Arnold Schwarzenegger
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REPOWERING THE APWRA: FORECASTING AND MINIMIZING AVIAN MORTALITY WITHOUT SIGNIFICANT LOSS OF POWER GENERATION

PIER PRELIMINARY PROJECT REPORT

Prepared For:
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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grant Program
- Energy-Related Environmental Research
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- Renewable Energy Technologies

What follows is the final report for the Avian – Energy System Mitigation Program, Contract Number 500-01-032 conducted by K. Shawn Smallwood and Lee Neher. The report is entitled *Repowering the APWRA: Forecasting and Minimizing Avian Mortality without Significant Loss of Power Generation.* This project contributes to the PIER Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's Web site www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-4628.

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Abstract

Researchers followed up on the 2004 Energy Commission final report on bird mortality in the Altamont Pass Wind Resources Area (APWRA) by geo-referencing bird behavior data collected during 2002 and 2003, and performing spatial analysis on these data to test hypotheses that could not be tested previously. They related their 1,152 observations of raptors in flight to landscape attributes derived from a slope curvature analysis based on a digital elevation model of the landscape and ArcMap geoprocessing tools, and combined with wind directions recorded during the observation sessions. Red-tailed hawk and American kestrel flew over convex slope structures typical of ridges and hills disproportionately more often than over concave slope structures typical of valleys, ravines and basins. Red-tailed hawk, American kestrel, and golden eagle flew over windward aspects of ridges disproportionately more often than over leeward aspects, and these results include the shifting of flights over aspects of the ridges (and hills) as the wind directions shifted. Locating new or existing wind turbines on the prevailing leeward aspects of ridges and hills should result in reduced encounter frequencies between flying raptors and wind turbines. Phase II of this project is ongoing, and will compare power output and wind turbine-caused bird impacts between the wind turbine owners' preferred wind farm design after repowering and a revised design based on our knowledge of bird behaviors and mortality patterns in the APWRA. The goal is to achieve an economically viable wind farm design that also minimizes bird mortality.

1.0 INTRODUCTION

The wind turbines in the Altamont Pass Wind Resources Area (APWRA) have been killing excessive numbers of birds during its operations, which began about 20 years ago. Orloff and Flannery (1992, 1996) reported high mortality levels of raptors in the APWRA, and most recently Smallwood and Thelander (2004) reported even higher levels of mortality based on additional research following Orloff and Flannery's work. Most of the existing wind turbines were sited in the APWRA without regard to patterns of bird flights or perching, and most are mounted on short towers that position the turbine rotors at the height domains of most flights of golden eagle, red-tailed hawk, American kestrel, and the other species that are often killed by wind turbines in the APWRA.

Smallwood and Thelander collected behavior data during 2003 and 2004, and designed the study to perform spatial analysis of raptor flight heights in order to elucidate flight patterns in response to topographic features and wind conditions. The locations of flights were recorded at one-minute intervals, along with attributes of the flights, such as height above ground and specific flight behavior. One of the motivations for this new approach was the anticipated conversion of the APWRA from the existing collection of wind turbines to a new collection of modern wind turbines. This conversion has been termed '"repowering," and will replace the existing turbines with larger turbines mounted on taller towers at a ratio of about 8–10 to 1.

The repowering of the APWRA presents the opportunity to more carefully site the new turbines based on knowledge of bird flight patterns in response to topography and wind patterns. It is our objective to add to this knowledge and to support repowering efforts that substantially reduce avian mortality, especially raptor mortality. This project was made possible by the principal investigator's access to the geographic information system (GIS), additional spatial data, and GIS specialists in the Lawrence Livermore National Lab.

Subsequent to the analyses of bird flight patterns in the APWRA, we will pursue the main study goal. The study goal is to forecast avian mortality in the repowered APWRA under two scenarios (additional scenarios could be forecast later should the stakeholders show interest in doing so). **Scenario One** would consist of the repowered APWRA according to the 1998 environmental impact report (EIR) and any additional new planning documentation, and will be called the **Power Maximizing (P-max) Scenario**. We will forecast mortalities of golden eagle, red-tailed hawk, and American kestrel due to the flight behaviors recorded during the recently concluded study in the APWRA, and due to the attributes of the proposed new wind turbines and their spatial locations and arrangements in the repowered APWRA.

Scenario Two includes the same number and type of wind turbines as proposed in the 1998 repowering EIR and whatever updates the wind turbine owners would prefer to provide, but arranged within the boundary of the APWRA in a manner that a careful examination of the bird behavior data suggests would minimize avian mortality, and based on the results of the fatality associations identified by Smallwood and Thelander (2004). This scenario will be called the **Bird Fatality Minimizing Scenario (F-min)**. **F-min** will include clumping of wind turbines into higher density turbine fields to the extent possible, as well as exclusion of wind turbines from saddles in ridges and ridgelines leading into major drainages. It will include minimized exposure of birds to isolated wind turbines and edge turbines, such as wind turbines on the ends of rows.

F-min will likely lead to somewhat less power generation than will **P-max,** because some of the sites excluded to minimize mortality are also high-energy micro-sites for power generation. Nevertheless we suspect that forecasts for **F-min** will indicate a much-reduced ratio of bird deaths to megawatts of power output and that forecasts for **P-max** would indicate a reduced ratio of mortality to power output compared to the output currently experienced in the APWRA.

2.0 METHODS

This study is being performed using behavior data collected during the study of avian mortality in the APWRA, which was funded by the California Energy Commission's Public Interest Energy Research (PIER) program. The following methods describe how behavior data were collected during that study.

Two biologists collected bird behavior data within 60 observation plots (hereinafter referred to as OPs) during 15 October 2002 through 14 May 2003. The study plot boundaries encompassed wind turbines easily visible to the observers from a fixed observation point, resulting in a mosaic of contiguous plots. These 61 plots covered all of the area studied during the behavior research performed under funding from the National Renewable Energy Laboratory (Smallwood and Thelander, In review), and included our longest time spans of fatality searches.

