Research Article

Burrowing Owl Mortality in the Altamont Pass Wind Resource Area

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ABSTRACT We estimated wind turbines in the Altamont Pass Wind Resource Area (APWRA), California, USA, kill >100 burrowing owls (*Athene cunicularia hypugaea*) annually, or about the same number likely nesting in the APWRA. Turbine-caused mortality was up to 12 times greater in areas of rodent control, where flights close to the rotor plane were disproportionately more common and fatalities twice as frequent as expected. Mortality was highest during January through March. Burrowing owls flew within 50 m of turbines about 10 times longer than expected, and they flew close to wind turbines disproportionately longer within the sparsest turbine fields, by turbines on tubular towers, at the edges of gaps in the turbine row, in canyons, and at lower elevations. They perched, flew close to operating turbine blades, and collided disproportionately more often at turbines with the most cattle dung within 20 m, with the highest densities of ground squirrel (*Spermophilus beecheyi*) burrow systems within 15 m, and with burrowing owl burrows located within 90 m of turbines. A model of relative collision threat predicted 29% of the 4,074 turbines in our sample to be more dangerous, and these killed 71% of the burrowing owls in our sample. This model can help select the most dangerous turbines for shutdown or relocation. All turbines in the APWRA could be shut down and blades locked during winter, when 35% of the burrowing owls were killed but only 14% of the annual electricity was generated. Terminating rodent control and installing flight diverters at the ends of turbine rows might also reduce burrowing owl mortality, as might replacing turbines with new-generation turbines mounted on taller towers. (JOURNAL OF WILDLIFE MANAGEMENT 71(5):1513–1524; 2007)

The western burrowing owl (*Athene cunicularia hypugaea*; hereafter owl) in California, USA, has declined in number and spatial distribution (DeSante et al. 1996, Klute et al. 2003). Nesting pairs occur individually or in small groups scattered among remnant habitat patches across their former geographic range, and previously known populations were extirpated in recent years (e.g., Johnson 1997). Owls residing in the Altamont Pass were omitted from the last statewide assessment of burrowing owls (DeSante et al. 1996). Researchers studying avian collisions with wind turbines observed many burrowing owls in the Altamont Pass Wind Resource Area (APWRA), as well as numerous owl carcasses under wind turbines (Rugge 2001; Thelander et al. 2003; Smallwood and Thelander 2004, 2005). Owls appeared so numerous in the APWRA that we concluded the population there must be regionally significant, and there appeared to be sufficiently high mortality to wonder whether the APWRA functions as an ecological sink.

Recent data suggested owls collide with wind turbines more often where owl burrows are more numerous near turbines (Smallwood et al. 2001). Smallwood et al. (2001) found the number of owl burrows (i.e., all burrows showing fresh signs of use, such as whitewash, pellets, decorations, or flushed owls) increased with the number of ground squirrel (*Spermophilus beecheyi*) burrow systems within 55 m of turbines. Owl nest sites close to wind turbines may expose owls to a greater threat of collision with wind turbines.

Therefore, wind turbines located on the landscape away from owl burrows may reduce turbine-caused owl mortality.

Our research objectives in the APWRA, as they related to burrowing owl, were to 1) compare human-caused mortality to the predicted habitat capacity of owls in the APWRA, 2) identify key patterns of owl mortality and behavior in the APWRA, and 3) relate management practices to owl behavior and mortality patterns, and suggest mitigation measures to reduce turbine-caused owl fatalities in the APWRA.

STUDY AREA

The APWRA was in central California's eastern Alameda and southeastern Contra Costa counties, including about 16,450 ha of annual grassland. Our study area ranged from 78 m to 470 m above mean sea level, was composed of hills, ridges, and valleys, and included stock ponds, small seasonal ponds, and marshes. Most ridges were oriented northwest to southeast and were bisected by seasonal streams.

Vegetation was predominantly nonnative annual grassland, including soft chess (*Bromus hordeaceus*), rip-gut brome (*Bromus diandrus*), foxtail barley (*Hordeum murinum leporinum*), Italian rye grass (*Lolium multiflorum*), and wild oats (*Avena fatua*). Common forbs included black mustard (*Brassica nigra*), fiddle-neck (*Amsinckia menziesii intermedia*), chick lupine (*Lupinus microcarpus* var. *densiflorus*), bush lupine (*Lupinus albifrons*), and wally baskets (*Triteleia laxa*). Grasses and forbs grew during the rainy months of January through March, then died or went dormant by early June. Physiographic elements of the APWRA included annual

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grassland, alkali meadow, emergent marsh, riparian woodland and scrub, creeks and drainages, stock ponds, cultivated land, and rock outcrops.

Landowners in the APWRA principally grazed livestock but also leased land to wind turbine owners. When our study began, the APWRA included about 5,400 wind turbines of various models with a total rated capacity of about 580 MW. These wind turbines were mounted on various types of tower and at heights ranging from 4 m to 43 m aboveground. Many were on ridge crests or on ridgelines that descend into ravines from the ridge crests. About 11% of the wind turbines were within large drainage basins we referred to as canyons, which included gullies, ridges, and some ridge crests occurring at lower elevations than the canyon boundary. Other turbines were on hill slopes away from ridges and drainages. Smallwood and Thelander (2004, 2005) provided additional detail on land uses in the APWRA, wind turbine attributes, and other aspects of the study area.

METHODS

Habitat Capacity of the APWRA

We obtained owl population density estimates and study area sizes used to estimate the density estimates from Coulombe (1971), Thomsen (1971), Martin (1973), Butts (1976), Gleason and Johnson (1985), Haug and Oliphant (1990), Rodriguez-Estrella and Ortega-Rubio (1993a, b), Trulio (1993), Leptich (1994), Desmond and Savidge (1996), Botelho and Arrowood (1998), and Wiley (1998). Following the methods of Smallwood (1995, 1998) and Smallwood and Schonewald (1996), we regressed $\log_{10}$ density on $\log_{10}$ study area size using linear regression analysis because most of the variation in intraspecific density estimates can be explained by study area size due to mathematical artifact of the predictor variable appearing as the denominator of the density estimate. We relied on the root mean-square error in the regression model to estimate the uncertainty range applied to the nesting pair density estimate to be applied to the spatial area of the APWRA. We multiplied the estimate of owl nesting pair density for the APWRA by the area of the APWRA to arrive at an abundance estimate in lieu of directed field research. To this number we added the number of fledglings/pair averaged from Thomsen (1971), Martin (1973), Haug and Oliphant (1990), Johnson (1997), Botelho and Arrowood (1998), Rosenberg and Haley (2004), Lantz (2005), Lutz and Plumpton (1997), and Teaschner (2005), and the number of floaters averaged from Thomsen (1971) and Botelho and Arrowood (1998).

Owl Fatalities

From March 1998 through September 2002, we searched for bird carcasses within 50 m of 1,526 wind turbines, hereafter set 1. We periodically added groups of wind turbines as we obtained access. By September 2002, set 1 included 182 rows of mostly regularly spaced wind turbines, which were all the wind turbines available to us. From November 2002 until May 2003, we added 2,548 turbines arranged in 380 rows, hereafter set 2. We systematically selected the set 2 turbine strings to ensure full representation of the north–south and east–west extents of the APWRA. In total, we sampled about 75% of the wind turbines in the APWRA. Fatality search intervals varied interannually and among groups of wind turbines, averaging 53 ± 11.6 days among set 1 wind turbines and >90 days for set 2 turbines. Search intervals were longer for set 2 because we gained access to them late in our study, and we decided to reduce search frequency per turbine in order to minimally sample more wind turbines in the APWRA.

