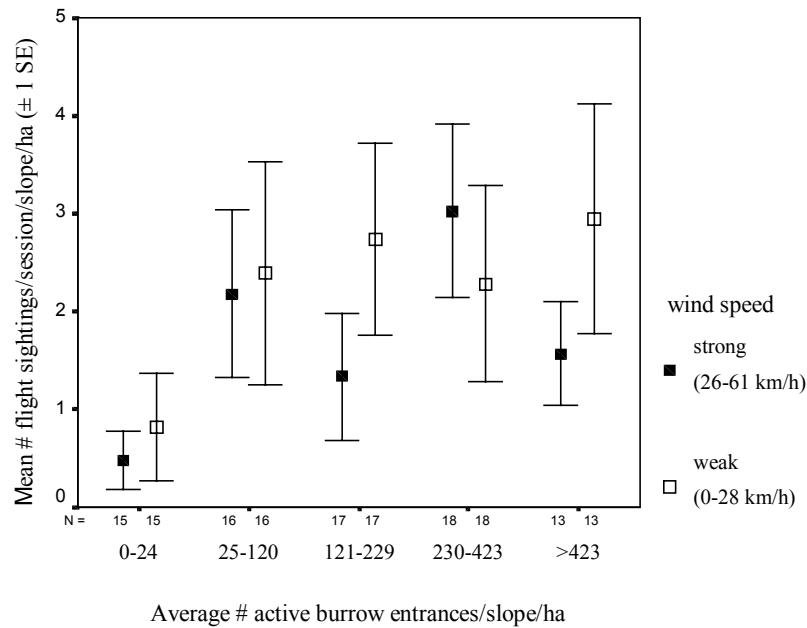
Figure 58. Mean number of golden eagle sightings/session/slope/ha (± 1 SE) for five burrow entrance density categories in two wind speed conditions. Means are calculated only from sessions in which golden eagle flight activity was observed (N = 73). Altamont Pass WRA, California, from June 1999–June 2000.

The mean amount of soaring, however, was greater for slopes with burrow entrance density in the range of 230–422/ha (3.6 sightings per session) than for slopes with a density of 0–24/ha (0.4 sightings per session) and 121–129/ha (1.1 sightings per session) (Kruskel-Wallis: P = 0.087, X^2 = 8.118, df = 4, Nemenyi: P = <0.05) (Figure 59).
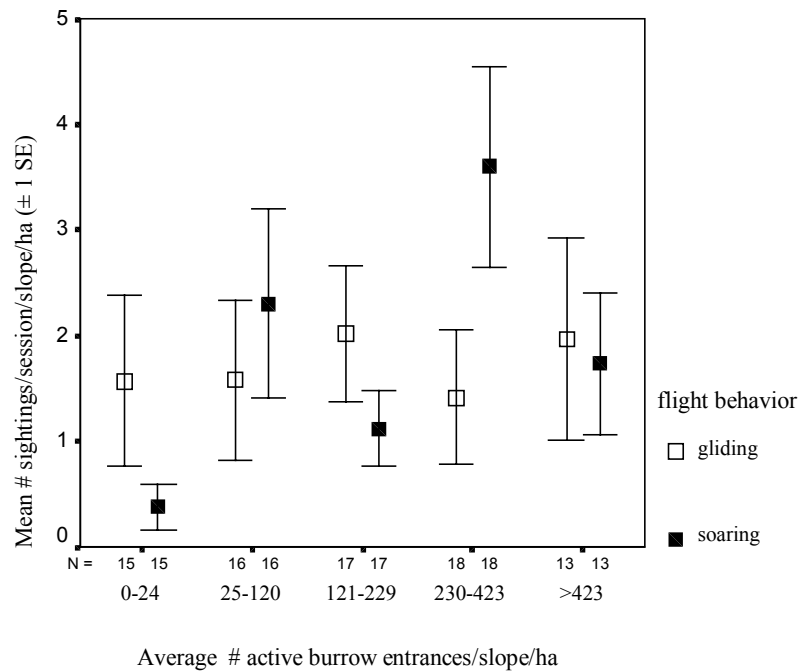
Figure 59. Mean number of golden eagle sightings/session/slope/ha (± 1 SE) for two common flight behaviors (gliding and soaring) and five squirrel burrow entrance density categories. Means were calculated for only the 73 sessions in which golden eagle flight activity was observed. Altamont Pass WRA, California, June 1999–June 2000.