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

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

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

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

In addition to the data collected each minute, we also recorded particular behavioral events whenever they occurred during the session. For example, we recorded observations of birds flying through the string of wind turbines, and when birds landed or interacted with others. We also made records whenever birds entered or exited the sampling area. For each record, we reported the species, flight, or perch behavior (Table 1), height above ground, and location on the maps we carried.

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

Using ArcMap GIS and geo-referenced aerial imagery available at Lawrence Livermore National Lab (LLNL), we digitized the locations of recorded bird observations. All of the attributes of each bird observation were then geo-referenced to the coverages of the APWRA landscape created by LLNL.

The location of each recorded bird observation was characterized by slope aspect, slope grade, rate of change in slope, direction of change in slope, and elevation. Slope aspect was classified as facing north, northeast, east, southeast, south, southwest, west, northwest, or located in a valley. For analysis we aggregated slope aspect into five categories: (1) northeast and east, (2) southeast and south, (3) southwest and west, (4) northwest and north, and (5) no aspect (flat terrain). For analysis, slope grade and elevation were lumped into ranges of values with fairly even distributions of wind turbine frequencies.

Table 1. Flight behaviors recorded during 30-minute observation sessions in the study plots.

Flight Behavior
1. Fly through
2. Gliding
3. Soaring
4. High soaring
5. Contouring
6. Circling
7. Kiting/hovering
8. Diving
9. Mobbing/chase
10. Mobbed
11. Soaring column
12. Surfing
13. Ground hopping
14. Fly-catching
15. Fleeing
16. Interacting
17. Flocking
18. Flushed
19. Land
20. Mating

These same variables were used to generate raster layers covering the study area; one raster expressing slope aspect, and the other expressing whether the landscape feature was trending toward convex versus concave orientation. These features were defined using geoprocessing at LLNL.

We used the existing USGS 10-m digital elevation model (DEM) as a starting point for characterizing the terrain of the Altamont Pass. This data set included some poor quality data, affecting about 25% of our study area. To replace these data, we used geo-referenced USGS 7.5′

digital raster[1] graphics (DRG) with GIS to capture the contour lines (hypsography). These contour vectors were then run through ESRI's Topograph tool to create a 10-m DEM, which was inserted into the existing USGS 10-m DEM.

From the final DEM of the Altamont Pass region, we limited (masked) the statistical analysis to data within 300 m of the wind turbines included in behavior observation plots. The resulting analytical grid was composed of 316,488 10 x 10-m cells.

We then used ESRI's Curvature function in the Spatial Analysis extension of ArcGIS to calculate the curvature of a surface at each cell center (Figures 1 and 2). A positive curvature indicates that the surface is upwardly convex at that cell, a negative curvature indicates that the surface is upwardly concave, and a value of zero indicates that the cell surface is flat. We classified the curvature data (-51 to 38) using the NaturalBreaks (Jenks) function with three classes of curvature – convex, concave, and mid-range. We then adjusted the break values through visual inspection to minimize the size of the mid-range class. We applied a series of geoprocessing steps using expand, shrink, regiongroup, and majority filter tools to enhance the primary slope curvature trend of a location. The end result was a surface that was almost exclusively defined as either convex or concave (Figure 3). The convex surface areas were composed primarily of ridge crests and peaks (hereafter referred to as *ridges*), and the concave surface areas were composed primarily of valleys, ravines, ridge saddles, and basins (hereafter referred to as *valleys*).

Each recorded raptor flight was categorized as occurring on the windward, leeward, or perpendicular-to-wind aspects of ridges. This categorization was performed after relating raptor flight locations to the derived coverage of ridges and valleys and factoring in the wind direction recorded during the associated behavior session. The observed frequencies of raptor flights on windward, leeward, and perpendicular-to-wind aspects of ridges were related to expected frequencies for chi-square analysis.

Expected values were calculated as the total number of flights recorded for a taxon (N) multiplied by the proportion of grid cells composing the windward, leeward, or perpendicular-to-wind aspects of ridges across all 240 behavior observation sessions (P_i):

Expected = $N*P_i$.

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[1] A raster is a grid, and is composed of equal-sized grid cells.