Two people explored the ground around each wind turbine row, maintaining a zigzag pattern about 4 m between each turn. Previous studies reported about 77% of all bird carcasses were found ≤40 m from the wind turbines (Orloff and Flannery 1992, Munsters et al. 1996, Howell 1997), so we decided to use 50 m as our search radius.

We examined all carcasses or body parts found, such as groups of flight feathers, head, wings, tarsi, and tail feathers, to determine species, age, sex, and probable cause of death. We determined cause of death by evidence of injuries, when available, such as burn marks or singed feathers typical of electrocution, and cut or twisted torsos, dismemberment, and other forms of blunt force trauma typical of collisions with wind turbine blades. Otherwise we relied on proximity of the carcass to the likely cause of death. We estimated days since death by analyzing carcass condition (e.g., fresh, weathered, dry, bleached bones) and decomposition level (e.g., flesh color, presence of maggots, odor). We used time-since-death estimate in which season the fatality occurred and to decide whether to use the fatality in our estimation of mortality.

We expressed wind turbine–caused mortality as the number of fatalities per megawatt (MW) per year, where MW was the sum of the rated power output of all wind turbines composing a row of turbines, and the number of years or fractions of a year were the time spans over which we performed searches at that wind turbine row. We derived our mortality estimates only from wind turbine–caused fatalities ≤90 days before the search. We added 0.25 (3 months) to the number of years we used in each mortality calculation to represent the time period when fresh carcasses could have accumulated prior to our first search. We assumed we would have found the same number of fatalities during a given year regardless of whether we performed 12 searches or 8 searches, but it is likely that the reduced search frequency at set 2 wind turbines yielded lower carcass detection rates.

We multiplied our raw mortality calculation by 1.164 to account for carcasses we did not find beyond our search radius only because we did not see them. While searching ≤50 m from turbines, we found 16.4% of the owl carcasses >50 m from turbines, and we assumed we missed as many of the carcasses as we found outside the search radius. We relied on other studies for searcher detection and scavenging removal rates. Orloff and Flannery (1992) estimated searcher detection of 85% of raptor carcasses in the APWRA, so we

conservatively used this value for owls and divided mortality by 0.85. We regarded the mortality estimate adjusted for search detection rates as the low end of an uncertainty range. The high end of the uncertainty range included an adjustment for rate of carcass removal by scavengers.

Erickson et al. (2003) estimated that after 40 days scavengers removed 58.6% of carcasses of large-bodied species and 80.2% of carcasses of small-bodied species. We considered burrowing owl a small-bodied species. Also, our average search interval was 53 days for set 1 wind turbines, and 90 days for set 2 wind turbines, so we adopted the carcass removal rate of Erickson et al. (2003) for set 1, assuming scavenger removal rates were similar between 40 days in their study and 53 days in ours, and we added 10% to these rates for set 2, assuming a 90.2% rate of carcass removal. To adjust our mortality estimates to include the carcasses removed by scavengers and undetected by us, we divided our raw mortality estimates by twice the proportion of carcasses detected by Erickson et al. (2003) after 40 days, which effectively halved their scavenger removal rate. Based on our experience observing raptor carcasses in the AP-WRA, we halved the scavenging rate of Erickson et al. We divided owl mortality in set 1 and set 2 wind turbines by 0.396 and 0.196, respectively, to adjust the estimates for carcasses we did not detect due to scavenger removal. We examined only unadjusted mortality estimates interannually because we assumed scavenger removal rates and searcher detection error did not vary interannually.

We related owl fatalities to the spatial distributions of mammal and owl burrows. We mapped burrows using a Trimble Pro-XR Global Positioning System within 90 m of 571 wind turbines composing 70 rows. We selected turbine rows representing a wide range of raptor mortality recorded during our fatality searches, as well as a variety of physiographic conditions and levels of rodent control ongoing in the APWRA (we did not participate in the rodent control program). Levels of rodent control were none, intermittent, and intense, where intense control effectively eliminated ground squirrels from the treated areas. We used a pacing method to separate burrow systems when continuity of sign rendered inter-burrow system distinctions difficult (Smallwood and Erickson 1995). We walked transects 0 m, 15 m, 30 m, 45 m, 60 m, 75 m, and 90 m away from the turbine string, thus covering increasingly larger areas around the turbine strings.

Owl Behavior

Two biologists collected bird behavior data within 28 study plots during 1,958 behavior-observation sessions (979 hr) from 26 March 1998 through 18 April 2000. The study plot boundaries encompassed wind turbines easily visible to the observers from a fixed observation point, resulting in a mosaic of irregularly shaped, nonoverlapping plots, each about 3 km². The plots contained 1,165 turbines, with 10–67 turbines per plot, representing the majority of the turbines accessible to us at the time. Each observer carried plot maps to identify each turbine by its number designation and to link it to recorded bird activities. A single observer performed circular visual scans (360°) to 300 m using 8×40 binoculars. After the 30-minute observation session, the observer moved to another sampling plot to begin another 30-minute session.

We sampled all 28 plots at least once per week stratified by morning and afternoon sessions. Morning sessions spanned 0700 hours to 1200 hours, and afternoon sessions spanned 1201 hours to dusk. We observed behaviors throughout the year in nearly every weather condition, unless rain or fog reduced observer visibility to <60%, which was too poor to track bird activity accurately. We completed 2 sessions simultaneously, averaging 6–8 sessions per field day. We conducted all simultaneous 30-minute sessions on non-adjacent plots to improve our degree of independence among sessions.

We continuously followed a bird until it left the plot. For each sighting, we recorded the species, number of birds in a group, the times when the bird was detected and last seen, predominant flight behavior, flight direction, distance to the nearest wind turbine, type of wind turbine, number of flights through a turbine string, and flight height relative to the rotor zone, which is the height aboveground from the lowest to the highest reaches of the turbine blades and extending laterally to 50 m from the rotor.

Behavior and Fatality Association Analysis

We tested measured variables for association with owl fatalities and with behaviors using chi-square analysis (Smallwood 1993, 2002). Observed values were either the number of minutes of activity of a particular behavior or the number of fatalities, and observed values were related to expected values for both statistical hypothesis testing and for deriving a measure of effect. We calculated the measure of effect as the observed divided by the expected values, and we measured the number of times greater or fewer each observed value deviated from the corresponding expected value. We calculated expected values as a product of the total sample size of the dependent variable and the incidence, or relative frequency of occurrence expressed as a proportion, of the ith condition of the association variable, where we also factored sampling effort into the incidence of the ith condition of the association variable. We caution, however, that the behavior observations are not independent events, so chi-square tests based on minutes of observation are prone to Type I error. For these reasons, we highlighted only the behavior associations with large measures of effect and significant test results. See Smallwood and Thelander (2004, 2005) for additional detail of the analytical methods.

Predictive Model

We developed a simple predictive model of each wind turbine's relative threat to owls:

$$\text{Accountable mortality} = (\text{obs} - \text{exp})/\text{total fatalities} \times 100\%.$$

Positive values expressed the percentage of total fatalities likely killed at wind turbines due to the attribute associated

with the value, and negative values expressed the percentage of total expected to have been killed but not killed. Thus, accountable mortality ranged from −100% to 100% and expressed the percentage of the fatalities attributable to a particular category of an association variable.