Additionally, there was no linear relationship between the mean amount of eagle flight activity and the mean amount of squirrel activity (model significance $P = 0.497$, $R^2 = 0.007$).

Of the 13 slopes on which golden eagles were observed to perch, 77% of them (10 of 13) had average squirrel burrow entrance densities over 415/ha (Table 8). This resulted in 83% of the total perch sightings taking place on slopes with densities in, or within, 98% of the highest density level.

Discussion

Red-tailed Hawk Activity

Two of my primary objectives were to determine the effect of weather and topography on red-tailed hawk activity. The results of my study can best be explained by the red-tailed hawks propensity to use wind currents, which are determined by the interaction between topography and weather. In particular, hawk activity was strongly influenced by declivity currents, which are created when wind is deflected upwards after encountering an obstacle, such as a hillside. This is consistent with the numerous studies describing raptors as adept manipulators of wind currents (Cone 1962; Janes 1985; Haugh 1986; Dunne, Sibley, and Sutton 1988). The variables showing the strongest relationship with red-tailed hawk behavior were wind speed, wind direction, and slope aspect. There is also evidence suggesting slope incline and slope elevation play a role in influencing red-tailed hawk activity.

The two most common flight behaviors displayed by red-tailed hawks were thermal soaring and kiting. Thermal soaring occurred more than three times more frequently in weak wind than in strong wind. This is presumably because such flight relies on rising bubbles of warm air, or thermals, that become disrupted in high-velocity winds (Preston 1981; Dunne, Sibley, and Sutton 1988).

In contrast, kiting activity, the primary form of flight observed during my study, was exhibited almost exclusively in strong winds and on hillsides that faced perpendicularly into the wind, where declivity currents were abundant and provided the most lift. Studies have shown raptor use of declivity currents to be positively correlated with increasing wind velocities, especially for red-tailed hawks (Schnell 1967; Pennycuick 1972; Preston 1981). For the most part, flight generated primarily by declivity currents is expected to be relatively unimportant for most foraging birds because of the strict requirements it involves. For declivity winds to be of sufficient strength to support static raptor flight, there must be strong surface winds and/or very large obstacles (Cone 1962). Altamont Pass has both characteristics, which has lead to the high frequency of kiting behavior exhibited by red-tailed hawks in the area.

Although my data showed mean kiting activity on the steepest inclines to be at least twice as high as that on less steep inclines, the difference was not significant because of the high degree of variability. Ninety percent of red-tailed hawk kiting activity occurred on only 3 of the 24 slopes in the steepest incline category. It is revealing to note that these specific slopes had similar topographic characteristics related to their ability to produce sizable declivity currents. They were steep hillsides. A sharper incline produces deflected wind that has more vertical force. This, in turn, increases the area in which the current can be used for flight (Cone 1962). Also, the slopes fell into the third highest peak elevation category [226–256 m (741–840 ft)], and were the highest peaks relative to surrounding hills. High elevation slopes can shelter, and thus block, declivity wind formation on adjacent smaller slopes.

The inconsistency regarding the lack of red-tailed kiting activity on the highest peak elevation slopes may be related to different land management between areas. Eighty-seven percent of the slopes in the highest elevation category also had the lowest squirrel burrow density (0–24 entrances/ha). This land routinely underwent a more rigorous squirrel control regimen than that used elsewhere within my study area (Smith, personal communication 2001). Therefore, red-tailed hawks may be choosing the tallest peaked slopes in a region provided those slopes have a minimum of squirrel activity.

This leads to my third objective of this study, which was to determine the extent in the distribution of red-tailed hawk activity was associated with ground squirrel activity. Some have suggested that the thriving squirrel population attracts raptors that become so distracted during foraging that their susceptibility to collision is heightened (Orloff and Flannery 1996). One of the goals of this study was to gain insight into whether or not manipulation of the abundant ground squirrel population would be a effective management option in decreasing raptor mortality.