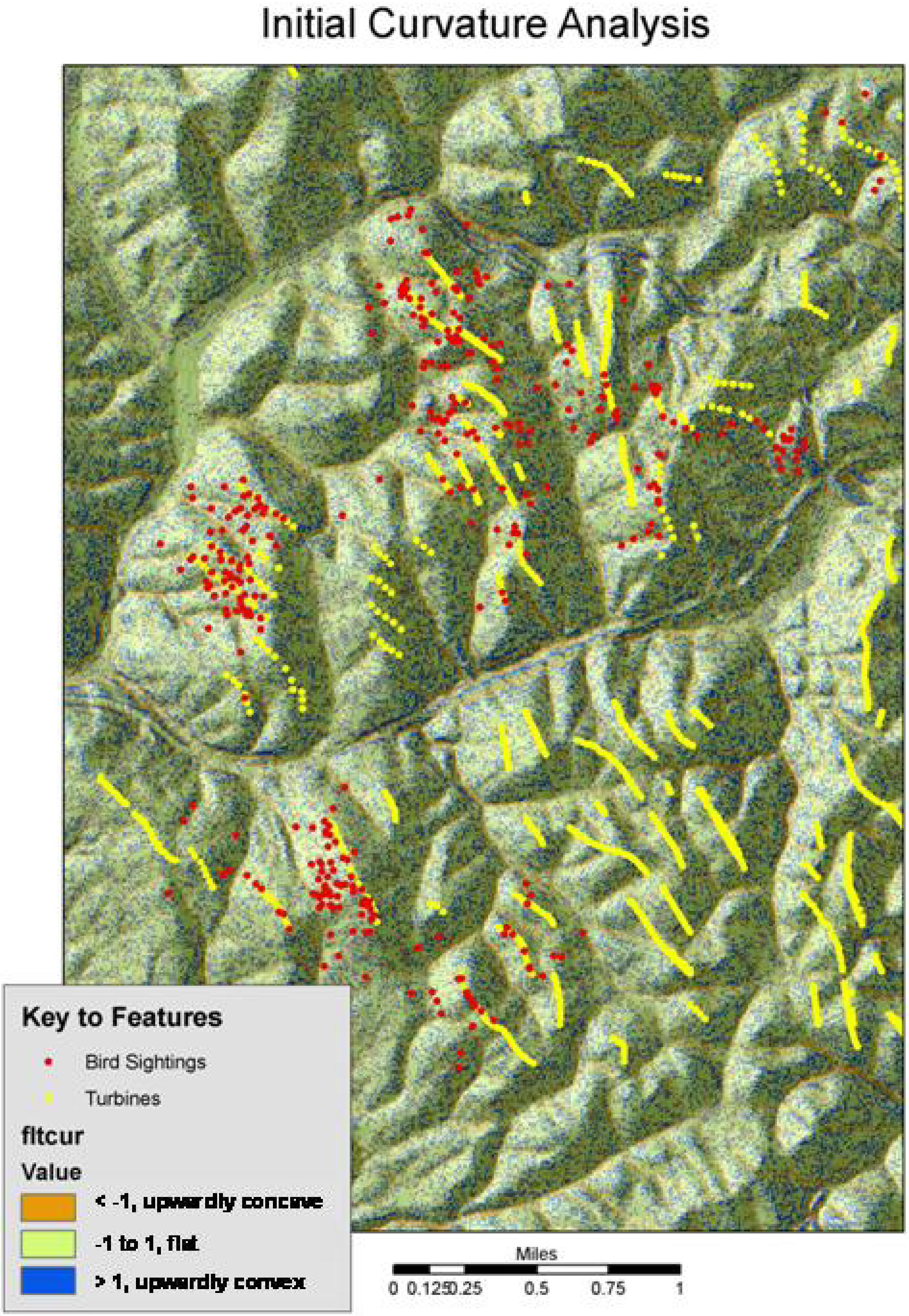

Figure 1. A portion of the APWRA landscape categorized into concave and convex slopes, as well as slopes intermediate between convex and concave orientations, following our use of the Jenks function to identify natural breaks in the frequency distribution of curvature values

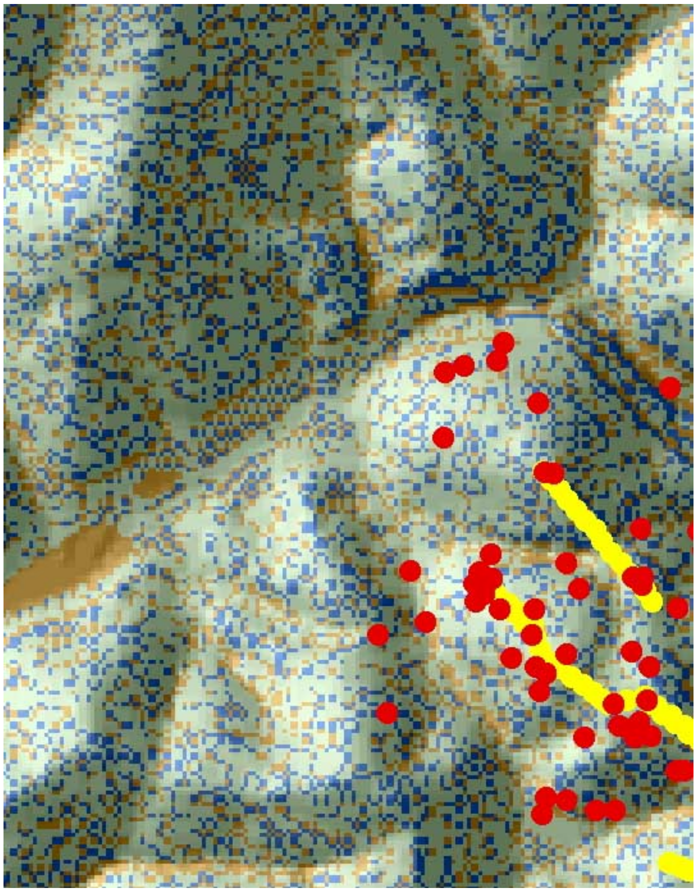

Figure 2. A zoomed-in view of the same portion of the APWRA landscape as that in Figure 1, revealing the 10 x 10-m resolution of the raster (grid)