We calculated accountable mortality only for variables whose chi-square tests for association with fatalities were significant with most expected cell values >5. These variables also were either categorical (e.g., tower type) or graded in value with accountable mortality. For those variables included in the model, we summed accountable mortality values across the variables to arrive at a score:

$$\text{Predicted impact} = \sum \text{accountable mortality.}$$

Predicted impact values >0 represented wind turbines more likely to kill owls, whereas values ≤0 represented wind turbines less likely to kill owls. Predicted impacts were additional to impacts we could not account for based on the data we collected, which probably included a baseline level of impact simply because all wind turbines pose an inherent danger to birds because turbines are tall structures with moving parts into which birds can collide.

We compared model predictions of impact to the number of fatalities we recorded at the particular wind turbine. We assessed model effectiveness by the percent correct classification of the wind turbines that killed owls. We also assessed the model based on the percent of wind turbines whose predicted impact was >0 but at which we found no fatalities. These wind turbines will more likely kill birds, even though we did not find them yet, and this percentage represents the level of effort needed to modify wind turbines and range management practices to substantially reduce owl collisions.

Lastly, we examined the percentage of fatalities corresponding with wind turbines correctly classified as more likely to kill owls. This percentage represented the degree to which mortality could be reduced by modifying conditions expressed by the variables composing the model, assuming no interaction effects between predictor variables.

RESULTS

Turbine-Caused Mortality and Habitat Capacity in the APWRA

According to our model of owl density regressed on study area size, the APWRA should support about 35–75 nesting pairs of owl (Fig. 1). If 35–75 pairs produced on average 3.08 fledglings per pair per year (the average reported from 10 studies across the western United States and Canada), and if the number of floaters average 43 per 100 nesting adults (the average reported from 2 studies in California and New Mexico, USA), then about 208–446 owls would be present as the breeding season ended. We estimated APWRA wind turbines kill 99–380 owls per year, or between 22% and 183% of the APWRA's estimated population.

Wind turbine–caused, unadjusted mortality estimates based on fatalities found May 1998 through September
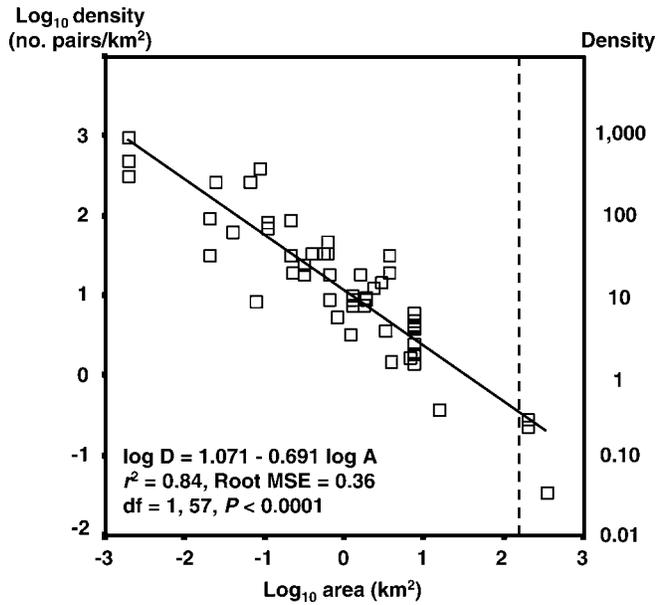
Figure 1. Nesting density estimates of burrowing owl related to study area size as an inverse power function among studies published 1971–1998 from throughout the species' geographic range. The vertical dashed line represents the geographic area of the Altamont Pass Wind Resource Area, California, USA. The abbreviation MSE stands for mean square error, expressing the percent error in the raw data.

2002 were 0.014 fatalities/MW, 0.163 fatalities/MW, and 0.087 fatalities/MW per year, respectively, among 118.02 MW, 65.33 MW, and 206.30 MW of rated capacity in areas of no rodent control (120 turbine rows), intermittent control (87 rows), and intense control (240 rows). These estimates differed (analysis of variance [ANOVA]: $F = 4.45$, df = 2, 445, $P = 0.012$). Mortality estimates adjusted by searcher detection and scavenger removal rates were 0.019–0.047 in areas of no rodent control, 0.224–0.564 in areas of intermittent rodent control, and 0.119–0.301 in areas of intense control.

Owl mortality increased from the first through third years of the study, according to the comparison including all turbine rows searched ≥1 year (ANOVA: $F = 3.20$, df = 3, 639, $P = 0.023$; Fig. 2), but it did not change among turbine rows searched all 4 years and where rodent control was applied all 4 years (ANOVA: $F = 1.24$, df = 3, 247, $P = 0.296$). At 10 turbine rows searched only during the first and second years in an area of intermittent rodent control, unadjusted owl mortality increased from 0 collisions/MW to 0.43 collisions/MW (ANOVA: $F = 5.05$, df = 1, 19, $P = 0.005$). Unadjusted owl mortality decreased between the third and fourth years in turbine fields where intense rodent control had been applied during the fourth year, from 0.42 fatalities/MW to 0.05 fatalities/MW (ANOVA: $F = 4.44$, df = 1, 75, $P = 0.039$).

Owl Fatalities and Behavior

Of the owl carcasses found during fatality searches in the APWRA, we attributed the cause of death of 79% (60 carcasses) to wind turbine collision, 13% (10 carcasses) to unknown causes we later assumed to be wind turbine
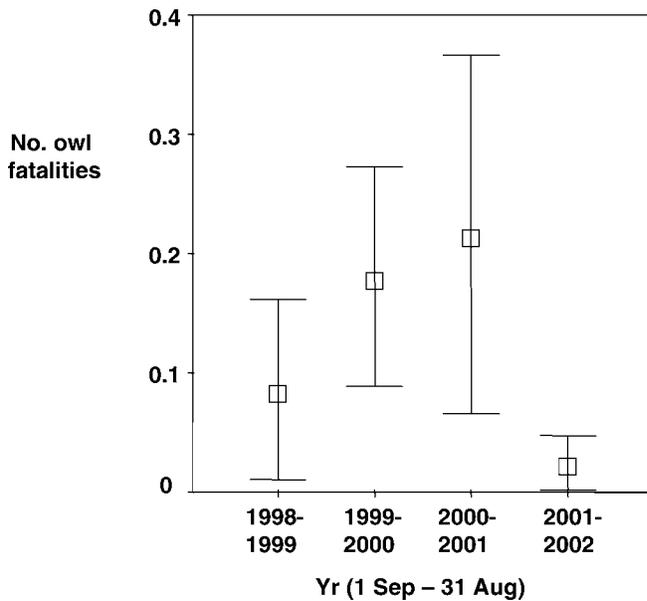
Figure 2. Burrowing owl mortality (no. fatalities/MW of wind turbines in turbine row; $\bar{x}$ and 95% CI) during 1998–2003 among 160 turbine strings searched ≥1 year in Altamont Pass Wind Resource Area, California, USA.

Figure 3. Number wind turbine–caused burrowing owl fatalities by the estimated number of days since death in the Altamont Pass Wind Resource Area, California, USA, 1998–2003.

collisions based on carcass locations, and 5% (4 carcasses) to predation. One owl collided with an automobile on an access road, and another collided with an electric distribution line. Field biologists searching for fatalities did not report the type of injury of most owl fatalities, but nearly half of the injury reports described broken or severed wings (Table 1). Most (76%) of the owl carcasses had been extensively scavenged, even though all but 2 appeared to have died ≤90 days before (Fig. 3).