During my study, red-tailed hawk flight activity did not increase in areas with progressively higher squirrel density. In fact, the 3 slopes responsible for 90% of the total red-tailed hawk kiting behavior had burrow densities between 135–185 entrances/ha, which put them in the middle density category (121–229/ha). The lack of association is probably due to the fact that ground squirrels are not the driving attractant to foraging red-tailed hawks within Altamont Pass, at least not when they are aerial hunting. Features of an area that produce favorable wind currents appear to have stronger appeal, most likely because they make foraging more energy efficient. This may result in a hawk achieving a higher net gain than if it chose a hunting site based on squirrel

density alone. The literature contains many examples of raptors choosing foraging sites based, in part, on habitat characteristics that make foraging more energy efficient or prey more vulnerable (Stinson 1980; Baker and Brooks 1981; Bechard 1982; Janes 1985).

Red-tailed hawks are also quite opportunistic with respect to prey (Janes 1985; Preston 1990). California voles (*Microtus californicus*), valley pocket gophers (*Thomomys bottae*), deer mice (*Peromyscus maniculatus*), and desert cottontails (*Sylvilagus auduboni*) are just a few of the other mammalian prey items available at Altamont Pass, not to mention snakes, lizards, and large insects inhabiting the area. Thus, red-tailed hawks, within the WRA, have the option of foraging on many different species.

My results revealed that in strong wind, hawks commonly perched in regions with the highest burrow entrance density as well as in regions with the second to the lowest squirrel density. In both situations, however, the slopes on which they perched were shielded from the high velocity winds. Again, this indicates that red-tailed hawks may be choosing areas, in this case to perch hunt, based more on weather and topographical features than on relative ground squirrel density.

Management Implications for Red-tailed Hawks

I was unable to detect a significant relationship between red-tailed hawk activity and ground squirrel abundance and distribution. Thus, I do not feel that approaching the problem of their mortality, within the Altamont WRA, by enacting ground squirrel control programs would be a successful management option. However, red-tailed hawks show specific foraging behaviors that may be used in addressing their vulnerability to turbine collisions.

Kiting behavior constitutes a common and potentially dangerous flight activity for red-tailed hawks inhabiting the Altamont Pass WRA for a number of reasons. First, as my data revealed, this flight style is used at distances [11–50 m (36–164 ft)] from the ground, which puts red-tailed hawks at the height of the rotating turbine blades. The turbine towers within my study area stand 25 m (82 ft) tall and have a rotor sweep area spanning the distance 15 to 35 m (49 to 115 ft) from the ground. Also, kiting is used primarily in strong winds where unpredictable gusts can throw a kiting hawk off-balance. Finally, kiting is a static style of flight. Thus, a hawk can remain in a hazardous position for a prolonged period of time, which increases the risk of turbine-related injury.

Fatality searches performed concurrently with my behavioral observations revealed that red-tailed hawks collided with turbines on the same slopes in which I observed the majority of kiting behavior. From February 1999 to March 2000**,** a disproportionate number of red-tailed hawk/turbine-related fatalities occurred on the few slopes where 90% of the kiting behavior took place (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.

The data obtained by my study show that there is strong potential for predicting which slopes will be used by kiting red-tailed hawks. Topographical features of the landscape and weather variables can predict the strength and location of the declivity winds necessary for kiting behavior. Thus, red-tailed hawk activity can be predicted, to a certain extent, by examining topographical features of an area.

During my 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. Thus, 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, i.e., when winds are strong and facing perpendicularly to the slope. Alternatively, bird-deterring methods to discourage raptor activity in the vicinity of turbines may be used on these slopes. One such method, presently being researched and developed, is to paint blades in a way that accentuates them. With knowledge of high-activity/high-risk areas, such as that provided by this study, expensive turbine modifications might be specifically applied where they will be most effective.

Golden Eagle Activity

During my study, golden eagle flight activity, like red-tailed hawk activity, was most closely associated with slope aspect, wind direction, and wind speed. This is presumably a result of their similar reliance on wind currents for foraging.