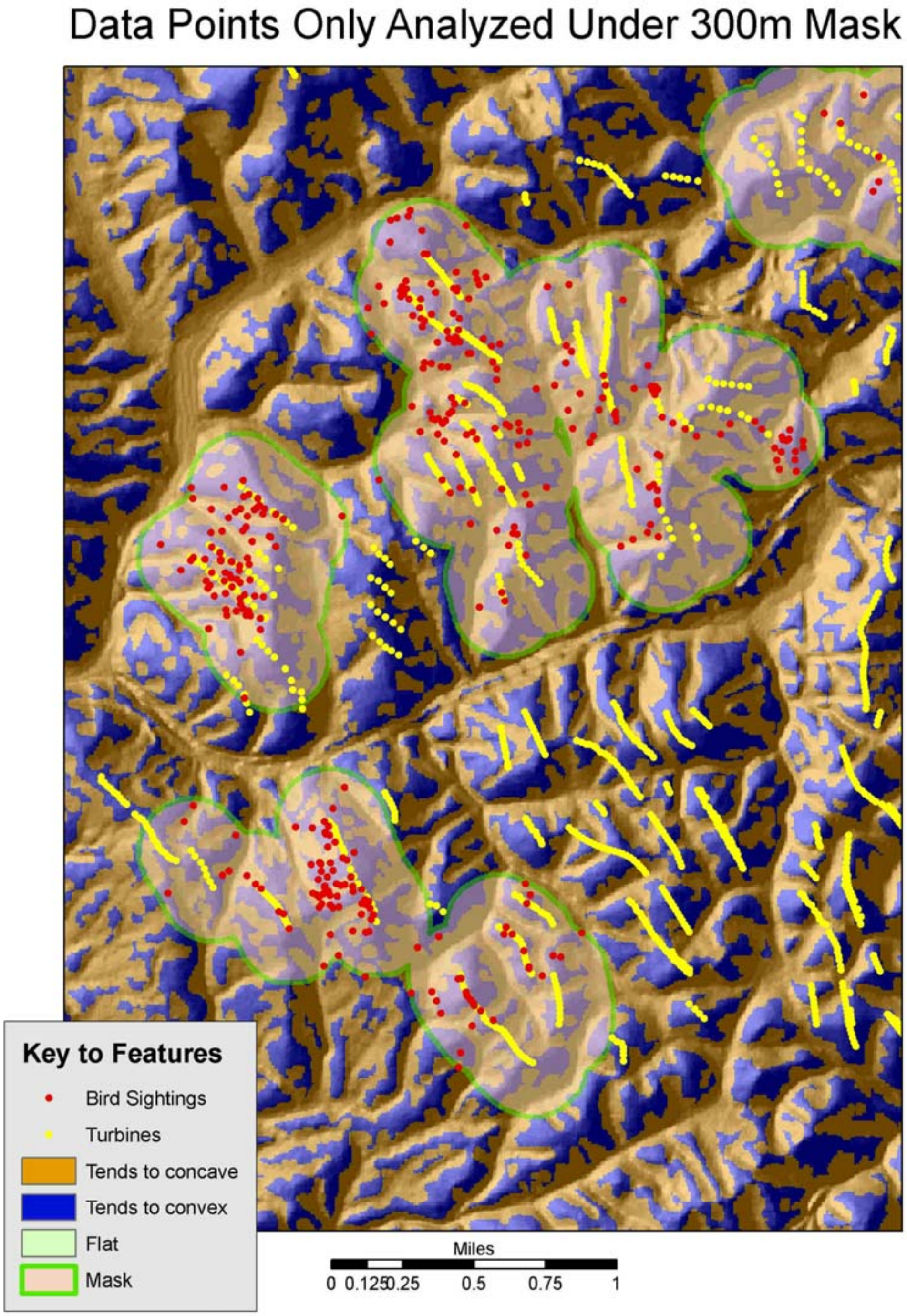

Figure 3. A portion of the APWRA landscape categorized into ridge versus valley features. The blue polygons indicate a tendency toward convex orientation typical of ridges and peaks; whereas, the gold matrix indicates a tendency toward concave orientation typical of valleys, saddles, ravines, and basins.

The number of grid cells composing the windward side during an observation session included the cells representing the slope aspect directly facing the oncoming wind, as well as the immediately adjacent slope aspects. For example, if the wind originated from the northwest during session X, then northwest slopes were considered windward, as were the west-facing and north-facing slopes. The opposite slopes were categorized as leeward, so in the case of our example, the leeward slopes were east-, southeast-, and south-facing slopes. Slopes perpendicular to the wind were the remaining two slope aspects, and in the case of the example, these would be southwest and northeast slopes. The numbers of grid cells composing the windward, leeward, and perpendicular-to-wind aspects of ridges were then multiplied by the frequencies of wind directions experienced during the 240 behavior observation sessions to arrive at the proportions of the grid representing windward, leeward, and perpendicular-to-wind aspects of ridges.

Response variables were tested for associations with other measured variables in chi-square analysis, for which expected cell values were calculated in the manner just described (Smallwood 1993, 2002). Statistical tests were performed only for the most commonly observed raptor species, because the results of tests involving small sample sizes are unreliable. These *target* species included red-tailed hawk, American kestrel, and golden eagle, though northern harrier and turkey vulture were included as well, for the sake of comparing associations for the target species to species infrequently killed by wind turbines in the APWRA.

Chi-square tests were performed across all plots in the study area, because every plot was sampled equally. Observed values were the number of flight observations (n_i), and were related to expected values for both statistical hypothesis testing and for deriving a measure of effect to be used in extrapolating the resulting patterns across the rest of the APWRA.

2.1. Measure of Effect

Examination of test results will also utilize a measure of effect—the observed–divided-by-expected frequency of a particular behavior of a particular taxon at the level or category of a measured association variable, where the expected frequency of the behavior at that level or category will be the frequency that would have resulted from a uniform or random distribution of that behavior throughout the measured set.

3.0 PRELIMINARY RESULTS

The behavior study in the APWRA that was funded by the California Energy Commission yielded 4,691 raptor observation records after 240 sessions (Smallwood and Thelander 2004). Of these records, 1,152 were of raptors in flight. After geo-referencing each of these, we obtained the ground elevation under each, as well as the elevation of the bird in flight, the difference between these elevations being the observer's estimated height of the bird above ground while flying (Figures 4 through 8). By comparing flight locations to our DEM of the landscape, we derived the aspect of the slope over which the bird was flying, as well as the slope grade, the curvature of the slope, and the direction of the slope curvature. We also characterized the topographic feature over which the bird was observed flying, and whether the flight was on the windward, leeward, or perpendicular-to-wind aspects of ridges.