Dead owls included 20 adults, 3 immature birds, and 53 of unknown age. Wind turbines killed 18 adults, 2 immature owls, and 50 of undetermined age. Most wind turbine–killed owls died September through December (Table 2). Owl mortality relative to seasonal APWRA power output was highest during January, February, and March (Fig. 4), which is when blades often move fast enough to kill birds but not fast enough to generate electric power. Generally, wind turbine–caused owl fatalities increased with energy gener-

ation ($\chi^2 = 0.51$, df = 1, 8, $P < 0.05$) after holding from the analysis fatalities in December, January, and March (Fig. 5). Wind turbine–caused owl fatalities associated with month of the year differently than did perch time or near-turbine flight time (Fig. 6).

Vertical axis turbines (i.e., Flowind turbines) killed disproportionately more owls, as did turbines on tubular towers (Table 3). Owls also flew close by and perched disproportionately more often near turbines on tubular towers. Turbines on lattice towers killed only half the owls expected.

Wind turbines with slower-moving blades killed 1.6–1.8 times more owls than expected, and turbines with faster-moving blades killed fewer than half the expected number ($\chi^2 = 42.26$, df = 2, $P < 0.005$). Similarly, wind turbines with the least rotor plane (in m²) swept/second killed 1.7–1.8 times the owls expected ($\chi^2 = 24.83$, df = 3, $P < 0.005$). Wind turbines with blades reaching as low as 4.0–5.1 m

Table 1. Number of wind turbine–caused burrowing owl fatalities and levels of scavenging by types of injury reported during 1998–2003 in the Altamont Pass Wind Resource Area, California, USA.

Type of injury	Burrowing owl fatalities (n = 70)	Reported scavenging (n = 54)		
		No evidence	Some	Extensive
Not reported	38	0	2	30
None apparent	2	1	0	0
Head	3	1	0	1
Neck	2	1	0	0
Decapitated	5	1	1	2
Torso cut or twisted	4	3	0	0
Torso cut in half	1	0	0	0
Broken wing	5	0	1	2
Severed wing	4	1	1	1
Dismembered	6	0	0	5

Table 2. Percentage of annual power output, burrowing owl fatalities (n = 70), and fatalities per age group by month of the year during 1998–2003 in the Altamont Pass Wind Resource Area, California, USA.

Month	% of annual power output	Turbine-caused deaths	Age of bird at death		
			Ad	Immature	Unknown
Jan	1.9	8	0	0	8
Feb	1.8	2	0	1[a]	1
Mar	1.7	3	1	0	2
Apr	2.2	1	0	0	1
May	4.6	0	0	0	0
Jun	9.4	2	1	0	1
Jul	17.7	10	2	0	8
Aug	15.8	6	1	1	4
Sep	16.5	14	6	0	8
Oct	15.5	4	0	0	4
Nov	8.9	8	4	0	4
Dec	3.8	12	3	0	9

[a] Assignment of the month of the fatality is uncertain because we estimated the carcass as 3 months old when we found it in May. Given its state of decomposition, we might have misclassified the bird as immature or as having been killed in Feb.
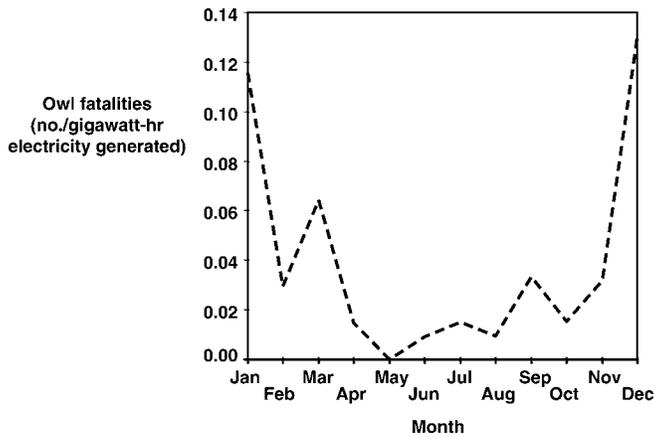
Figure 4. Number of wind turbine–caused burrowing owl fatalities (no./1,000 searches) per gigawatt-hour of electricity generated in 1999 in Altamont Pass Wind Resource Area, California, USA. Note that owl fatalities per gigawatt-hour peaks during winter and March.

aboveground killed 2.2 times the number of owls expected, and turbines whose low reach of blade was 11.1–14.9 m aboveground killed 1.5 times the number of owls expected ($\chi^2 = 22.01$, df = 4, $P < 0.005$).

Whereas owls flew within 50 m and perched nearby turbines at the edges of gaps in turbine rows nearly 1.7 times longer than expected, they collided with these turbines about as often as expected (Table 3). End-of-row turbines killed owls 2.1 times more often than expected, and interior turbines killed them disproportionately less often.

During the 1,958 behavior-observation sessions, we reported 100 owl sightings totaling 1,622 minutes, of which owls flew 193 minutes and perched 1,438 minutes. Owls averaged 117 m to the nearest wind turbine and we never saw them flying through turbine rows. However, we saw them flying within the rotor zone 31 times.
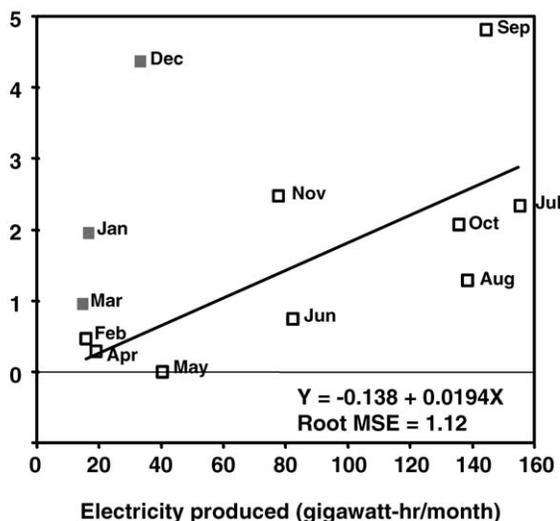
Figure 5. The number of burrowing owl deaths (no./1,000 searches) per month as a function of power output in 1999 in the Altamont Pass Wind Resource Area, California, USA. The filled squares represent outliers we held out of the analysis. The abbreviation MSE stands for mean square error, expressing the percent error in the raw data.

No. obs/no. exp
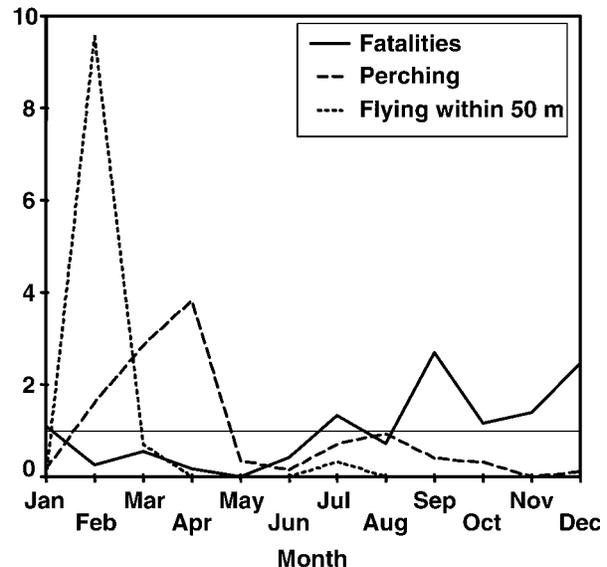
Figure 6. Number observed/number expected burrowing owl fatalities caused by wind turbines, owls perching on turbines, and owls flying within 50 m of wind turbines versus month of the year at Altamont Pass Wind Resource Area, California, USA, 1998–2003.