Unlike red-tailed hawks, golden eagles did not use kiting flight. Instead, they used only two primary styles of flight: thermal soaring and gliding. Although both styles were most common 11–50 m (36–164 ft) from the ground, gliding was 4 times more likely than soaring at heights of 1–10 m (3.2–32.8 ft). Gliding flight was also used primarily in strong winds and was twice as likely to occur on slopes facing into the wind, where declivity currents were strongest. These results can be explained by the golden eagles' foraging style. They often use declivity currents to gain altitude. Then, from an elevated position, they flex their wings and descend gradually, gliding for considerable distances in search of prey. Descents often terminate in a high-speed glide low over the ground [often less than 3 m (10 ft)]. This behavior is termed *contour hunting,* whereby an eagle hugs the contour of the terrain in search of unsuspecting prey (Callopy 1983; Dekker 1985; Hunt 1995).

Soaring behavior was also used 11–50 m (36–164 ft) from the ground; however, it was four times more likely than gliding to also occur at heights greater than 100 m (328 ft). Birds often use high soaring flight to travel over large tracts of land by passing from one thermal to the next (Cone 1962; Haugh 1986). In contrast to low gliding flight, which did not show a relationship to squirrel burrow density, golden eagles soared over locations with the second-to-highest burrow entrance density three to nine times more frequently than over areas with lesser densities. This finding suggests that, within the Altamont Pass WRA, eagles may be using thermal soaring to search for ground squirrels. Perhaps soaring at lower altitudes constitutes foraging behavior while soaring at higher altitudes is used for traveling.

Aside from this finding, I was unable to detect a link between golden eagle flight activity and squirrel activity, even though golden eagles nesting in the northern Diablo Range, and hunting within Altamont Pass, are thought to forage primarily on California ground squirrels (Hunt 1995). The overall lack of association, during my study, is most likely a matter of scale. I recorded behavioral data on a fine scale, relating eagle activity to characteristics of specific slopes, which were of small size [approximately 200 m x 200 m (656 ft x 656 ft)]. Foraging eagles are likely selecting areas based on a larger landscape-level scale, however, and probably take little notice of small, individual slopes.

Brown and Watson (1964) found that golden eagles in Scotland chose hilly terrain in which to forage, but their hunting territories were often more than 1,200 ha (4.6 mi^2) in size. This suggests that golden eagles may use a broad searching technique rather than concentrating on locally dense regions of prey activity. Additionally, nonbreeding eagles may go a week between feedings.

Because their home ranges may be fixed at such a large size, they are assured a more than adequate food supply even after precipitous drops in prey abundance (Brown and Watson 1964).

In light of the expansive nature of golden eagle foraging behavior, it is possible that my entire study area may have been smaller than a hunting territory of a single eagle or eagle pair. Thus, the incongruity between the scale of my study and that of foraging golden eagles may also explain why topographic features, other than aspect, showed little relationship to eagle activity as well. Of the 100 observational sessions where a golden eagle activity was recorded, 36 of them consisted of a single sighting of an eagle gliding straight through the plot. A possible explanation of these results is that golden eagles in my study area chose slopes with aspects that allowed them to use declivity currents to gain flight altitude. Once they began to descend, however, they glided more or less randomly over a wider area, proceeding in and out of squirrel-dense areas, and over slopes of various incline and elevation.

Management Implications for Golden Eagles

During my study, golden eagles used a low gliding flight that was frequently at the height of turbine blades [11–50 m (36–164 ft) from the ground] and most often occurred in strong wind. These flight characteristics put them at risk of colliding with turbines. However, unlike red-tailed hawks, golden eagles did not spend a disproportionate amount of time in specific areas. Instead, they appeared to take long searching routes throughout the whole area. Consequently, mitigation measures to reduce bird-turbine collisions will need to be species-specific.

Although golden eagles appeared to choose foraging sites based on a larger scale than that detected by my analysis, it was apparent that they were using routes or corridors during foraging. These routes seemed to take advantage of specific topographical features. Golden eagles were seen to follow the contour of hillsides facing into prevailing winds. Additionally, they made particular use of narrow corridors that transect large hills rather than flying over the tops of the hills. This is presumably because canyons and valleys serve as corridors for bird movements.

These observations are consistent with the 1989–1991 Altamont Pass WRA study by Orloff and Flannery (1992) in which 39 golden eagle/turbine-related fatalities were recovered. Results of their study showed that turbines located close [within 200 m (656 ft)] to canyons were closely associated with eagle mortality. Orloff and Flannery defined canyons as narrow valleys with steep sides, such as drainages, ravines, or draws.