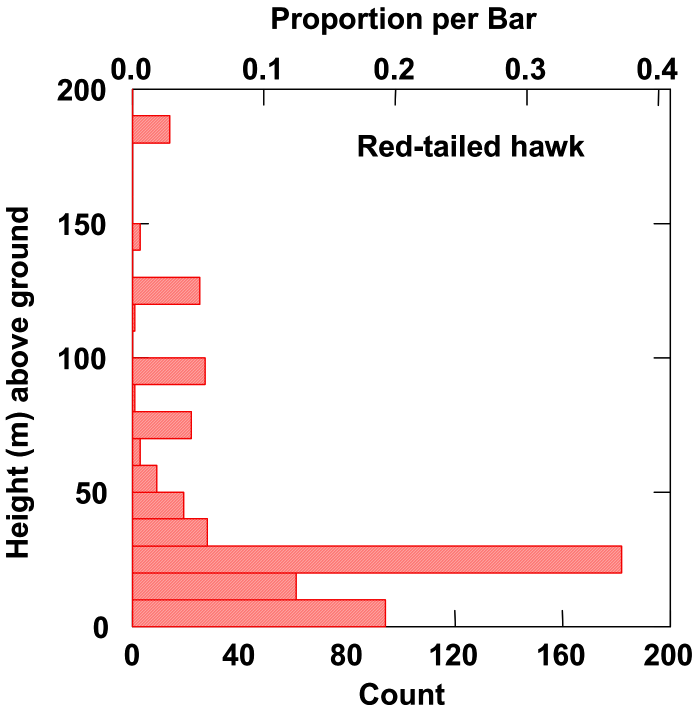

Figure 4. Distribution of flight heights above ground level among red-tailed hawks observed during behavioral observation sessions during 2003 and 2004 in the APWRA

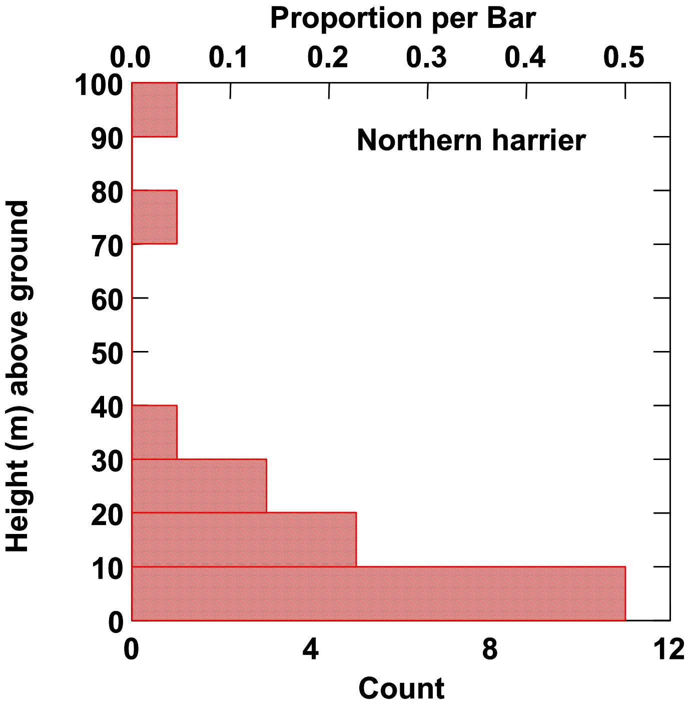

Figure 5. Distribution of flight heights above ground level among northern harriers observed during behavioral observation sessions during 2003 and 2004 in the APWRA

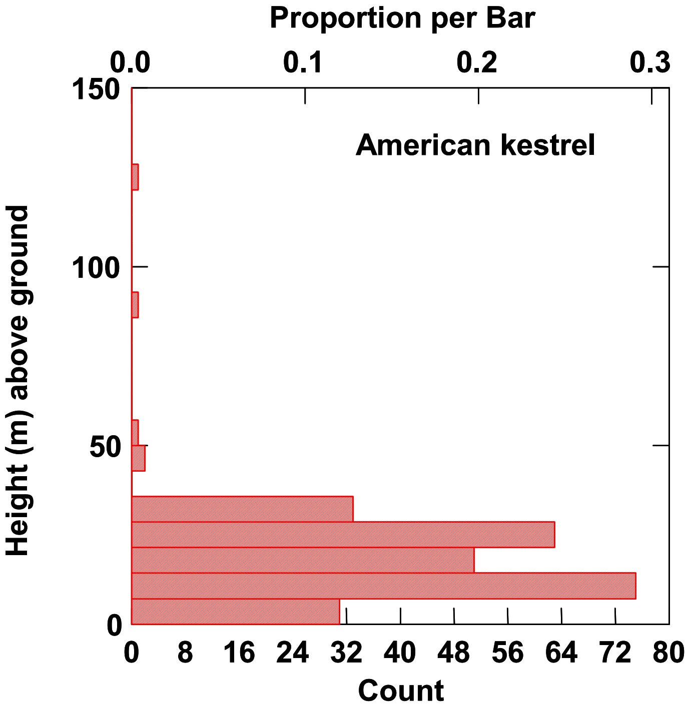

Figure 6. Distribution of flight heights above ground level among American kestrels observed during behavioral observation sessions during 2003 and 2004 in the APWRA

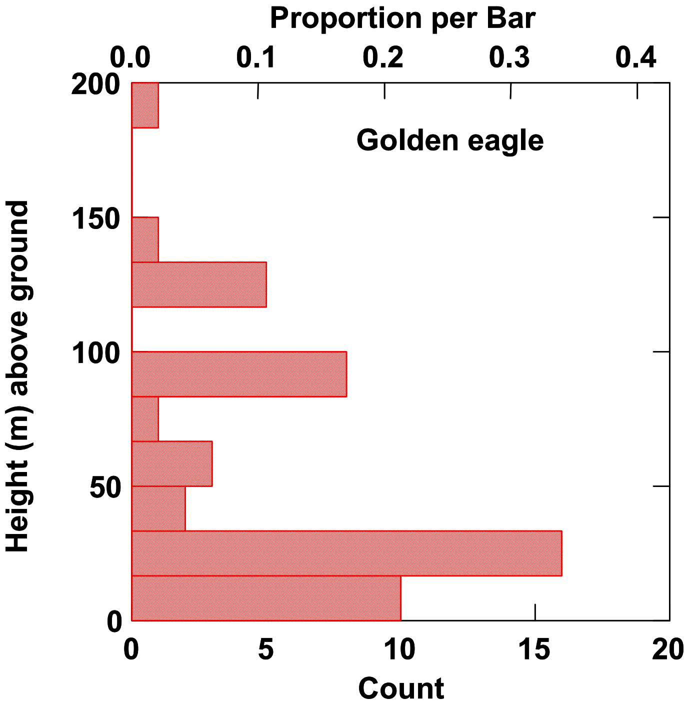

Figure 7. Distribution of flight heights above ground level among golden eagles observed during behavioral observation sessions during 2003 and 2004 in the APWRA