We observed owls flying ≤50 m from wind turbines about 10 times more often than expected ($\chi^2 = 1,358.15$, df = 2, $P < 0.005$), whereas we saw them perched 50–100 m from turbines >4 times longer than expected ($\chi^2 = 2,454.02$, df = 2, $P < 0.005$; Fig. 7). To wind turbines most sparsely distributed in the APWRA, owls flew ≤50 m from wind turbines ($\chi^2 = 711.56$, df = 3, $P < 0.005$) and perched ($\chi^2 = 278.77$, df = 3, $P < 0.005$) 6 times longer than expected (Fig. 8). However, owl collisions with turbines did not associate significantly with the number of turbines within 300 m ($\chi^2 = 6.04$, df = 3, $P > 0.05$).

Nearly all owls killed by wind turbines were outside wind walls (wind walls are turbines mounted on lattice towers of 2 heights to achieve a greater height domain of wind capture within a single row of turbines), as were all observations of owls flying close by and perching nearest wind turbines (Table 3).

Most owls were killed outside canyons, but they were killed in canyons 1.4 times more often than expected (Table 3). In canyons they also flew within 50 m of turbines and perched nearest turbines 2.6 times and 1.9 times more than expected, respectively. At the APWRA's lowest elevations, 85–235 m above mean sea level, owls collided with wind turbines 1.6–2.5 times more than expected (Table 3). We observed disproportionately longer close-by flights and perching between 135 m and 185 m elevation. Owls collided with turbines uniformly among landscape features, even though they flew close by wind turbines and perched 2.5 times longer than expected on ridge crests (Table 3).

Disproportionately more owls were killed by wind turbines with the most cattle dung within 20 m, which was also where we observed owls perching and flying close to turbines 3.3 times longer than expected (Table 3).

Owls collided with wind turbines nearly twice as often as expected in areas of intermittent rodent control, which were also where we saw them for disproportionately longer periods flying within 50 m of turbines and perching (Table 3). Disproportionately fewer collisions occurred in areas of intense rodent control. Owl mortality was greater at wind turbines with higher densities of burrow systems of fossorial mammals within 90 m (Table 4). Mortality was disproportionately greater at wind turbines with intermediate densities of ground squirrel and desert cottontail (*Sylvilagus auduboni*) burrow systems within 90 m, and it tended to be greater at the highest densities of ground squirrel burrow systems within 15 m (Table 4). Owl mortality was also significantly greater at wind turbines with owl burrows within 90 m, and the occurrence of these burrows could account for 23% of the owl fatalities in our sample (Table 4).

Predictive Model of Turbine Threat

Various wind turbine attributes contributed to model predictions of threat posed to owls by wind turbines (Table 5). We did not use some variables that related significantly to owl fatalities to construct the predictive model because they were limited in scope and we could not measure them at all wind turbines in our sample.

The model correctly predicted wind turbines to be greater collision threats where 71% of the owl fatalities actually occurred (Fig. 9). It predicted 1,215 (30%) of the wind turbines to be more dangerous, including 70% of the turbines we documented as having killed owls. The more dangerous wind turbines were distributed mostly along a low-elevation band across the wind farm, but also between the Patterson Pass and the Highway 205 corridor.

DISCUSSION

Our results suggest APWRA wind turbines annually kill somewhere between one-fifth and nearly twice the number of estimated owls in the available habitat area. We do not know the population-level impact of wind turbine–caused mortality on owls in the Altamont Pass, but it is potentially substantial. Future research in the APWRA is needed to test the following 4 alternative hypotheses stemming from our uncertain impact estimates and from the potentially paradoxical result of equal or greater adults killed compared to the number nesting in the APWRA.

Hypothesis 1: The APWRA Is an Ecological Sink for Owls

Mortality might equal or exceed production in the APWRA because owls dispersing from natal populations outside the APWRA quickly replace wind turbine–killed owls. Generally, population densities can be relatively high in ecological sinks even though mortality is high, which is one reason density is considered a poor indicator of habitat quality (Lidicker 1975, Van Horne 1983, Smallwood 2002). Although local numbers of owls might not decline in the face of wind turbine–caused mortality, other populations lose recruitment from the owls dispersing to and never leaving the APWRA.

Hypothesis 2: Many Turbine-Killed Owls Are Migrants

Many of the adults killed by APWRA wind turbines might be migrants moving through but not nesting in the APWRA. The Altamont Pass is a migration route for multiple species of raptor, and might be a route for owls because it is the low spot in the hills between the Central Valley and San Francisco Bay area populations. Most of the collisions occurred during fall and early winter when migration movements would be expected.

Hypothesis 3: We Underestimated Local Population Abundance

Our regression model (Fig. 1) might have underestimated owl abundance in the APWRA, but if it did, then spatial patterns of owl in the APWRA differ from those at study sites used to generate the published density estimates. Either the higher densities typical of smaller study areas extend to a larger portion of the APWRA than observed in similar-sized areas elsewhere, or the APWRA includes multiple high-density clusters of owls. Based on our incidental observations of owls in the APWRA, we suspect our model underestimated the number of nesting pairs, but focused research will be needed to test our suspicion.

Hypothesis 4: We Overestimated Turbine-Caused Mortality

Our mortality estimate might be too high, but if it is, then our searcher detection rates must be greater than those used by Erickson et al. (2003) or the scavenger removal rate must be lower. Mounting evidence (K. S. Smallwood, unpublished data) indicates we may have underestimated the scavenger removal rate of owls, which means we likely underestimated owl mortality. On the other hand, if we erroneously attributed a substantial portion of the owl fatalities to wind turbine collision, then we would have overestimated owl mortality. In our experience performing field work around owls in environments lacking wind turbines, however, we have not found nearly the number of owl carcasses as we found around APWRA wind turbines.

Fatality Associations

Wind turbine–caused owl fatalities were more numerous during fall and early winter, the latter season corresponding with the APWRA's reduced energy output. K. S. Smallwood and L. Spiegel (California Energy Commission, unpublished data) estimated shutting down wind turbines November through February should reduce annual owl fatalities 35% while giving up only 14% of annual electricity generation in the APWRA.

Wind turbines with lowest reach of blades ≤15 m aboveground killed disproportionately more owls. Replacing the older wind turbines with new-generation turbines mounted on much taller towers might reduce the collision rate by raising the rotor blades above most owl flights.

Owl perception of the turbine field might affect collision rate. Owls appeared to favor areas of lesser wind turbine presence and operations, flying and perching 6 times more than expected among turbines most sparsely distributed.

Table 3. Number of burrowing owl fatalities and observed number/expected number of fatalities, flight observations within 50 m of turbines, and observations of perching by wind turbine model, tower type, the turbine's position in the row, whether the turbine was in a wind wall, whether in a canyon, by elevation, landscape feature, level of rodent control, and abundance of cattle pats within 20 m of turbines during 1998–2003 in the Altamont Pass Wind Resource Area, California, USA.