The canyons that appeared to be significant during my study, and that of Rugge's (2001), however, had specific characteristics that would allow for more precise mitigation measures aimed at decreasing eagle mortality. Three canyons, with similar topographical features, were routinely used as corridors by golden eagles during my study. The canyons were oriented from east to west and had steep (>23% average grade) and tall [peak elevations of 170–205 m (558–673 ft)] hills located on the north and south sides. Additionally, these canyons opened up westerly onto valley floors, measuring approximately 900 m^2 (9,687 ft^2), where low-elevation turbines were located [~125 m (410 ft) above sea level]. The turbines in these three valley areas were responsible for all seven eagle fatalities recovered during the Rugge study (2001).

It is the characteristics of these specific canyons that set them apart from the many other ravines and drainages within my study. The large valley plateau at the end of the each canyon is perhaps the most notable feature because this is where the eagle collisions took place (Rugge 2001). Thus, it may be possible to reduce eagle-turbine mortality by closing down the turbines that were constructed on valley plateaus or along the rim where the plateau meets the sloping hillsides.

More specifically, valleys at the terminal ends of canyons fitting the above-mentioned topographic model should be targeted.

Furthermore, I encourage additional studies of golden eagle flight behavior on a landscape scale to determine what local flyways and routes are being used within the Altamont Pass WRA. By choosing additional study sites that contain similar canyons to those observed during my study, it would be possible to test whether this topographic model is accurate in predicting golden eagle activity and mortality. One method of obtaining this information would be to capture and radio tag golden eagles foraging within the WRA. Their foraging routes could be tracked and plotted on topographical maps. When combined with weather variables and fatality surveys, it would be possible to obtain a clearer picture of what specific flight routes lead to golden eagle/turbine collisions.

Literature Cited

Baker, J.A.; Brooks, R.J. (1981). "Distribution Patterns of Raptors in Relation to Density of Meadow Vole." *Condor*, 83:42-47.

Bechard, M.J. (1982). "Effect of Vegetative Cover on Foraging Site Selection by Swainson's Hawk." *Condor*, 84:153-159.

Bergo, G. (1987). "Territorial Behavior of Golden Eagles in Western Norway." *Brit. Birds*, 80:361-376.

Brown, L.H.; Watson, A. (1964). "The Golden Eagle in Relation to its Food Supply." *Ibis*,106:78-100.

Callopy, M.W. (1983). "Foraging Behavior and Success of Golden Eagles." *Auk*, 100(3):747-749.

Carnie, S.K. (1954). "Food Habits of Nesting Golden Eagles in the Coast Ranges of California." *Condor*, 56(1): 3-12.

Cone, C.D. (1962). "Thermal Soaring of Birds." *Am. Sci.*, 50:180-209.

Craighead, J.J.; Craighead, F.C., Jr. (1956). *Hawks, Owls, and Wildlife*. Harrisburg, PA: Stackpole Co.

Crystal, D. (ed). (1997). *The Cambridge Factfinder*. 2nd edition. Cambridge, MA: Cambridge University Press, p.35.

Dekker, D. (1985). "Hunting Behaviour of Golden Eagles, *Aquila chrysaetos*, Migrating in Southwestern Alberta." *Can. Field-Natur.*, 99(3):383-385.

Drennen, J.E.; Beier, P.; Dodd, N.L. (1998). "Use of Track Stations to Index Abundance of Sciurids." *Journal of Mammalogy*, 79(1):352-359.

Dunne, P.; Sibley, D.; Sutton, C. (1988). *Hawks in Flight*. Boston, MA: Houghton Mifflin Company, p. 254.

Haugh, J.R. (1986). "Raptors in Migration," pp.35-48 *in Raptor Conservation in the Next 50 Years*. Raptor Research Reports No.5. The Raptor Research Foundation, Inc.

Howell, J.; DiDonato, J. (1991). *Assessment of Avian Use and Mortality Related to Wind Turbine Operations, Altamont Pass, Alameda and Contra Costa Counties, California, September 1988 Through August 1989*. *Final Report.* Submitted to U.S. WindPower.