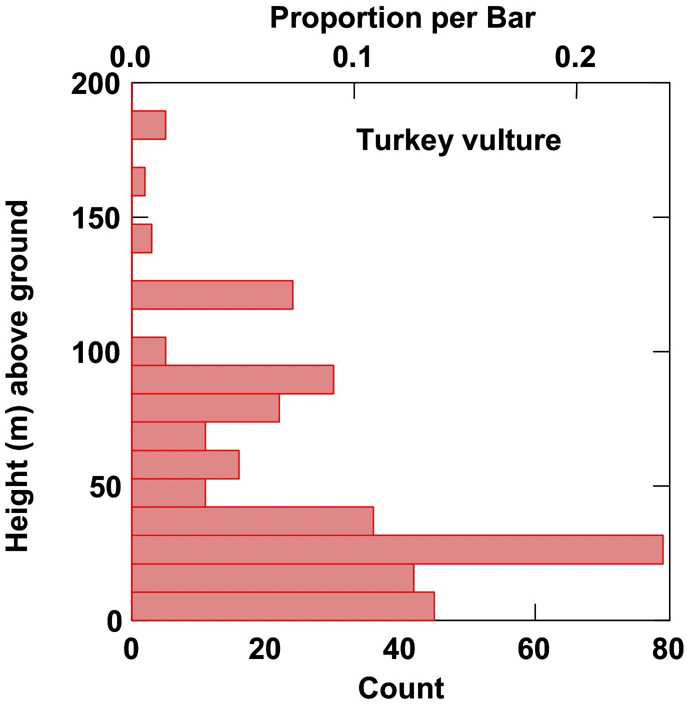

Figure 8. Distribution of flight heights above ground level among turkey vultures observed during behavioral observation sessions during 2003 and 2004 in the APWRA

Our derived coverage of the topography indicated that 37.057% of the study area was composed of convex (ridge) features, and the remaining 62.943% was composed of concave-trending features (valleys). Table 2 summarizes tests for association between raptor flights and underlying topographic feature. Red-tailed hawks and American kestrels disproportionately flew over convex slopes typical of ridge structures; whereas, northern harrier, golden eagle, and turkey vulture were not associated with whether the underlying features were dominated by upwardly concave slopes (Table 2).

Our derived coverage of the topography indicated that 0.94% of the study area was composed of flat features with no slope orientation; the largest proportions of the study area faced north, northeast, and east; and the smallest proportions faced south, southwest, and west (Figure 9). Red-tailed hawks flew disproportionately more often over northwest- and west-facing slopes and disproportionately least often over east and southeast slopes (Table 3). American kestrels flew disproportionately more often over flat terrain, followed by northwest- and west-facing slopes, and disproportionately least often over south and east slopes. Golden eagle flew over flat terrain nearly 7 times more often than expected by chance, and otherwise favored west- and south-facing slopes, and most strongly avoided southwest and east slopes. Turkey vultures flew disproportionately over flat terrain, and southwest south slopes, and least often over southeast, east and northeast slopes. No association between flights of northern harrier and slope aspect could be identified.

Table 2. Summary of chi-square tests for association between the observed number of flights and the underlying topography. Observed-divided-by-expected values express the number of times fewer or greater than the expected number of flights over ridges or valleys than would be expected by a uniform (or random) distribution of flights in the study area. Chi-square values accompanied by * indicate the test of association was significant at an α-level of 0.05, and ** indicate significance at an α-level of 0.005.

Taxon / Topographic feature	Observed	Expected	Observed ÷ Expected	Chi-square value
Red-tailed hawk				
Ridges	231	181.2	1.27	
Valleys	258	307.8	0.84	21.73**
Northern harrier				
Ridges	6	8.1	0.74	
Valleys	16	13.9	1.15	0.86
American kestrel				
Ridges	129	95.6	1.35	
Valleys	129	162.4	0.79	18.54**
Golden eagle				
Ridges	17	17.4	0.98	
Valleys	30	29.6	1.01	~0
Turkey vulture				
Ridges	122	122.7	0.99	
Valleys	209	208.3	1.00	~0