Association variable	Turbine-caused deaths	Obs/exp		
		Collisions	Flight time ≤50 m from turbines	Perch time
Wind turbine model[a]				
Micon	8	1.63		
Bonus	31	1.60	2.13	2.16
Danwin	0	0.00	0.00	0.00
Flowind	10	3.54	0.00	0.00
Windmatic	0	0.00		
Enertech	6	1.67		
KCS-56 and Vestas	14	0.40	0.04	0.00
KVS-33	0	0.00	0.00	0.00
Howden	0	0.00		
Nordtank	0	0.00		
W.E.G.	0	0.00		
χ^2 test result		$P < 0.05$	$P < 0.05$	$P < 0.05$
Tower type				
Vertical axis	10	3.54	0.10	0.26
Tubular	39	1.49	1.77	1.53
Lattice	20	0.50	0.00	0.61
χ^2 test result		$P < 0.05$	$P < 0.05$	$P < 0.05$
Turbine position in row				
End of row	32	2.12	0.05	0.00
Gap	7	1.15	1.66	1.69
Interior	29	0.62	0.00	0.00
χ^2 test result		$P < 0.05$	$P < 0.05$	$P < 0.05$
Wind wall				
Not in wind wall	68	1.15	1.13	1.13
In wind wall	1	0.10	0.00	0.00
χ^2 test result		$P < 0.05$	$P < 0.05$	$P < 0.05$
Whether in canyon				
Not in canyon	54	0.92	0.10	0.47
In canyon	15	1.43	2.61	1.94
χ^2 test result		$P < 0.10$	$P < 0.05$	$P < 0.05$
Elevation (m above mean sea level)				
85–134	17	1.65	0.00	0.00
135–184	24	1.65	6.74	4.08
185–234	23	2.48	0.00	0.00
235–284	2	0.46	0.22	0.00
285–334	0	0.00	0.00	0.00
335–384	3	0.38	0.00	0.00
385–534	0	0.00	0.00	0.00
χ^2 test result		$P < 0.05$	$P < 0.05$	$P < 0.05$
Landscape feature				
Peak	0	0.00	0.00	0.00
Plateau	5	1.06	0.00	0.00
Ridge crest	22	1.01	2.49	2.52
Ridgeline	8	0.58	0.00	0.00
Slope	29	1.26	0.03	0.00
Swale	3	1.00	0.00	0.00
Ravine	1	1.96	0.00	0.00
χ^2 test result		ns[b]	$P < 0.05$	$P < 0.05$
Rodent control				
Unknown	2	2.40		
None	13	0.82	0.00	0.00
Intermittent	35	1.90	1.83	1.12
Intense	19	0.56	0.08	0.99
χ^2 test result		$P < 0.05$	$P < 0.05$	$P < 0.05$
No. of cattle pats ≤20 m from turbines				
0–2	4	0.47	0.00	0.00

Table 3. Continued.

Association variable	Turbine-caused deaths	Obs/exp		
		Collisions	Flight time ≤50 m from turbines	Perch time
3–9	15	0.68	0.05	0.00
10–25	25	1.18	0.00	0.00
>25	21	1.59	3.27	3.32
χ^2 test result		$P < 0.05$	$P < 0.05$	$P < 0.05$

[a] Manufacturers: Micon = Moerup Manfacturing Co., Randers, Denmark; Bonus = Bonus Wind Turbines, Inc., Brande, Denmark; Danwin = Danwin A/S, Helsingør, Denmark; Flowind = FloWind Corp., San Rafael, CA; Windmatic = Windmatic, Herring, Denmark; Enertech = Enertech Corporation, Norwich, VT; KCS-56 and KVS-33 = Kenetech Windpower Inc., Livermore, CA; Vestas = Vestas Wind Systems A/S, Randers, Denmark; Howden = James Howden and Company, Renfrew, Scotland; Nordtank = Nordtank Energy Group, Balle, Denmark; W.E.G. = Wind Energy Group, Ltd., Southall, Middlesex, England.

[b] ns = not significant.

Flights, perching, and collisions occurred primarily among wind turbines on tubular and vertical axis towers, secondarily among lattice towers, and least among wind walls, corresponding with a declining gradient of visibility through to the other side of a wind turbine row. Owls perched and flew more often in the rotor zone of turbines with slower-moving blades. Furthermore, owls perched on turbines or their towers only while the turbines did not operate, indicating the owls' awareness of turbine operations. Our findings indicate owls avoid areas they perceive as busy with fast-moving turbines, and they instead fly through areas of sparsely distributed turbines with slower-moving blades mounted on tubular towers they can more readily see around. Owls may perceive these turbine fields as safer, making them more dangerous.

Compared to expected frequencies, owls flew more often through gaps in turbine rows and were killed more often by end-of-row turbines. Owls may have approached closer and died more often at turbines in canyons because they use canyons for flight pathways or because turbines in canyons are often at row's end and their blades obscured by hills. Placing flight diverters at the ends of turbine rows, especially those extending into canyons, might encourage owls to fly farther from operating turbines while maneuvering around turbine rows. Smallwood and Thelander (2004, 2005) proposed flight diverters as tall poles erected in parallel beyond the rotor planes of the end-of-row turbines.

Despite owls staying well away from wind turbines most of the time, they still flew into the rotor zone 10 times more than expected. Flights into the rotor zone and collisions were disproportionately more common among wind turbines with the most cattle dung within 20 m. We noticed cattle congregate at the wind turbines (see photos in Smallwood and Thelander 2004, 2005) and spend more time close to the wind turbines than in the grasslands between the turbine rows. As a result, most turbine rows have shorter grass and more cattle dung. Shorter grass has often been associated with owl habitat selection, and the cattle dung fuels a food web utilized by owls, such as large
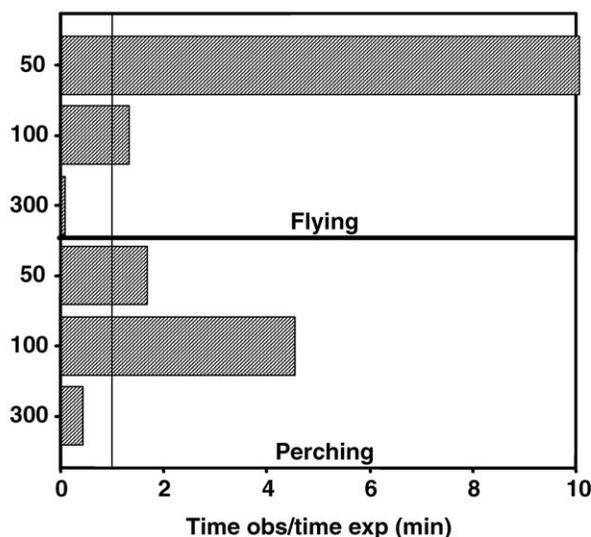
Figure 7. We observed burrowing owls longer than expected flying within 50 m and perching 100–300 m from turbines in the Altamont Pass Wind Resource Area, California, USA, 1998–2003.
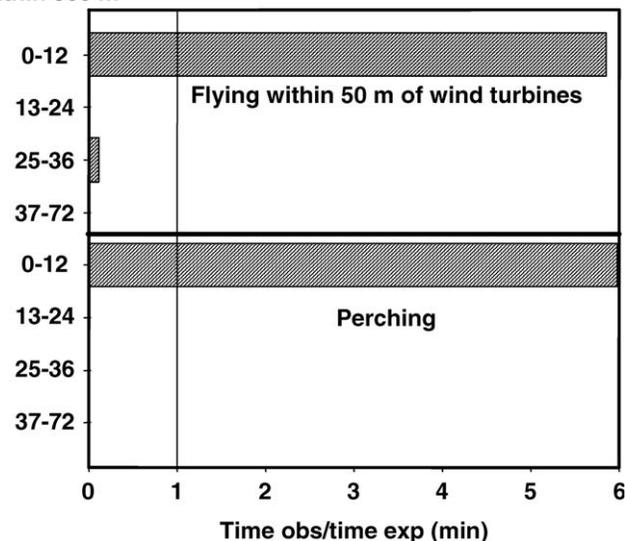
Figure 8. We observed burrowing owls longer than expected flying within 50 m of turbines and perching in areas of lower turbine density in the Altamont Pass Wind Resource Area, California, USA, 1998–2003.

Table 4. Observed number, expected number, and observed number/expected number of collision-caused fatalities of burrowing owls by ranges of density and degree of clustering of fossorial mammals and burrowing owl burrows among 27 rows of turbines in the Altamont Pass Wind Resource Area, California, USA, 1998–2003.

Variable and attribute[a]	Obs collisions	Exp collisions	Obs/exp collisions
Burrow systems/ha of all species to 90 m*			
0–5	4	10.75	0.37
5–10	15	9.77	1.54
10–22.5	8	6.49	1.23
Ground squirrel burrow systems/ha to 90 m**			
0–2	5	12.65	0.40
3–7	17	8.91	1.91
7–19.2	5	5.44	0.92
Desert cottontail burrows/ha to 90 m***			
0	9	8.75	1.03
0.2–0.7	15	10.10	1.49
0.8–1.7	3	8.16	0.37
Ground squirrel burrow systems/ha to 15 m from turbines***			
0	2	4.81	0.42
0.3–5.2	14	15.88	0.88
6.6–26.6	11	6.30	1.75
Obs/exp no. of ground squirrel burrow systems/ha ≤15 m from turbines*			
0	2	4.65	0.43
0.3–1.0	13	16.76	0.78
1.1–5.2	12	5.43	2.21
Burrowing owl burrows/ha to 90 m*			
0	12	18.16	0.66
0.02–0.88	15	8.84	1.70

* $P < 0.05$, ** $P < 0.005$, *** $0.05 < P < 0.10$.

numbers of grasshoppers (Acrididae) covering the cattle dung and lizards (*Uta stansburiana* and *Sceloporus occidentalis*) that feed on the grasshoppers. Owls may visit wind turbine rows to prey upon grasshoppers and lizards, and to

Table 5. Magnitude (%) of increase or decrease in burrowing owl mortality associated with attributes of independent variables measured during 1998–2003 in Altamont Pass Wind Resource Area, California, USA.

Variable	Magnitude of increase in mortality
Sec/rotor sweep at blade tip	30% at turbines with longer time per rotor sweep at blade tip
Tower type	19% at tubular towers, 10% at vertical axis towers
Tower ht	16% at towers of medium height
Whether in wind wall	13% at turbines not in wind walls
Position in turbine row	24% at the end of turbine row
Whether in canyon	6% in canyon
Elevation	44% at lowest elevation
Rodent control	24% in areas with intermittent control
Cattle dung at wind turbines	18% at turbines with more cattle dung
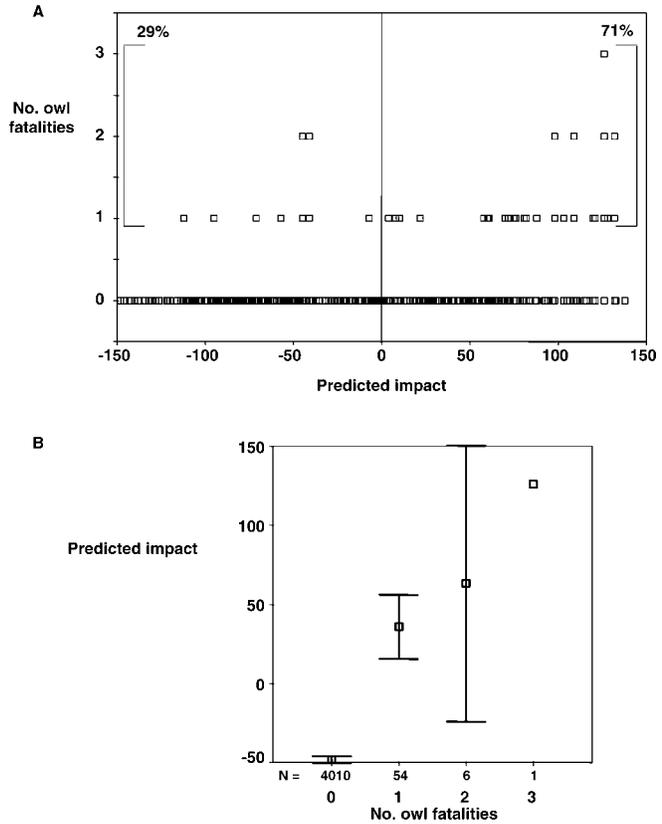
Figure 9. Using our empirical model, we predicted 71% of the wind turbines known to have killed burrowing owls were more likely to kill owls, that is, (A) predicted impact >0, and (B) our predicted impacts ($\bar{x}$ and 95% CI) increased with the actual number of owls killed by the wind turbine in the Altamont Pass Wind Resource Area, California, USA, 1998–2003.

collect cattle dung for display around their burrow entrances as dung beetle lures (Levey et al. 2004) or to mask scent from mammalian carnivores (Green and Anthony 1989), though Smith (2004) supported the former hypothesis but not the latter. We hypothesize that encouraging cattle to congregate other than around the bases of wind turbines would reduce owl flights in the rotor zone, and collisions.

Owl fatalities at wind turbines positively associated with densities of ground squirrel burrow systems and presence of owl burrows within 90 m. We found owl mortality decreased the year rodent control was implemented but eventually increased after it was implemented intermittently for >1 year. Repetitive, intense control would likely eliminate this pattern, however, because vacant squirrel burrows eventually collapse and become unavailable to owls. In fact, we did not find evidence of active owl burrows within the areas of intense control. Intense rodent control might reduce owl collisions, but results in habitat loss not only for the owl, but also for California red-legged frog (*Rana aurora draytonii*), California tiger salamander (*Ambystoma californiense*), and San Joaquin kit fox (*Vulpes macrotis mutica*), which are threatened and endangered species under the federal Endangered Species Act. Ceasing intermittent rodent control might reduce turbine-caused mortality, and ceasing intensive control might increase the habitat capacity of the APWRA.

Our model predicted 29% of the 4,074 sampled wind turbines pose greater collision threat. This 29% of the turbines killed 71% of the turbine-killed owls we found. These turbines occurred in a low-elevation band along the east side of the wind farm, where we saw disproportionately more owls flying within the rotor zone. This model can be used along with other scientific information to select a relatively small set of wind turbines for shutdown, relocation, installation of flight diverters, or other mitigation measures. We hypothesize that a small set of turbines selected in this manner could reduce owl mortality while only minimally reducing APWRA power generation.

MANAGEMENT IMPLICATIONS

In the APWRA, and to the extent managers feel comfortable extending our results to other wind farms, our results can guide the selection of wind turbine design, where to locate wind turbines in the project area, when not to operate wind turbines, and how to manage other resources to minimize owl collisions with wind turbines. To minimize collisions in the APWRA, new wind turbines should be mounted on taller towers as close together as feasible, and outside canyons, ravines, and valleys, and where rodent and owl burrows are relatively scarce. Grazing practices should be modified to prevent accumulations of dung around wind turbines. Understanding biological impacts through additional research can provide the basis of equitable compensatory mitigation for unavoidable impacts.

ACKNOWLEDGMENTS

LITERATURE CITED

Botelho, E. S., and P. C. Arrowood. 1998. The effect of burrow site use on the reproductive success of a partially migratory population of western burrowing owls (*Speotyto cunicularia hypugaea*). Journal of Raptor Research 32:233–240.

Butts, K. O. 1976. Burrowing owls wintering in the Oklahoma Panhandle. Auk 93:510–516.

Coulombe, H. N. 1971. Behavior and population ecology of the burrowing owl, *Speotyto cunicularia*, in the Imperial Valley of California. Condor 73:162–176.

DeSante, D. F., E. Ruhlen, and D. K. Rosenberg. 1996. The distribution and relative abundance of burrowing owls in California: evidence for a declining population. Institute for Bird Populations, Point Reyes Station, California, USA.

Desmond, M. J., and J. A. Savidge. 1996. Factors influencing burrowing owl (*Speotyto cunicularia*) nest densities and numbers in western Nebraska. American Midland Naturalist 136:143–148.

Erickson, W. P., J. Jeffrey, K. Kronner, and K. Bay. 2003. Stateline wind project wildlife monitoring annual report, results for the period July 2001–December 2002. Technical report submitted to FPL Energy, the Oregon Office of Energy, and the Stateline Technical Advisory Committee. Western EcoSystems Technology, Cheyenne, Wyoming, USA.

Gleason, R. S., and D. R. Johnson. 1985. Factors influencing nesting success of burrowing owls in southeastern Idaho. Great Basin Naturalist 45:81–84.

Green, A. G., and R. G. Anthony. 1989. Nesting success and habitat relationships of burrowing owls in the Columbia Basin, Oregon. Condor 91:347–354.

Haug, E. A., and L. W. Oliphant. 1990. Movements, activity patterns, and habitat use of burrowing owls in Saskatchewan. Journal of Wildlife Management 54:27–35.

Howell, J. A. 1997. Avian mortality at rotor swept area equivalents, Altamont Pass and Montezuma Hills, California. Transactions of the Western Section of the Wildlife Society 33:24–29.

Johnson, B. S. 1997. Demography and population dynamics of the burrowing owl. Journal of Raptor Research 9:28–33.

Klute, D. S., L. W. Ayers, M. T. Green, W. H. Howe, S. L. Jones, J. A. Shaffer, S. R. Sheffield, and T. S. Zimmerman. 2003. Status assessment and conservation plan for the western burrowing owl in the United States. U.S. Department of Interior, Fish and Wildlife Service Biological Technical Publication FWS/BTP-R6001–2003, Washington, D.C., USA.

Lantz, S. J. 2005. Nesting ecology and habitat selection of western burrowing owls (*Athene cunicularia hypugaea*) in the Thunder Basin National Grassland, northeastern Wyoming. Thesis, University of Wyoming, Laramie, USA.

Leptich, D. J. 1994. Agricultural development and its influence on raptors in southern Idaho. Northwest Science 68:167–171.

Levey, D. J., R. S. Duncan, and C. F. Levins. 2004. Animal behaviour: use of dung as a tool by burrowing owls. Nature 431:39.

Lidicker, W. Z., Jr. 1975. The role of dispersal in the demography of small mammals. Pages 103–128 in F. B. Golley, K. Petusewicz, and L. Ryszkowski, editors. Small mammals: their productivity and population dynamics. Cambridge University Press, New York, New York, USA.

Lutz, R. S., and D. L. Plumpton. 1997. Metapopulation dynamics of a burrowing owl (*Speotyto cunicularia*) population in Colorado. Pages 255–259 in J. R. Duncan, D. H. Johnson, and T. H. Nicholls, editors. Biology and conservation of owls of the northern hemisphere. Second International Symposium, 5–9 February 1997, Winnipeg, Manitoba, Canada.

Martin, D. J. 1973. Selected aspects of burrowing owl ecology and behavior. Condor 75:446–456.

Munsters, C. J. M., M. A. W. Noordervliet, and W. J. Ter Keurs. 1996. Bird casualties caused by a wind energy project in an estuary. Bird Study 43:124–126.

Orloff, S., and A. Flannery. 1992. Wind turbine effects on avian activity, habitat use, and mortality in Altamont Pass and Solano County Wind Resource Areas: 1989–1991. Report to California Energy Commission, Sacramento, USA.

Rodriguez-Estrella, R., and A. Ortega-Rubio. 1993a. Nest site characteristics and reproductive success of burrowing owls (Strigiformes: Strigidae) in Durango, Mexico. Revista de Biologia Tropical 41:143–148.

Rodriguez-Estrella, R., and A. Ortega-Rubio. 1993b. Burrowing owls in Mapimi, Mexico. Journal of Raptor Research 27:62–63.

Rosenberg, D. K., and K. L. Haley. 2004. The ecology of burrowing owls in the agroecosystem of the Imperial Valley, California. Studies in Avian Biology 27:120–135.

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

Smallwood, K. S. 1993. Understanding ecological pattern and process by association and order. Acta Oecologica 14:443–462.

Smallwood, K. S. 1995. Scaling Swainson's hawk population density for assessing habitat-use across an agricultural landscape. Journal of Raptor Research 29:172–178.

Smallwood, K. S. 1998. On the evidence needed for listing northern

goshawks (*Accipter gentilis*) under the Endangered Species Act: a reply to Kennedy. Journal of Raptor Research 32:323–329.

Smallwood, K. S. 2002. Habitat models based on numerical comparisons. Pages 83–95 *in* J. M. Scott, P. J. Heglund, M. Morrison, M. Raphael, J. Haufler, and B. Wall, editors. Predicting species occurrences: issues of scale and accuracy. Island Press, Covelo, California, USA.

Smallwood, K. S., and W. A. Erickson. 1995. Estimating gopher populations and their abatement in forest plantations. Forest Science 41:284–296.

Smallwood, K. S., L. Rugge, S. Hoover, M. L. Morrison, and C. Thelander. 2001. Intra- and inter-turbine string comparison of fatalities to animal burrow densities at Altamont Pass. Pages 23–37 *in* S. S. Schwartz, editor. Proceedings of the National Avian–Wind Power Planning Meeting IV. RESOLVE, Inc., 16–17 May 2000, Washington, D.C., USA.

Smallwood, K. S., and C. Schonewald. 1996. Scaling population density and spatial pattern for terrestrial, mammalian carnivores. Oecologia 105: 329–335.

Smallwood, K. S., and C. Thelander. 2004. Developing methods to reduce bird mortality in the Altamont Pass Wind Resource Area. Final report to the California Energy Commission, Public Interest Energy Research— Environmental Area, Contract 500-01-019, Sacramento, USA.

Smallwood, K. S., and C. Thelander. 2005. Bird mortality at the Altamont Pass Wind Resource Area, March 1998–September 2001. Final report,

National Renewable Energy Laboratory NREL/SR-500–36973, Golden, Colorado, USA.

Smith, M. D. 2004. Function of manure-scattering behavior of burrowing owls (*Athene cunicularia*). Thesis, University of Arizona, Tucson, USA.

Teaschner, A. 2005. Burrowing owl nest site use and productivity on prairie dog colonies in the southern high plains of Texas. Thesis, Texas Tech University, Lubbock, USA.

Thelander, C. G., S. Smallwood, and L. Rugge. 2003. Bird risk behaviors and fatalities at the Altamont Pass Wind Resource Area. Period of performance: March 1998–December 2000. National Renewable Energy Laboratory NREL/SR-500–33829, U.S. Department of Commerce, National Technical Information Service, Springfield, Virginia, USA.

Thomsen, L. 1971. Behavior and ecology of burrowing owls on the Oakland Municipal Airport. Condor 73:177–92.

Trulio, L. A. 1993. Comparisons of selected aspects of burrowing owl ecology at two sites in Santa Clara County, California. Journal of Raptor Research 27:63–64.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893–901.

Wiley, J. W. 1998. Breeding-season food habits of burrowing owls (*Athene cunicularia*) in southwestern Dominican Republic. Journal of Raptor Research 32:241–245.

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