Howell, J.A. (1997). "Bird Mortality at Rotor Swept Area Equivalents, Altamont Pass and Montezuma Hills, California." *Trans. West. Sect. Wildl. Soc*., 33:24-29.

Hunt, G. (1995). *A Pilot Study Golden Eagle Population Study in the Altamont Pass Wind Resource Area, California*. Work performed by Predatory Bird Research Group, Santa Cruz, CA. Golden, CO: National Renewable Energy Laboratory.

_____. (1997). *A Population Study of Golden Eagles in the Altamont Pass Wind Resource Area: Population Trend Analysis 1997*. Work performed by Predatory Bird Research Group, Santa Cruz, CA. Golden, CO: National Renewable Energy Laboratory.

Janes, W.W. (1985). "Habitat Selection in Raptorial Birds." Cody, M.L., ed. *Habitat Selection in Birds*. New York: Academic Press, pp. 159-1888.

Knowles, C.J. (1987). "Reproductive Ecology of Black-tailed Prairie Dogs in Montana." *Great Basin Nat*., 47:202-206.

Krebs, J.R.; Davies, N.B. (1993). *An Introduction to Behavioural Ecology*. Cambridge, MA: Blackwell Science.

Martin, P.; Bateson, P. (1986). *Measuring Behaviour: An Introductory Guide*. Cambridge, MA: Cambridge University Press.

Menkens, G.E.; Biggins, D.E.; Anderson S.H. (1990). "Visual Counts as an Index of White-tailed Prairie Dog Density." *Wildl. Soc. Bull*., 18:290-296.

Morrison, M.L.; Marcot, B.G.; Mannan, R.W. (1998). *Wildlife-Habitat Relationships; Concepts and Applications*. Madison, WI: University of Wisconsin Press.

Musters, C.J.M.; Noordervliet, M.A.W; Ter keurs, W.J. (1996). "Bird Casualties Caused by a Wind Energy Project in an Estuary." *Bird Study*, 43:124-126.

NREL. (1999). National Renewable Energy Lab at a glance. http://www.nrel.gov/lab/ataglance.html.

Nydegger, N.C.; Smith, G.W. (1986). "Prey Populations in Relation to *Artemisia* Vegetation Types in Southwestern Idaho." MacArthur, E.D.; B.L. Welch, eds. In *Proc.- Symposium on the Biology of* Artemisia *and* Chrysothamnus. Ogden, UT: U.S. For. Serv. Int. Res. Sta.; pp. 152-156

Orloff, S. (1992). *Tehachapi Wind Resource Area Avian Collision Baseline Study*. Work performed by BioSystems Analysis, Inc., Tiburon, CA. Sacramento, CA: California Energy Commission.

Orloff, S.; Flannery, A. (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 No. 990-89-003. Tiburon, CA: BioSystems Analysis, Inc.

_____. (1996). *A Continued Examination of Avian Mortality in the Altamont Pass Wind Resource Area*. Consultant report P700-96-004CN. Work performed by BioSystems Analysis, Inc., Santa Cruz, CA. Sacramento, CA: California Energy Commission.

Owings, D.H.; Borchert, M. (1975). "Correlates of Burrow Locations in Beechey Ground Squirrels." *Great Basin Nat.*, 35:402-404.

Pennycuick, C.J. (1972). *Animal Flight*. London, England: Edward Arnold.

Powell, K.L.; Robel, R.J.; Kemp, K.W.; Nellis, M.D. (1994). "Aboveground Counts of Black-tailed Prairie Dogs: Temporal Nature and Relationship to Burrow Entrance Density." *J. Wildl. Manage.*, 58(2):361-366.

Preston, C.R. (1981). "Environmental Influence on Soaring in Wintering Red-tailed Hawks." *Wilson Bull.*, 93(3):350-356.

_____. (1990). "Distribution of Raptor Foraging in Relation to Prey Biomass and Habitat Structure." *Condor*, 92: 107-112.

Quy, R.J.; Cowan, D.P.; and Swinney, T. (1993). "Tracking as an Activity Index to Measure Gross Changes in Norway Rat Populations." *Wildl. Soc. Bull.*, 21:122-127.