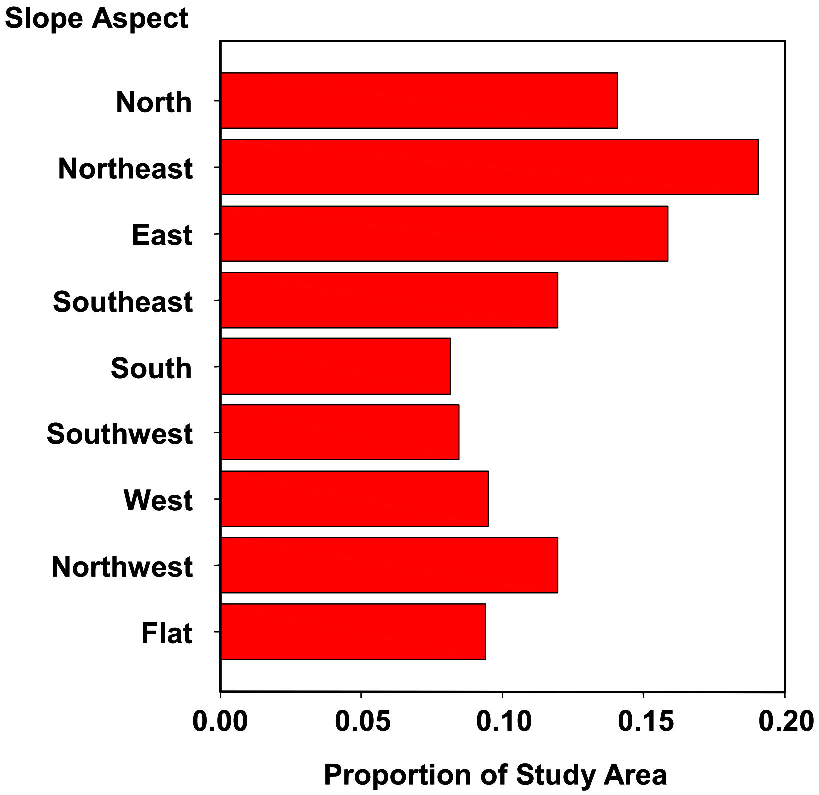

Figure 9. Distribution of slope aspects throughout the study area

Table 3. Summary of chi-square tests for association between the observed number of flights and the underlying slope aspect. Observed-divided-by-expected values express the number of times fewer or greater than the expected number of flights over each slope aspect than would be expected by a uniform (or random) distribution of flights in the study area. Chi-square values accompanied by * indicate the test of association was significant at an α-level of 0.05, and ** indicate significance at an α-level of 0.005.

Taxon / Topographic feature	Observed	Expected	Observed ÷ Expected	Chi-square value
Red-tailed hawk				
Flat	3	4.6	0.65	
North	53	68.9	0.77	
Northeast	76	93.2	0.82	
East	51	77.6	0.66	
Southeast	42	58.5	0.72	
South	39	39.9	0.98	
Southwest	37	41.4	0.89	
West	82	46.5	1.76	
Northwest	106	58.5	1.81	87.38**
Northern harrier				
Flat	0	0.2	0.00	
North	5	3.1	1.61	
Northeast	5	4.2	1.19	
East	1	3.5	0.29	
Southeast	1	2.6	0.38	
South	0	1.8	0.00	
Southwest	1	1.9	0.54	
West	5	2.1	2.39	
Northwest	4	2.6	1.52	11.26
American kestrel				
Flat	9	2.4	3.72	
North	27	36.3	0.74	
Northeast	39	49.2	0.79	
East	28	41.0	0.68	
Southeast	25	30.9	0.81	
South	11	21.0	0.52	
Southwest	24	21.8	1.10	
West	49	24.5	2.00	
Northwest	46	30.8	1.49	64.44**
Golden eagle				
Flat	3	0.4	6.81	
North	6	6.6	0.91	
Northeast	8	9.0	0.89	
East	5	7.5	0.67	
Southeast	6	5.6	1.07	
South	5	3.8	1.31	
Southwest	2	4.0	0.50	
West	7	4.5	1.57	
Northwest	5	5.6	0.89	18.69*

Table 3. (continued)

Taxon / Topographic feature	Observed	Expected	Observed ÷ Expected	Chi-square value
Turkey vulture				
Flat	6	3.1	1.93	
North	52	46.6	1.12	
Northeast	47	63.1	0.74	
East	40	52.5	0.76	
Southeast	27	39.6	0.68	
South	35	27.0	1.30	
Southwest	42	28.0	1.50	
West	36	31.5	1.14	
Northwest	46	39.6	1.16	25.49**

Factoring in both the number of DEM grid cells composing each slope aspect and the number of sessions when winds were recorded originating from each direction, the composite windward landscape features of the study area comprised 35.76% of the study area, leeward features comprised 38.61% of the area, features perpendicular to the wind comprised 24.69% of the area, and flat features comprised 0.94% of the area. Red-tailed hawks, Northern harriers, American kestrels, and golden eagles flew about twice as often on the windward aspect of ridges, and red-tailed hawks, American kestrels, and golden eagles flew significantly disproportionately more often on the windward sides of ridges (Table 4). Golden eagles were seen flying disproportionately more often over landscape features that were oriented perpendicular to the wind.

Table 4. Summary of chi-square tests for association between the observed number of flights and the aspect of the nearest ridge structure with respect to wind direction. The undefined category was omitted because it includes mostly sessions when there were no winds, so flights during these conditions were not likely to result in collisions with turbine blades. Observed-divided-by-expected values express the number of times fewer or greater than the expected number of flights over each ridge aspect than would be expected by a uniform (or random) distribution of flights in the study area. Chi-square values accompanied by ^{t} indicate the test of association tended toward significance with the P-value between 0.05 and 0.10, * indicate the test of association was significant at an α-level of 0.05, and ** indicate significance at an α-level of 0.005.

Taxon / Aspect of Ridge	Observed	Expected	Observed ÷ Expected	Chi-square value
Red-tailed hawk				
Windward	233	163.1	1.43	
Leeward	109	176.1	0.62	
Perpendicular	114	112.6	1.01	55.55**
Northern harrier				
Windward	12	7.9	1.53	
Leeward	6	8.5	0.71	
Perpendicular	4	5.4	0.74	3.28
American kestrel				
Windward	110	77.2	1.42	
Leeward	60	83.4	0.72	
Perpendicular	46	53.3	0.86	21.46**
Golden eagle				
Windward	17	13.9	1.22	
Leeward	8	15.1	0.53	
Perpendicular	14	9.6	1.45	5.96 ^{t}
Turkey vulture				
Windward	119	116.2	1.02	
Leeward	122	125.5	0.97	
Perpendicular	84	80.2	1.05	0.34

3.1. Flight Heights

Flight heights did not correlate significantly with slope grade or elevation at ground level for any of the raptor species. For red-tailed hawks, flights were higher on average over north- and southeast-facing slopes (Figure 10). Turkey vultures tended to fly lowest over south-facing slopes (Figure 11), but flight heights of other target species did not relate significantly to slope aspect.

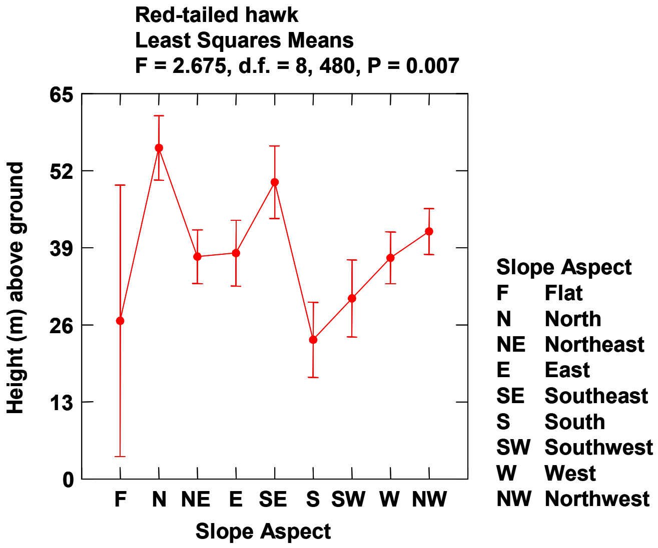

Figure 10. Mean flight heights of red-tailed hawk over slopes of different aspects

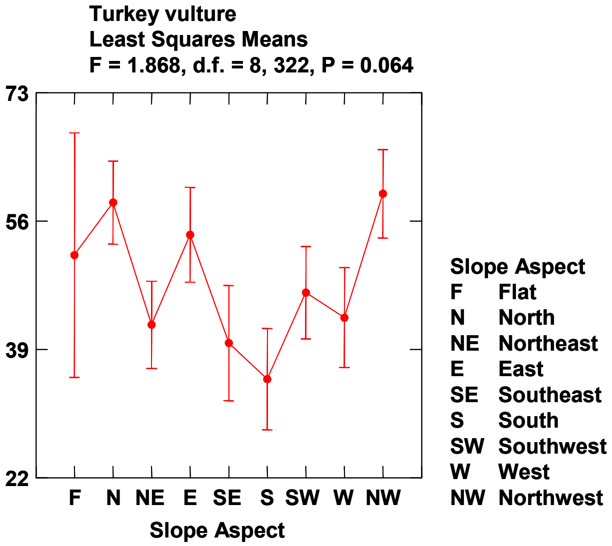

Figure 11. Mean flight heights of turkey vulture over slopes of different aspects

Red-tailed hawk tended to fly highest over the windward sides of ridges, lower on the leeward sides, and lowest over flat areas and when there were no winds (Figure 12). Flight heights of other target species did not relate significantly to ridge aspect, relative to oncoming winds.

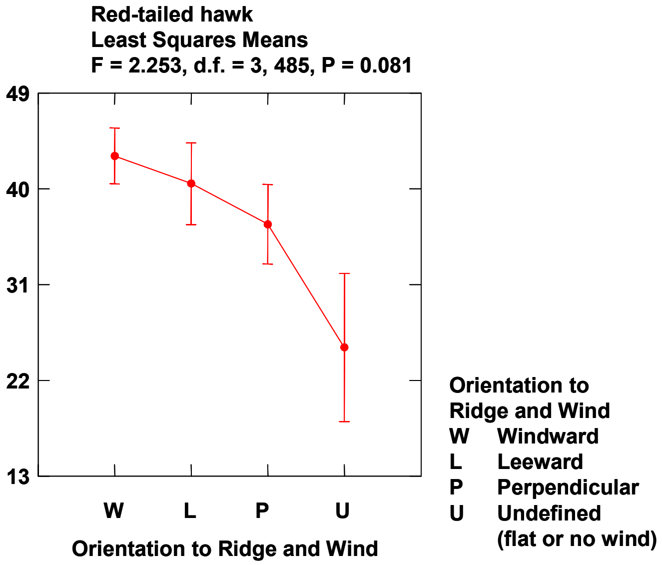

Figure 12. Mean flight heights of red-tailed hawk over aspect of ridge relative to oncoming winds

4.0 DISCUSSION

Tests for association between frequencies of raptor flights and convex versus concave slope orientations were significant but not very strong. Associations were stronger for slope aspect, but the most elegant and biologically meaningful associations were those between frequencies of raptor flights and their locations relative to orientation of oncoming winds to the convex slope features. These latter associations suggest raptors adjust their flight patterns to capitalize on the direction the wind is blowing, perhaps to optimize energy allocated to their flights and/or to position themselves for utilizing the winds to make controlled flights when attacking prey. For the next phase of this study, we will attribute the landscape by prevailing windward, prevailing leeward and prevailing perpendicular aspect of the slope relative to winds, and we will use these landscape features for assessing their suitability as wind turbine sites.

We gained considerable insight from our spatial analysis of raptor flight patterns even though our sample size of bird observations was smaller than we preferred and our study period did not encompass all the seasons of the year. This insight should facilitate the effectiveness of the repowering programs in minimizing and reducing raptor mortality caused by wind turbines. Already, the Buena Vista Wind Energy Project EIR proposes to site the new wind turbines on the prevailing leeward sides of ridges, where feasible. Our study results indicate that wind turbines sited on the leeward side of ridges, based on prevailing wind directions, should expose the rotor planes of operating turbines to raptors about half as frequently as the current exposure rates due to this factor alone. Factoring in the increased tower heights and avoidance of low-lying portions of the project area should further reduce the exposure of the rotor planes to raptors.

The geo-processing steps that were undertaken in this study are readily applicable to any wind farm in the United States. These steps, combined with pre-construction bird behavior observations based on our methodology, can lead to forecasts of rotor plane exposure rates to birds. From these forecasts, Richard Podolsky's Avian Risk of Collision (ARC) model can estimate a bird's risk of collision while it is using the wind farm.

However, the accuracy of our forecasts will not be known until repowering is completed and monitoring of bird flights and fatalities is performed over several years post-construction. Surprising changes in bird behavior have been noted in wind farms, such as American kestrels perching atop 100-m towers in the High Winds Energy Project in Solano County, California (unpublished data), and such as several raptor species flying within 50 m of existing wind turbines in the APWRA multiple times more often than expected by chance. The type and arrangement of wind turbines in the repowered portions of the APWRA could possibly alter behaviors and result in unexpected mortality levels for certain species, so our forecasts will require monitoring and validation.

The Power Maximizing and Bird Impact Minimizing scenarios for the APWRA repowering projects will be assessed during the next phase of this project.

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