Ratti, J.T.; Garton, E.O. (1996). "Research and Experimental Design." Bookhout, T.A., ed. *Research and Management Techniques for Wildlife and Habitats,* Fifth ed. Bethesda, MD: The Wildlife Society, pp. 1-23.

Rugge, L. (2001). *An Avian Risk Behavior and Mortality Assessment at the Altamont Wind Resource Area in Livermore, California*. MS Thesis. Sacramento, CA: California State University.

Schmutz, J.K.; Hungle, D.J. (1989). "Populations of Ferruginous and Swainson's Hawks Increase in Synchrony with Ground Squirrels." *Can. J. Zool.*, 67:2596-2601.

Schnell, G.D. (1968). "Differential Habitat Utilization by Wintering Rough-legged and Red-tailed Hawks." *Condor*, 70:373-377.

Smith, D.G.; Murphy, J.R. (1973). "Breeding Ecology of Raptors in the Eastern Great Basin of Utah." *Sci. Bull. Biol. Ser.*, Vol. 18, pp.1-76. Provo, UT: Brigham Young University.

Smith, J. (2001). Personal communication. Alameda County Agricultural Commission.

Steenhof, K.; Kochert, M.N. (1988). "Dietary Responses of Three Raptor Species to
     Changing Prey Densities in a Natural Environment." *J. Anim. Ecol*., 57:37-48.

Stinson, C.H. (1980). "Weather-dependent Foraging Success and Sibling Aggression in
     Red-tailed Hawks in Central Washington." *Condor*, 82:76-80.

Thompson, I.D.; Davidson, I.J.; O'Donnell, S.; Brazeau, F. (1989). "Use of Track
     Transects to Measure the Relative Occurrence of Some Boreal Mammals in Uncut Forest
     and Regeneration Stands." *Can. J. Zool.,* 67:1816-1823.

Van Horne, B.; Schooley, R.L.; Knick, S.T.; Olson, G.S.; Burnham, K.P. (1997). "Use
     of Burrow Entrances to Indicate Densities of Townsend's Ground Squirrels." *J. Wildl.
     Manage*., 6(1)92-101.

Weddell, B.J. (1989). "Dispersion of Columbian Ground Squirrels (*Spermophilus
     columianus*) in Meadow Steppe and Coniferous Forest." *J. Mamm*., 70(4)842-845.

Zar, J.H. (1996). *Biostatistics*. 3rd ed. Upper Saddle River, NJ: Prentice-Hall, Inc.

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 2002	3. REPORT TYPE AND DATES COVERED Subcontract Report

4. TITLE AND SUBTITLE
The Response of Red-Tailed Hawks and Golden Eagles to Topographical Features, Weather, and Abundance of a Dominant Prey Species at the Altamont Pass Wind Resource Area, California

5. FUNDING NUMBERS
TA: WER2 1610

6. AUTHOR(S)
S. Hoover

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
California State University
Sacramento, California

8. PERFORMING ORGANIZATION REPORT NUMBER
XAT-9-29208-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
SR-500-30868

11. SUPPLEMENTARY NOTES

NREL Technical Monitor: Karin Sinclair

12a. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Studies have shown that raptors flying within the Altamont Pass WRA are vulnerable to fatal turbine collisions, possibly because of their specific foraging and flight behavior. Between June 1999 and June 2000, I conducted 346.5 hours of raptor observations within the Atlamont Pass WRA. Behavior was recorded in relation to characteristics of the topography (slope aspect, elevation, and inclination), the weather, and ground squirrel abundance, as determined by active burrow entrances. The most significant finding of this study revealed that red-tailed hawks and golden eagles flew more in strong winds than in weak winds, particularly along hillsides facing into prevailing winds (as opposed to hillsides shielded from the wind). This is likely a result of the birds' use of declivity currents for lift during flights. These results suggest that certain combinations of topography and weather produce wind currents that are sought out by foraging red-tailed hawks and golden eagles within the Altamont Pass WRA. To decrease raptor mortality, mitigation measures can be targeted to specific areas likely to attract foraging raptors because of their capacity to create particularly favorable wind currents.

14. SUBJECT TERMS
wind energy, avian impacts, Altamont Pass Wind Resource Area

15. NUMBER OF PAGES
72

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL