PARTIAL RE-ASSESSMENT OF AN ADAPTIVE MANAGEMENT PLAN FOR THE APWRA: ACCOUNTING FOR TURBINE SIZE

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Smallwood and Spiegel (2005) provided an assessment of key mitigation measures proposed by WEST, Inc. on behalf of the wind turbine owners in the Altamont Pass Wind Resources Area (APWRA). That assessment of the selective turbine removal relied on significant associations between fatalities and measured environmental variables, as reported in Smallwood and Thelander (2004) and Smallwood and Neher (2005). WEST, Inc. suggested the wind turbines recommended for removal/relocation by Smallwood and Spiegel (2005) included a disproportionately large number of large wind turbines, and that the tests for association in Smallwood and Thelander (2004) should be performed again, this time including rotor swept area in the sampling effort term. We concurred that incorporating turbine size into the sampling effort term might result in different associations, and a different distribution of wind turbines in the top tiers of priority candidates for shutdown/relocation. Seawest then requested that we explore whether including turbine size will result in a more equitable distribution of wind turbines recommended for selective shutdown/relocation. This staff report summarizes our effort to this effect.

Adjusting the ratings of collision threat among wind turbines by their sizes did not change which turbines were predicted to be the most dangerous in the APWRA, when the predictions were based on the tests of association. By including turbine size in the tests for association between turbine-caused fatalities and measured variables, we changed the associations with turbine attributes but not the associations with environmental variables. It was the environmental variables, including attributes of the spatial distribution of wind turbines, that most influenced the original ratings of collision threat in Smallwood and Spiegel (2005), and remained so this time. In order to factor in turbine size effectively we needed to do so after the ratings of collision threat were developed, and not before. This staff report presents new ratings based on incorporation of turbine size both at the front and tail ends of the development of our rating system for collision threat.

Using turbine size-adjusted ratings of collision threat posed by wind turbines, a permanent shut down of 3.5% of the turbines could lead to fatality reductions of the four focal raptor species from 4% to 19% depending on the species and a 12% reduction in overall raptor fatalities at a cost of 15.3 MW of rated capacity APWRA-wide. A 10.3% shut down could lead to 21% to 44% reductions of the focal raptor species and a 31% reduction of all raptor fatalities at a cost of 29.6 MW. An 18.8% shutdown of selective turbines could reduce fatalities by 40% to 57% for the focal raptor species and 46% for all raptors together at a cost of 37.3 MW. Our new assessment performed as efficiently as our original, but selected mostly small wind turbines and left the larger turbines in lower tiers of priority for shutdown or relocation.

A combination of permanent and seasonal shutdowns will result in a reduction of fatalities somewhat less than a strictly permanent shutdown provided that the seasonal shutdown covers a suitable timeframe during the most dangerous season. A longer seasonal shutdown of relatively more dangerous turbines will have a greater effect than a short-term shutdown of half of the entire set of turbines, particularly if combined with other mitigation measures. Turbines not selected for permanent shut down and occurring within the top three tiers of priority are the strongest candidates for effective seasonal shut down, and there may be some turbines in tier 4 that could also be shut down seasonally with greater affect, based on their locations relative to other wind turbines. Given that only 82.2 MW of turbines compose Tiers 1 through 3, this alternative may, in fact, be more financially appealing to the owners than the latter.

While all predictive models in ecology are imperfect, we believe this analysis provides a scientifically sound basis for guiding selective permanent shutdown of turbines for the purpose of reducing avian mortality at the APWRA. The data used in this analysis are the most extensive collected in the APWRA, and are focused on identifying causal factors of avian mortality. Wind turbine operators who find this measure of reducing fatalities inequitable could implement a smaller scale of shutdown combined with aggressive practices of land management, such as reduced grazing near turbines. We emphasize, however, that mitigation must be implemented on a scale large enough to demonstrate an effect toward accomplishing acceptably stated goals. CEC staff will continue to provide analyses and technical guidance, as requested and deemed appropriate, on how best to design and implement such efforts.

Accounting for Turbine Size in a Second Analysis of Fatality Associations

In order to account for wind turbine size, as requested by WEST, Inc. and Seawest, we performed a second set of tests for association between fatalities and measured environmental variables in the APWRA. In this second set, we included rotor-swept area (m^2) in our fatality search effort term:

$$\text{Fatality Search Effort} = (Y_t \times R_t) \div \Sigma\,(Y_t \times R_t),$$

and,

$$\text{Incidence, } P_i = \Sigma\,(\text{Fatality Search Effort of all wind turbines composing element } i),$$

and then,

$$\text{Expected} = N \times P_i,$$

where Y_t is the number of years during which fatality searches were performed at a given wind turbine, R_t is the rotor-swept area of the wind turbine, and N represents the total number of fatalities compared within the measured set of environmental elements.

In-depth examination of test results was based on two measures of effect. The first was the observed divided by expected values, which measures the number of fatalities at that element of the measured set as a multiple of what would be expected from a uniform or random distribution of fatalities throughout the measured set. The second was the percentage of total fatalities that can be attributed to the variable's attribute in question, and is measured as the following:

$$\text{Accountable Mortality} = (\text{Observed} - \text{Expected}) \div \text{Total fatalities} \times 100\%.$$

The accountable mortality metric ranged from -100 to 100% of the fatalities attributable to a particular category of an association variable. A value of zero indicates observed fatalities were equal to the expected number of fatalities based on random or uniform distribution of fatalities among levels or values of the association variable. Positive values express the percent of the total fatalities killed at wind turbines and which can be attributed to the associated environmental element or turbine attribute. Negative values express the percent of the total number killed that should have been killed based on a random or uniform distribution of fatalities among the levels or values of the association variable, but were not killed.

Appendix A includes the detailed results from this second set of tests for association. Tables 1 through 4 summarize the largest measures of effect from the significant test results. Differences in results for golden eagle are summarized below by association variable, as examples of the sorts of shifts in results we observed.

The observed/expected number of golden eagle fatalities originally attributed to the Howden turbines decreased substantially between the original and our second analysis, whereas the accountable mortality value did not. The accountable mortality of KCS56-100 turbines doubled, however. Other turbine attributes, each related to turbine model, shifted in their measures of effect similarly.

The observed/expected number of golden eagle fatalities originally attributed to lattice towers did not change after the second analysis, but accountable mortality increased from 1 to 7%. Measures of effect did not change much for tower height, rotor orientation to wind, blade color scheme, perch guards, whether next to derelict turbines, heights of the blade reach, whether in a wind wall, position in the turbine string, location in the wind farm, number of wind turbines within 300 meters, elevation of the tower base, slope grade, topographic relief, whether in a canyon, slope index, edge index at the tower base, number of rock piles nearby, level of rodent control, number of cattle pats, abundance of cottontail pellets, vegetation height, clustering and density of small mammal burrow systems, or season of the year. The environmental variables largely remained unchanged in their measures of effect and test results between analyses, meaning the inclusion of turbine size in the sampling effort term would not greatly effect the predictive models of collision threat to golden eagles.

Similar patterns were observed for the other focal species. Incorporating turbine size into the sampling effort term did not change the ratings of collision threat because most of the contributing association variables were environmental variables and not turbine attributes. If turbine size is to be considered in an effort to more equitably select turbines for shutdown or removal, then it will need to be incorporated in a later step during the development of the rating system. We take this approach later in this assessment.

Table 1. The directions and magnitudes of the associations between wind turbine-caused golden eagle fatalities and levels within independent variables, taking rotor swept are into account. The measure of effect used in the right column is accountable mortality. The left column identifies the relationships selected for use in the rating system.

Selected	Variable	Magnitude of increase in mortality
	Tower height	26% at turbines on 18.5-m towers
Yes	Low blade reach	25% at turbines with blades 8 to 9.6 m above ground
	High blade reach	24% at turbines with highest blade reach ≤ 27.4 m from ground
	Rotor orientation	22% facing away from wind (KCS-56 turbine)
Yes	Wind wall	11% outside wind walls
Yes	Position in turbine string	16% at the string end
Yes	Location in wind farm	11% at local cluster of turbines
Yes	Wind turbine congestion	16% at turbines with ≤24 other turbines within 300 m
Yes	Physical relief	21% on ridgeline
Yes	Slope grade	10% on slopes >14 degrees
Yes	Whether in canyon	9% in canyon
Yes	Aspect of ridge to wind	14% on slopes windward to 1 prevailing direction (NW or SW), and perpendicular to the other (2)
	Edge index at tower base	26% at turbines with lots of vertical and/or lateral edge (3)
	Rodent control	17% in areas with no control
	Pocket gopher density	30% at turbines with >3.5 gopher burrows/ha within 90 m
	Density of all mammals	33% at turbines with ≥5 burrow systems/ha within 90 m

Table 2. The directions and magnitudes of the associations between wind turbine-caused red-tailed hawk fatalities and levels within independent variables, taking rotor swept are into account. The measure of effect used in the right column is accountable mortality. The left column identifies the relationships selected for use in the rating system.

Selected	Variable	Magnitude of increase in mortality
Yes	Position in turbine string	10% at the string end
Yes	Location in wind farm	9% at local cluster of turbines
Yes	Wind turbine congestion	5% at turbines with ≤12 turbines within 300 m
Yes	Whether in canyon	12% in canyon
Yes	Slope aspect	6% on northwest slopes, 5% on south/southeast slopes
Yes	Elevation	-8% at or above 385 m
	Slope grade	7% on 2 to 14 degrees
Yes	Physical relief	3% on saddles; 5% on ridgelines
	Edge index	11% at sites with at least some vertical edge
	Cattle pats	8% in areas without cattle pats along the turbine string
	Pocket gopher density	9% at turbines with ≤ 1.4 burrow systems/ha within 90 m
	Density of all mammals	10% at turbines with < 5 burrow systems/ha within 90 m
	Season of the year	10% during winter

Table 3. The directions and magnitudes of the associations between wind turbine-caused American kestrel fatalities and levels within independent variables, taking rotor swept are into account. The measure of effect used in the right column is accountable mortality. The left column identifies the relationships selected for use in the rating system.

Selected	**Variable**	**Magnitude of increase in mortality**
	Turbine model	10% at KCS-56, 9% at KVS-33
	Rated power	10% at 100 kW, 9% at 400 kW
	Sec per sweep at blade tip	10% at fewest, 9% at most
Yes	Rotor plane (m^2) swept/s	18% ≥3286
	Tower type	15% at lattice
Yes	Physical relief	11% on ridgeline, 3% on saddle
Yes	Elevation	8% below 135 m, 11% above 385 m
	Ground squirrel clustering	24% at turbines with obs/exp >1.14 within 15 m
	Pocket gopher density	32% at turbines with ≤1.4 burrows/ha within 90 m
	Season of the year	18% during winter

Table 4. The directions and magnitudes of the associations between wind turbine-caused burrowing owl fatalities and levels within independent variables, taking rotor swept are into account. The measure of effect used in the right column is accountable mortality. The left column identifies the relationships selected for use in the rating system.

Selected	**Variable**	**Magnitude of increase in mortality**
	Turbine model	10% Bonus, 11% Flowind, 6% Micon, 6% Enertech
	Blade tip speed	27% ≤194.69 kph
	Sec per sweep at blade tip	25% ≥0.3438
Yes	Rotor plane (m^2) swept/s	33% at turbines ≤ 2141
Yes	Tower type	13% at tubular towers, 11% at vertical axis towers
Yes	Derelict turbine	6% at turbines that are derelict or next to derelicts
Yes	Whether in wind wall	11% at turbines *not* in wind walls
Yes	Position in turbine string	25% at the string end
Yes	Whether in canyon	6% in canyon
Yes	Elevation	43% at turbines ≤ 235 m
Yes	Curvature feature	15% in valleys (trending toward upwardly concave)
Yes	Aspect of ridge to wind	13% on slopes windward to NW or SW directions
	Rodent control	18% in areas with intermittent rodent control
	Cattle pats by turbines	9% at turbines with cattle pats 40 m away
	Season of the year	19% during summer, 6% during winter

Rating Turbines for Priority Shutdown Using New Associations Based on Turbine Size

We scored wind turbines for their threat to golden eagle according to the following conditions taken from Table 1:

Condition	**Score**
Turbines reaching 8 to 9.6 m above ground	1
Fewer than 24 other turbines within 300 meters	1
At the edge of a local cluster of turbines	1
Turbine is not part of a wind wall	1
At the end of a turbine string	1
On a ridgeline	1
In a canyon	1
On steep slopes, >14˚	1
On slopes windward to one prevailing wind direction (NW or SW) and perpendicular to other	1

Sum Score _____ (9 possible).

We scored wind turbines for their threat to red-tailed hawk according to the following conditions taken from Table 2:

Condition	**Score**
At the end of a turbine string	1
Fewer than 13 other turbines within 300 meters	1
At the edge of a local cluster of turbines	1
In a canyon	1
On a ridgeline or ridge saddle	1
On a northwest- or south/southeast-facing slope	1
At or above 385 m elevation	-1

Sum Score _____ (6 possible).

We scored wind turbines for their threat to American kestrel according to the following conditions taken from Table 3:

Condition	**Score**
Rotor plane swept/s > 3285 m^2	1
On ridgeline or ridge saddle	1
Below 135 m or above 385 m elevation	1

Sum Score _____ (3 possible).

We scored wind turbines for their threat to burrowing owl according to the following conditions taken from Table 4:

Condition	Score
Rotor plane swept/s < 2142 m^2	1
Tubular tower or vertical axis tower	1
Turbine is a derelict or next to derelict turbine	1
Turbine is not in a wind wall	1
At the end of a turbine string	1
In a canyon	1
At or below 235 m elevation	2[a]
In valleys (trending toward upwardly convex)	1

Sum Score _____ (10 possible).

[a] Score doubled over others due to large effect.

The sum scores were aggregated into 4 groups per species, similar to the grouping of the red-tailed hawk scores in Smallwood and Spiegel (2005). Next the aggregated scores were subjected to conditional statements, similar to the method used in Smallwood and Spiegel (2005). Despite trying multiple combinations of conditional statements, none of the turbine tier outcomes reduced the number of large wind turbines in the top two tiers, which are the tiers with turbines that we predict relocation or shutdown would result in the greatest reduction in bird collisions. Therefore, as mentioned earlier in this assessment we decided to more directly incorporate turbine size into the rating system by incorporating it as one of the last steps in the development of the rating system.

MW-Adjusted Ratings of Wind Turbines for Collision Threat and Priority Shutdown

The sum score of each species was divided by the highest score recorded for the species. This step transformed the scores so that they were equal between species in their ranges from 0 to 1. These *transformed scores* were then divided by the MW of rated power output of the corresponding wind turbine, arriving at *MW-adjusted scores*. The frequency distributions of these scores were then examined in order to identify cut-off values for five aggregated groups of MW-adjusted scores, referred to hereafter as *grouped MW-adjusted scores*. Generally, Group 5 consisted of the largest 10% of the scores, Group 4 consisted the next largest 10%, Group 3 consisted of the third largest 10%, Group 2 consisted of the 20% range of values between the 50 and 70 percentiles, and Group 1 consisted of the smallest 50% of values (e.g., Figure 1). Some variation on this pattern of group aggregation was necessary for red-tailed hawk and American kestrel due to discontinuous frequency distributions, but we attempted to keep the group aggregation for these species as close to the others as possible (e.g., Figure 2).

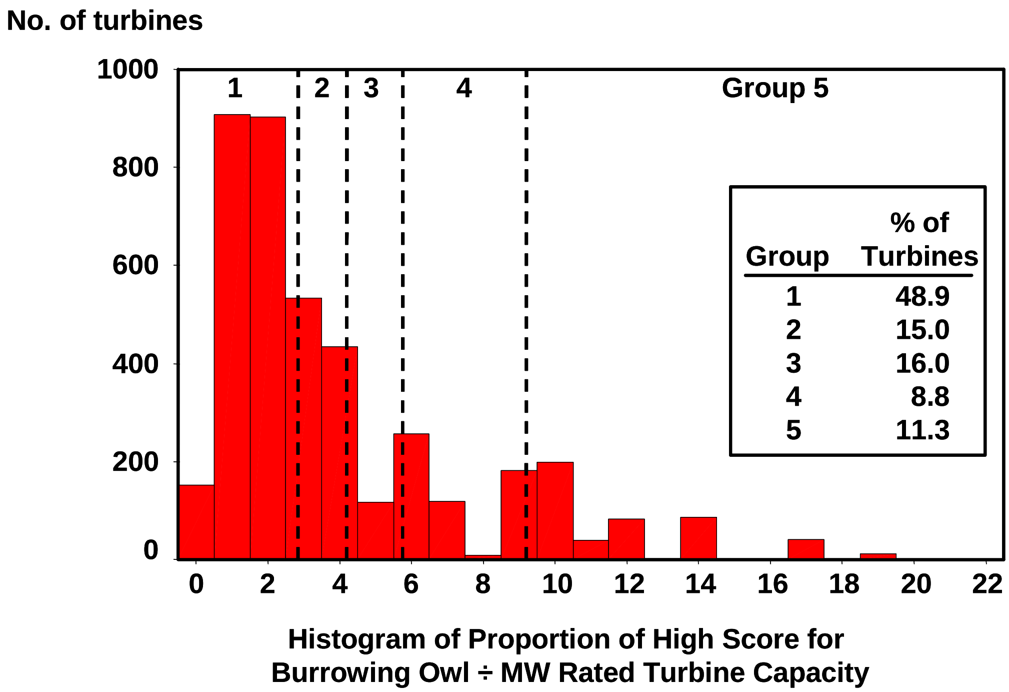

Figure 1. Frequency distribution of MW-adjusted scores for threat of collision to burrowing owl. Dashed lines are the cut-offs between five groups of scores.

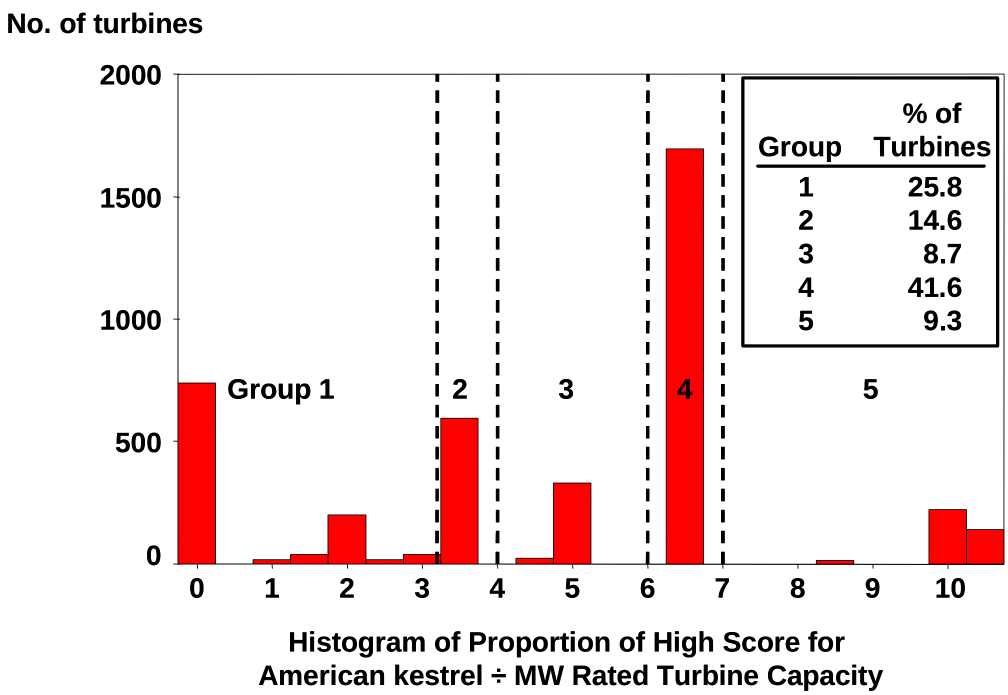

Figure 2. Frequency distribution of MW-adjusted scores for threat of collision to American kestrel. Dashed lines are the cut-offs between five groups of scores.

Table 5 summarizes the performance of the grouped MW-adjusted scores for each species. The turbines in group 5, consisting of 35 MW of rated capacity, included 10 of the documented golden eagle fatalities, which turned out to be 4.59 times more numerous than expected by chance. The loadings of red-tailed hawk, American kestrel and burrowing owl into their respective Group 5 turbines were also relatively high, and indicated we selected subsets of turbines that kill disproportionately more of each species. Some of these loadings for Groups 4 and 5, however, were not larger than obtained in Smallwood and Spiegel (2005) for their groups 3 and 4 (the highest in their study).

Table 5. Summary of fatalities and rated power output of turbines in each scoring group, as well as the proportion of the total fatality search effort, and the ratio of the observed to expected number of fatalities in each scoring group. Expected values are the total number of fatalities of the species multiplied by the proportion of the fatality search effort (i.e., the proportion of the cumulative product of time turbines were searched and the turbine's rotor-swept area).

Species, Scoring group	**Proportion of fatality search effort**	**MW of capacity (437.63 in sample)**	**Fatalities**	**Observed ÷ Expected fatalities**
Golden eagle			54	
1	0.50841	186.44	10	0.36
2	0.24012	88.13	10	0.77
3	0.12950	79.74	12	1.72
4	0.07646	47.28	12	2.91
5	0.04033	35.28	10	4.59
Red-tailed hawk			211	
1	0.51669	180.44	61	0.56
2	0.28002	118.32	66	1.12
3	0.09856	73.85	35	1.68
4	0.06077	34.87	26	2.03
5	0.03807	29.23	23	2.86
American kestrel			59	
1	0.47758	151.83	19	0.67
2	0.16868	59.40	9	0.90
3	0.05178	24.98	6	1.96
4	0.22704	169.40	17	1.27
5	0.07415	31.97	8	1.83
Burrowing owl			69	
1	0.42735	242.59	4	0.14
2	0.18509	70.85	10	0.78
3	0.22782	69.69	27	1.72
4	0.08585	28.70	16	2.70
5	0.07268	25.80	12	2.39

As stated earlier in this assessment, multiple combinations of conditional statements did not generate tiers of priority that performed better than did the top tiers in Smallwood and Spiegel (2005). It appears that using the conditional statement approach failed to improve the loadings of recorded raptor fatalities in the top tiers of priority for relocating/shutting down turbines after factoring in turbine size at the root of our analysis – in the association tests – as well as toward the end of our rating process. Therefore, we tried a different approach than in Smallwood and Spiegel (2005).

We calculated a weighted sum of MW-adjusted scores across all four focal species, where the weighting factor was the mortality estimate of each species as a proportion of the highest mortality recorded for these species in Smallwood and Thelander (2004). Because red-tailed hawk was the most frequently killed species, its MW-adjusted score was multiplied by 1.0, and thus unchanged. The MW-adjusted scores of golden eagle, American kestrel and burrowing owl were multiplied by 0.36, 0.35 and 0.47, respectively, in order to reflect their relative frequencies in our fatality data set compared to the most frequent of the four species killed -- red-tailed hawk (see Table 3-11 in Smallwood and Thelander 2004). The weighted sum of MW-adjusted scores was then aggregated into five tiers of priority for turbine relocation/shutdown were identified from the resulting frequency distribution. The non-aggregated frequency distribution of the weighted summed scores is shown in Figure 3 and the tiers of priority for turbine relocation/shutdown are shown in Figure 4.

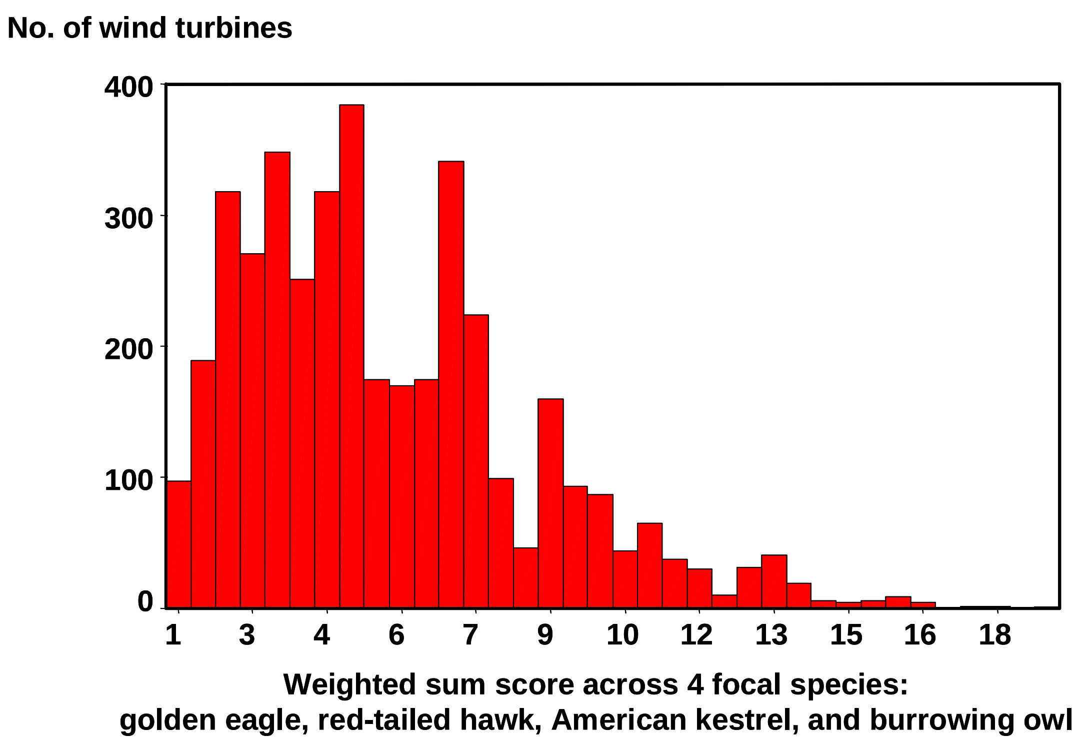

Figure 3. Frequency distribution of weighted sum scores of level of threat posed by wind turbines to golden eagle, red-tailed hawk, American kestrel and burrowing owl.

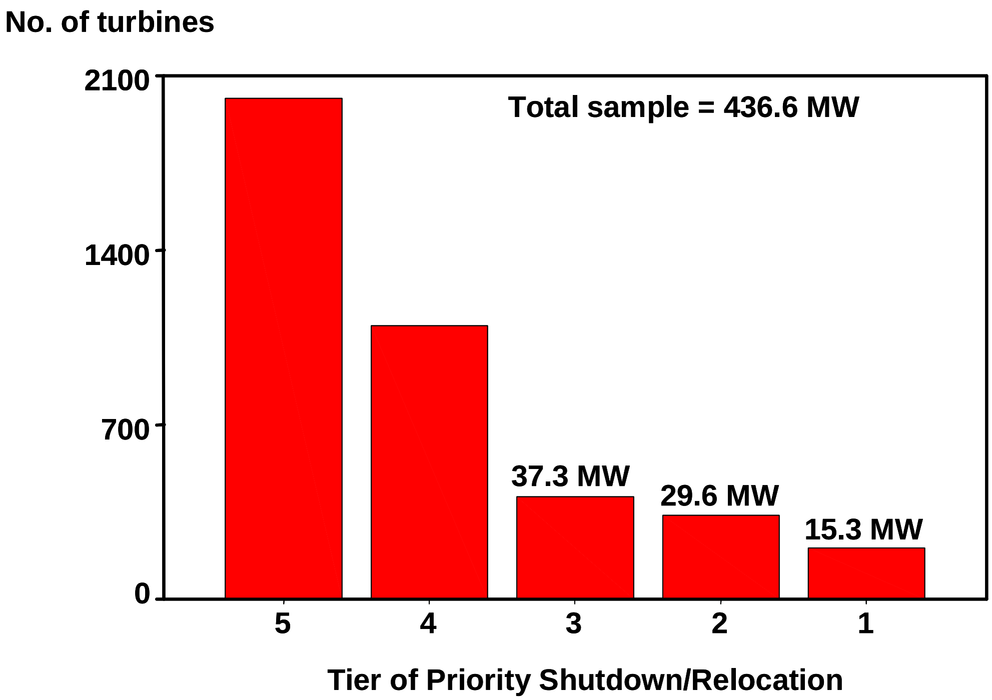

Figure 4. Frequency distribution of wind turbines grouped into tiers, which were derived from weighted sum scores of level of threat posed by wind turbines to 4 focal raptor species.

Table 6 summarizes the performance of the tiers of priority based on *a posteriori* loading of documented fatalities into the top tiers. For example, golden eagle fatalities occurred in Tier 1 about 5.5 times more often than expected by chance, and American kestrel fatalities occurred there more than 5 times expected by chance. Burrowing owl fatalities did not load strongly into Tier 1, but it did in Tiers 2 and 3.[1] The recorded fatalities in the categories of *all raptors* and *all birds* also loaded strongly into the top tiers of priority shutdown/relocation, indicating that our focal raptor species served as relatively effective indicators of collision threat posed by wind turbines to other bird species.

Table 6. Performance of tiers of priority for wind turbine shutdown/relocation, where GOEA = golden eagle, RTHA = red-tailed hawk, AMKE = American kestrel, and BUOW = burrowing owl.

Tier of Priority	MW of capacity	Observed ÷ Expected No. of Fatalities					
		GOEA	RTHA	AMKE	BUOW	Raptors	Birds
1	15.3	5.52	3.18	5.05	1.10	3.48	2.85
2	29.6	3.77	3.21	2.30	2.49	2.77	2.27
3	37.3	1.38	1.56	1.77	2.20	1.71	1.71
4	109.8	1.57	1.36	0.80	1.52	1.29	1.23
5	244.6	0.58	0.70	0.86	0.66	0.72	0.77

[1] Owners wanting to reduce burrowing owl fatalities will want to select turbines from tiers 2 and 3.

To summarize the development of the rating system, the following steps were taken:

1. Added turbine size (rotor-swept area) to the fatality search effort term in association analysis;

2. Used new associations to rate threat of turbine collision as simple summations of points given to conditions associated with disproportionately larger numbers of fatalities;

3. Divided sum score (in step 2) by highest sum score recorded for the species, arriving at constant value range from 0 to 1 for each species. This ratio is called the transformed score;

4. Divided transformed score by MW of rated turbine capacity of the wind turbine, and this new value is called the MW-adjusted score;

5. Aggregated the transformed, MW-adjusted scores into 5 groups based on the scores' frequency distributions, arriving at grouped MW-adjusted scores;

6. Tested performance of grouped MW-adjusted scores by examining the degree to which recorded turbine-caused fatalities loaded across these groups *a posteriori*;

7. Calculated weighted sum of MW-adjusted scores, where weights were mortality estimates as proportions of the red-tailed hawk mortality estimate, which was the highest mortality among the 4 focal raptor species;

8. Aggregated weighted sums into 5 tiers of priority for turbine shutdown;

9. Tested performance of tiers of priority for turbine shutdown.

Shutting down wind turbines in Tier 1 should reduce golden eagle fatalities in the APWRA by 19%, or more than five times the loss of power resulting from the shutdown (Tables 6 and 7). Shutting down this tier would not reduce burrowing owl fatalities any more than it would the proportional loss of power output (4% compared to 3.5%, respectively), but it should reduce fatalities of all raptors more than three times the loss of power output, and it should reduce fatalities of all birds nearly three times the loss of power output.

Table 7. Summary of fatality and mortality reductions after shutting down all wind turbines within priority Tier 1, totaling 15.3 MW of rated capacity or 3.5% of the capacity used in this exercise.

Focal Raptor Species	Total Fatality Estimate		Total Fatality Reduction	Total Mortality Reduction (deaths/MW/year)
	Among 4,074 turbines	Among turbines in Tier 1		
Golden eagle	72	14	19%	17%
Red-tailed hawk	191	21	11%	8%
American kestrel	152	27	18%	15%
Burrowing owl	179	7	4%	1%
All Raptors	821	100	12%	9%
All Birds	2442	244	10%	7%

Shutting down wind turbines in Tiers 1 and 2 should reduce golden eagle fatalities in the APWRA by 44%, or more than four times the loss of power resulting from the shutdown (Tables 6 and 8). Shutting down these tiers would also reduce burrowing owl fatalities at twice the rate of lost power output. It should also reduce fatalities of all raptors more than three times the loss of power output, and it should reduce fatalities of all birds more than twice the loss of power output.

Table 8. Summary of fatality and mortality reductions after shutting down all wind turbines within priority tiers 1 and 2, totaling 44.9 MW of rated capacity or 10.3% of the capacity used in this exercise.

Focal Raptor Species	Total Fatality Estimate		Total Fatality Reduction	Total Mortality Reduction (deaths/MW/year)
	Among 4,074 turbines	Among turbines in Tiers 1 and 2		
Golden eagle	72	32	44%	38%
Red-tailed hawk	191	63	33%	25%
American kestrel	152	51	34%	26%
Burrowing owl	179	37	21%	12%
All Raptors	821	254	31%	23%
All Birds	2442	619	25%	17%

Shutting down turbines in Tiers 1 through 3 should reduce golden eagle fatalities in the APWRA by nearly 60%, or three times the loss of power resulting from the shutdown (Tables 6 and 9). It should also reduce fatalities of all raptors and all birds more than two times the loss of power output.

Table 9. Summary of fatality and mortality reductions after shutting down all wind turbines within priority Tiers 1 through 3, totaling 82.2 MW of rated capacity or 18.8% of the capacity used in this exercise.

Focal Raptor Species	Total Fatality Estimate		Total Fatality Reduction	Total Mortality Reduction (deaths/MW/year)
	Among 4,074 turbines	Among turbines in Tiers 1-3		
Golden eagle	72	41	57%	47%
Red-tailed hawk	191	88	46%	34%
American kestrel	152	74	49%	137%
Burrowing owl	179	71	40%	26%
All Raptors	821	374	46%	33%
All Birds	2442	976	40%	26%

Our top tiers of priority for relocation/shutdown are distributed differently than they were in Smallwood and Spiegel (2005), due to the strong influence of turbine size on the ratings (Figure 5). Generally, Figure 5 illustrates a distribution of collision threat to raptors that we would expect, based on our research experience in the APWRA, but with a couple of exceptions. One exception is the appearance of top tier turbines in the Midway turbine field, which is a small cluster of turbines located at the east end and southern half of the APWRA. We recorded no raptor fatalities in this turbine field after four years of searching, so we did not expect to see any top-tiered turbines there. Another exception is the low incidence of the top two tiers in the turbine field now owned by Santa Clara and formerly owned by Enron. This turbine field is centrally located in the APWRA, and includes mostly green symbols for wind turbines (Figure 5). Based on our research experience there, we expected to see multiple top-tiered turbines along the northern portion of the string in the northeast portion of this turbine field; we know these turbines have killed relatively high numbers of red-tailed hawks and American kestrels. Perhaps the owners of these turbine fields would benefit by consulting separately to determine selective high risk turbines and/or choosing alternative mitigation measures to reduce bird fatalities. Despite these exceptions, the overall distribution of priority tiers appeared to represent the threat of turbine collision we expected to see based on our research experience.

Predictive models in ecology are rarely if ever perfect, and ours is no exception. The tiers of priority could be used as guides when selecting turbines for relocation or shutdown. Generally, we suggest wind turbines be selected from the top three tiers, but not necessary all of them.

Overall, we feel that our second assessment of turbines for selective relocation or shutdown is more efficient and more elegant than the first assessment. The new tiers of priority favor large wind turbines in the APWRA (Table 10), while still reducing raptor fatalities relative to power loss at similar rates as we obtained in our first assessment. Carefully utilized and/or combined with winter-time shutdown of wind turbines, we feel that our top tiers of turbines can contribute to a substantial reduction in bird fatalities caused by wind turbines in the APWRA.

Figure 5. Map of wind turbine locations depicting Ratings of Raptor Threat across the APWRA.

Table 10. Distribution or turbine sizes by tier of priority for wind turbine relocation or shutdown.

Tier	Rated turbine capacity in kW								
	40	**65**	**100**	**110**	**120**	**150**	**250**	**330**	**400**
1	22	110	73	0	0	0	0	0	0
2	5	113	209	4	6	0	0	0	0
3	48	51	282	3	18	9	0	0	0
4	1	126	846	1	58	66	0	0	0
5	85	181	1097	17	136	335	41	77	39

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Appendix A1. Chi-square test statistics and derived measures of effect for golden eagle.

Variable & Attribute	Obs ÷ Exp without rotor swept area	Observed	Expected	Obs ÷ Exp with rotor swept area	Accountable percent
Turbine model					
Micon	0.52	2	2.81	0.71	-1
Bonus	1.12	17	18.95	0.90	-4
Danwin	0.00	0	0.50	0.00	-1
Flowind	0.00	0	1.94	0.00	-4
Windmatic	0.00	0	0.39	0.00	-1
Enertech	0.71	2	1.47	1.37	1
KCS-56	1.10	30	24.73	1.21	10
KVS-33	0.00	0	1.79	0.00	-3
Howden	8.20	2	0.69	2.91	2
Nordtank	1.12	1	0.65	1.54	1
W.E.G.	0.00	0	0.10	0.00	0
Rated turbine power (kW)					
40	0.71	2	1.47	1.37	1
65	0.56	3	3.85	0.78	-2
100	1.10	30	24.73	1.21	10
110	0.00	0	0.50	0.00	-1
120	1.00	10	10.91	0.92	-2
150	1.00	7	9.63	0.73	-5
250	0.00	0	0.46	0.00	-1
330	8.20	2	0.69	2.91	2
400	0.00	0	1.79	0.00	-3
Rotor diameter (m)					
13.5 – 14.8	0.58	2	1.85	1.08	0
16.0	0.63	3	3.46	0.87	-1
17.2 – 17.8	1.03	30	26.31	1.14	7
19.1 – 19.5	0.94	10	11.76	0.85	-3
23.4 – 25.2	1.35	7	8.15	0.86	-2
31.4 – 33.2	2.47	2	2.48	0.81	-1
Blade tip speed (kph)					
136.77	0.00	0	0.39	0.00	-1
143.20	1.12	1	0.65	1.54	1
146.42	1.00	10	10.91	0.92	-2
148.03	0.71	2	1.47	1.37	1
149.64	0.52	2	2.81	0.71	-1
173.77	1.36	7	8.04	0.87	-2
180.21	0.00	0	1.79	0.00	-3

193.08	0.00	0	2.08	0.00	-4
194.69	0.00	0	0.35	0.00	-1
212.39	0.00	0	0.10	0.00	0
239.74	8.20	2	0.69	2.91	2
246.18	1.10	30	24.73	1.21	10
Blade tip speed (kph)					
137.77 – 149.64	0.82	15	16.22	0.92	-2
173.77 – 194.69	0.85	7	12.27	0.57	-10
212.39 – 246.18	1.16	32	25.52	1.25	12
Seconds/sweep at blade tip					
0.272583	1.10	30	24.73	1.21	10
0.343807	0.71	2	1.47	1.37	1
0.374882	0.00	0	0.50	0.00	-1
0.403091	0.52	2	2.81	0.71	-1
0.407945	0.00	0	0.39	0.00	-1
0.421219	1.12	1	0.65	1.54	1
0.447299	0.00	0	0.10	0.00	0
0.493765	8.20	2	0.69	2.91	2
0.502071	1.00	10	10.91	0.92	-2
0.503748	0.00	0	1.58	0.00	-3
0.507659	1.36	7	8.04	0.87	-2
0.554769	0.00	0	0.35	0.00	-1
0.694529	0.00	0	1.79	0.00	-3
Seconds/sweep at blade tip					
0.2726	1.10	30	24.73	1.21	10
0.3438 – 0.4938	0.80	7	6.60	1.06	1
0.5021 – 0.6945	0.95	17	22.68	0.75	-11
Rotor plane (m^2) swept/s					
1498.8	0.71	2	1.47	1.37	1
1518.1	0.00	0	0.39	0.00	-1
1660.5	0.00	0	1.58	0.00	-3
1718.4	1.12	1	0.65	1.54	1
1795.7	0.52	2	2.81	0.71	-1
1859.3	0.00	0	0.35	0.00	-1
2141.4	1.00	10	10.91	0.92	-2
2780.4	0.00	0	0.50	0.00	-1
3049.7	1.36	7	8.04	0.87	-2
3286.5	1.10	30	24.73	1.21	10
4014.2	0.00	0	0.10	0.00	0
4487.2	0.00	0	1.79	0.00	-3
5645.9	8.20	2	0.69	2.91	2
Rotor plane (m^2) swept/s					
1499 - 1859	0.48	5	7.25	0.69	-4
2141	1.00	10	10.91	0.92	-2

2780 - 3287	1.13	37	33.27	1.11	7
4014 - 5646	2.31	2	2.58	0.78	-1
Tower type					
Vertical axis	0.00	0	1.94	0.00	-4
Tubular	1.07	22	23.73	0.93	-3
Lattice	1.02	32	28.33	1.13	7
Tower type, outside canyons					
Vertical axis		0	1.67	0.00	-4
Tubular		11	13.07	0.84	-5
Lattice		28	24.26	1.15	10
Tower type, inside canyons [t]					
Vertical axis		0	0.08	0.00	-1
Tubular		11	13.50	0.81	-17
Lattice		4	1.42	2.81	17
Tower height (m) *					
14.0	0.00	0	1.28	0.00	-2
18.5	1.55	31	16.87	1.84	26
24.0	0.00	0	0.50	0.00	-1
24.6	0.64	15	24.17	0.62	-17
25.2	1.37	7	7.99	0.88	-2
29.5	0.00	0	1.58	0.00	-3
32.3	0.00	0	0.35	0.00	-1
36.9	0.00	0	0.06	0.00	0
43.1	0.75	1	1.21	0.83	0
Tower height (m) **					
14.0	0.00	0	1.28	0.00	-2
18.5	1.55	31	16.87	1.84	26
24.0 – 25.2	0.76	22	32.66	0.67	-20
29.5 – 32.3	0.00	0	1.94	0.00	-4
36.9 – 43.1	0.73	1	1.27	0.79	0
Rotor orientation to wind **					
Faces wind	0.74	22	32.10	0.69	-19
Away from wind	1.46	32	19.96	1.60	22
Vertical axis	0.00	0	1.94	0.00	-4
Blade color scheme					
White	0.97	51	52.07	0.98	-2
Black stripes	0.00	0	0.70	0.00	-1
Red stripes	0.00	0	0.04	0.00	0
Red tips	2.17	1	0.42	2.40	1
Green tips	3.54	2	0.78	2.58	2
Perch guard *					
None	0.97	52	53.47	0.97	-3
Wire netting	3.41	2	0.53	3.74	3
Derelict turbines					

Operating & away from derelict	0.98	49	50.23	0.98	-2
Derelict	1.07	2	1.69	1.19	1
Next to derelict	1.29	3	2.08	1.44	2
Height (m) of low blade reach *					
4.0	0.00	0	1.94	0.00	-4
5.1	0.00	0	1.28	0.00	-2
8.0	0.00	0	1.79	0.00	-3
8.9	8.20	2	0.69	2.91	2
9.6	1.75	29	15.04	1.93	26
11.1	0.00	0	0.36	0.00	-1
11.8	0.71	2	1.47	1.37	1
12.0	0.00	0	0.10	0.00	0
13.5	1.37	7	7.99	0.88	-2
14.4	0.00	0	0.50	0.00	-1
14.9	1.00	10	10.91	0.92	-2
15.7	0.00	0	7.21	0.00	-13
16.6	0.64	3	3.45	0.87	-1
17.2	0.00	0	0.03	0.00	0
25.2	0.00	0	0.05	0.00	0
28.9	0.00	0	0.01	0.00	0
34.2	0.75	1	1.21	0.83	0
Height (m) of low blade reach **					
4.0 – 5.1	0.00	0	3.21	0.00	-6
8.0 – 9.6	1.78	31	17.51	1.77	25
11.1 – 14.85	1.01	19	21.33	0.89	-4
15.7 – 17.2	0.24	3	10.68	0.28	-14
25.2 – 34.2	0.73	1	1.27	0.79	0
Height (m) of high blade reach *					
22.9	0.00	0	1.28	0.00	-2
25.3	0.71	2	1.47	1.37	1
25.9	0.00	0	0.36	0.00	-1
27.4	1.75	29	15.04	1.93	26
29.5	0.00	0	1.58	0.00	-3
32.0	0.00	0	0.03	0.00	0
32.3	0.00	0	0.35	0.00	-1
32.6	0.64	3	3.45	0.87	-1
33.5	0.00	0	7.21	0.00	-13
33.6	0.00	0	0.50	0.00	-1
34.4	1.00	10	10.91	0.92	-2
36.9	1.37	7	7.99	0.88	-2
37.2	0.00	0	0.10	0.00	0
40.3	8.20	2	0.69	2.91	2
41.2	0.00	0	1.79	0.00	-3
44.9	0.00	0	0.01	0.00	0

48.6	0.00	0	0.05	0.00	0
52.0	0.75	1	1.21	0.83	0
Height (m) of high blade reach **					
22.9 – 27.4	1.45	31	18.14	1.71	24
29.5 – 33.6	0.20	3	13.12	0.23	-19
34.4	1.00	10	10.91	0.92	-2
36.9 – 52.0	1.36	10	11.84	0.84	-3
Wind wall [t]					
In zigzag pattern	---	0	3.76	0.00	-7
Not in wind wall	1.14	53	47.14	1.12	11
In wind wall	0.13	1	3.10	0.32	-4
Position in string *					
End	1.75	21	12.38	1.70	16
Edge of gap	1.24	6	5.50	1.09	1
Interior	0.73	27	35.93	0.75	-17
Non-operational	0.00	0	0.16	0.00	0
Location in wind farm *					
Edge of farm	0.99	7	6.60	1.06	1
Edge of local cluster	2.14	12	5.82	2.06	11
Interior of wind farm	0.85	35	41.41	0.85	-12
Turbine congestion (no. in 300 m) [t]					
0 - 12	1.13	7	7.83	0.89	-2
13 - 24	1.43	35	26.26	1.33	16
25 - 36	0.61	8	11.78	0.68	-7
37 - 72	0.40	4	8.11	0.49	-8
Elevation (m)					
85 - 135	0.75	6	6.70	0.90	-1
135 - 185	1.05	12	11.24	1.07	1
185 - 235	1.38	10	8.98	1.11	2
235 - 285	1.48	5	3.68	1.36	2
285 - 335	0.43	4	8.85	0.45	-9
335 - 385	1.77	11	5.71	1.93	10
385 - 535	0.72	6	8.82	0.68	-5
Slope grade (degrees) *					
0	0.51	11	19.96	0.55	-17
2 - 5	1.88	8	4.08	1.96	7
6 - 14	0.98	13	13.36	0.97	-1
15 - 58	1.46	22	16.58	1.33	10
Physical relief **					
Peak	1.08	1	0.83	1.20	0
Plateau	0.27	1	2.84	0.35	-3
Ridge crest	0.58	10	19.94	0.50	-18
Ridgeline	2.01	22	10.57	2.08	21
Slope	0.93	17	17.42	0.98	-1

Saddle	0.84	2	2.07	0.97	0
Ravine	2.47	1	0.32	3.14	1
Canyon [t]					
Not in canyon	0.85	39	44.02	0.89	-9
In canyon	1.82	15	9.98	1.50	9
Slope curvature feature					
Valley (concave trending)		12	11.43	1.05	1
Ridge (convex trending)		42	42.57	0.99	-1
Slope aspect					
None (flat)	0.70	11	15.49	0.71	-8
North-facing	0.89	7	7.38	0.95	-1
Northeast	0.57	2	3.41	0.59	-3
East	0.88	4	4.57	0.87	-1
Southeast	1.14	7	5.67	1.23	2
South	1.12	5	4.73	1.06	0
Southwest	1.06	1	0.98	1.02	0
West	3.00	6	2.07	2.90	7
Northwest	1.24	11	9.63	1.14	3
Slope aspect					
None (flat)	0.70	11	15.49	0.71	-8
East-northeast	0.75	6	7.98	0.75	-4
South-southeast	1.13	12	10.40	1.15	3
West-southwest	2.38	7	3.05	2.30	7
North-northwest	1.08	18	17.01	1.06	2
Aspect of ridge relative to wind [t]					
Flat		16	24.29	0.66	-15
Windward to NW or SW winds		14	13.12	1.07	2
Windward & perpendicular		20	12.67	1.58	14
Windward to NW & SW winds		4	3.92	1.02	0
Edge index at tower base **					
No edge	0.48	1	1.87	0.53	-2
Some lateral edge	1.16	6	5.12	1.17	2
Lots lateral edge	0.41	7	16.41	0.43	-17
Some vertical edge	0.75	13	17.48	0.74	-8
Lots vertical edge	1.62	18	11.22	1.60	13
Lots vertical & lateral edge	5.80	9	1.90	4.74	13
Rock piles ≤50 m away					
None	0.94	40	41.78	0.96	-3
1	1.28	6	4.91	1.22	2
≥2	1.36	5	4.31	1.16	1
Rodent control through 2001 **					
Unknown	1.53	1	0.83	1.20	0
None	1.61	20	9.81	2.04	19
Control	1.18	17	17.59	0.97	-1

Intense control	0.61	16	25.77	0.62	-18
Rodent control through 2002 **					
Unknown	1.53	1	0.83	1.20	0
None	1.85	17	7.95	2.14	17
Control	1.18	17	17.61	0.97	-1
Intense control	0.64	19	27.62	0.69	-16
Cattle pats 40 m from turbines					
0	0.00	0	2.02	0.00	-9
1 - 9	1.00	11	10.68	1.03	1
10 - 25	1.22	9	7.62	1.18	6
>25	1.21	3	2.68	1.12	1
Cattle pats at turbines					
0 - 2	0.00	0	2.51	0.00	-11
3 - 9	0.90	7	7.08	0.99	0
10 - 25	0.93	7	7.90	0.89	-4
>25	1.93	9	5.52	1.63	15
Cottontails 40 m from turbines					
No pellets	0.95	17	18.59	0.91	-7
Some pellets	1.24	5	3.57	1.40	6
Abundant pellets	0.94	1	0.84	1.19	1
Cottontails at turbines					
No pellets	1.03	18	18.30	0.98	-1
Some pellets	1.00	4	3.53	1.13	2
Abundant pellets	0.68	1	1.18	0.85	-1
Vegetation height (cm)					
0 - 10	0.76	3	3.73	0.80	-3
11 - 20	0.67	5	7.28	0.69	-10
21 - 35	0.71	5	6.66	0.75	-7
> 35	2.18	10	5.34	1.87	20
Pocket gopher clustering					
Obs/Exp in 15 m = 0	1.85	2	1.08	1.85	6
Obs/Exp in 15 m <1.5	1.12	2	1.79	1.12	1
Obs/Exp in 15 m = 1.5-3.0	0.98	6	6.11	0.98	-1
Obs/Exp in 15 m >3	0.86	6	7.02	0.86	-6
Ground squirrel clustering					
Obs/Exp in 15 m = 0	0.89	5	5.64	0.89	-4
Obs/Exp in 15 m ≤1.14	1.45	9	6.20	1.45	18
Obs/Exp in 15 m >1.14	0.48	2	4.16	0.48	-14
Pocket gopher density ≤90 m *					
0 – 1.4/ha	0.54	3	5.51	0.54	-16
1.41 – 3.5/ha	0.58	3	5.21	0.58	-14
>3.5/ha	1.90	10	5.25	1.90	30
Ground squirrel density ≤90 m					
0/ha	0.35	1	2.85	0.35	-12

0.01 – 5.99/ha	0.96	9	9.36	0.96	-2
≥6/ha	1.58	6	3.79	1.58	14
Clustering of all burrows					
Obs/Exp in 15 m = 0-1.2	0.90	3	3.32	0.90	-2
Obs/Exp in 15 m = 1.2-3.0	1.33	11	8.30	1.33	17
Obs/Exp in 15 m >3	0.46	2	4.38	0.46	-15
Density of all burrow systems *					
< 5/ha	0.16	1	6.16	0.16	-32
5 – 9/ha	1.70	8	4.71	1.70	21
> 9/ha	1.36	7	5.13	1.36	12
Season of the year					
Spring	0.71	5	6.92	0.72	-8
Summer	1.60	10	6.29	1.59	15
Fall	0.68	3	4.47	0.67	-6
Winter	0.95	7	7.32	0.96	-1

Appendix A2. Chi-square test statistics and derived measures of effect for red-tailed hawk.

Variable & Attribute	Obs ÷ Exp without rotor swept area	Observed	Expected	Obs ÷ Exp with rotor swept area	Accountable percent
Turbine model					
Micon	0.73	11	11.08	0.99	0
Bonus	1.22	73	74.75	0.98	-1
Danwin	0.91	1	1.96	0.51	0
Flowind	0.34	3	7.64	0.39	-2
Windmatic	0.82	2	1.53	1.31	0
Enertech	0.36	4	5.78	0.69	-1
KCS-56	0.98	106	97.53	1.09	4
KVS-33	1.35	3	7.05	0.43	-2
Howden	3.12	3	2.71	1.11	0
Nordtank	2.00	7	2.57	2.73	2
W.E.G.	0.00	0	0.40	0.00	0
Rated turbine power (kW)					
40	0.36	4	5.78	0.69	-1
65	0.95	20	15.18	1.32	2
100	0.98	106	97.53	1.09	4
110	0.91	1	1.96	0.51	0
120	0.86	34	43.02	0.79	-4
150	1.48	41	37.98	1.08	1
250	0.64	1	1.80	0.56	0
330	3.12	3	2.71	1.11	0
400	1.35	3	7.05	0.43	-2
Rotor diameter (m)					
13.5 – 14.8	0.44	6	7.31	0.82	-1
16.0	0.96	18	13.65	1.32	2
17.2 – 17.8	0.94	108	103.78	1.04	2
19.1 – 19.5	0.86	36	46.37	0.78	-5
23.4 – 25.2	1.90	39	32.13	1.21	3
31.4 – 33.2	1.88	6	9.76	0.61	-2
Blade tip speed (kph) [t]					
136.77	0.82	2	1.53	1.31	0
143.20	2.00	7	2.57	2.73	2
146.42	0.86	34	43.02	0.79	-4
148.03	0.36	4	5.78	0.69	-1
149.64	0.73	11	11.08	0.99	0
173.77	1.92	39	31.73	1.23	3
180.21	1.35	3	7.05	0.43	-2

193.08	0.35	3	8.21	0.37	-2
194.69	0.75	1	1.39	0.72	0
212.39	0.00	0	0.40	0.00	0
239.74	3.12	3	2.71	1.11	0
246.18	0.98	106	97.53	1.09	4
Blade tip speed (kph)					
137.77 – 149.64	0.81	58	63.98	0.91	-3
173.77 – 194.69	1.42	46	48.38	0.95	-1
212.39 – 246.18	1.00	109	100.64	1.08	4
Seconds/sweep at blade tip [t]					
0.272583	0.98	106	97.53	1.09	4
0.343807	0.36	4	5.78	0.69	-1
0.374882	0.91	1	1.96	0.51	0
0.403091	0.73	11	11.08	0.99	0
0.407945	0.82	2	1.53	1.31	0
0.421219	2.00	7	2.57	2.73	2
0.447299	0.00	0	0.40	0.00	0
0.493765	3.12	3	2.71	1.11	0
0.502071	0.86	34	43.02	0.79	-4
0.503748	0.27	2	6.25	0.32	-2
0.507659	1.92	39	31.73	1.23	3
0.554769	0.75	1	1.39	0.72	0
0.694529	1.35	3	7.05	0.43	-2
Seconds/sweep at blade tip					
0.2726	0.98	106	97.53	1.09	4
0.3438 – 0.4938	0.81	28	26.03	1.08	1
0.5021 – 0.6945	1.12	79	89.44	0.88	-5
Rotor plane (m^2) swept/s [t]					
1498.8	0.36	4	5.78	0.69	-1
1518.1	0.82	2	1.53	1.31	0
1660.5	0.27	2	6.25	0.32	-2
1718.4	2.00	7	2.57	2.73	2
1795.7	0.73	11	11.08	0.99	0
1859.3	0.75	1	1.39	0.72	0
2141.4	0.86	34	43.02	0.79	-4
2780.4	0.91	1	1.96	0.51	0
3049.7	1.92	39	31.73	1.23	3
3286.5	0.98	106	97.53	1.09	4
4014.2	0.00	0	0.40	0.00	0
4487.2	1.35	3	7.05	0.43	-2
5645.9	3.12	3	2.71	1.11	0
Rotor plane (m^2) swept/s					
1499 - 1859	0.66	27	28.60	0.94	-1
2141	0.86	34	43.02	0.79	-4

2780 - 3287	1.13	146	131.22	1.11	7
4014 - 5646	1.76	6	10.16	0.59	-2
Tower type					
Vertical axis	0.34	3	7.64	0.39	-2
Tubular	1.17	95	93.61	1.01	1
Lattice	0.93	115	111.75	1.03	2
Tower type, outside canyons					
Vertical axis	0.43	3	6.34	0.47	-2
Tubular	1.03	45	49.58	0.91	-3
Lattice	1.03	100	92.08	1.09	5
Tower type, inside canyons **					
Vertical axis	0.00	0	0.33	0.00	-1
Tubular	0.91	50	58.50	0.85	-13
Lattice	1.60	15	6.16	2.43	14
Tower height (m)					
14.0	0.54	3	5.03	0.60	-1
18.5	0.89	70	66.52	1.05	2
24.0	0.91	1	1.96	0.51	0
24.6	1.00	93	95.33	0.98	-1
25.2	1.94	39	31.53	1.24	4
29.5	0.27	2	6.25	0.32	-2
32.3	0.75	1	1.39	0.72	0
36.9	0.00	0	0.23	0.00	0
43.1	0.76	4	4.76	0.84	0
Tower height (m)					
14.0	0.54	3	5.03	0.60	-1
18.5	0.89	70	66.52	1.05	2
24.0 – 25.2	1.16	133	128.81	1.03	2
29.5 – 32.3	0.34	3	7.64	0.39	-2
36.9 – 43.1	0.74	4	4.99	0.80	0
Rotor orientation to wind					
Faces wind	1.12	132	126.61	1.04	3
Away from wind	0.90	78	78.75	0.99	0
Vertical axis	0.34	3	7.64	0.39	-2
Blade color scheme **					
White	0.98	204	205.38	0.99	-1
Black stripes	1.14	1	2.76	0.36	-1
Red stripes	11.30	2	0.16	12.48	1
Red tips	2.20	4	1.65	2.43	1
Green tips	0.90	2	3.06	0.65	0
Perch guard **					
None	0.97	205	210.89	0.97	-3
Wire netting	3.46	8	2.11	3.80	3
Derelict turbines					

Operating & away from derelict	1.04	205	198.14	1.03	3
Derelict	0.41	3	6.66	0.45	-2
Next to derelict	0.55	5	8.20	0.61	-2
Height (m) of low blade reach					
4.0	0.34	3	7.64	0.39	-2
5.1	0.54	3	5.03	0.60	-1
8.0	1.35	3	7.05	0.43	-2
8.9	3.12	3	2.71	1.11	0
9.6	0.98	64	59.32	1.08	2
11.1	0.88	2	1.43	1.40	0
11.8	0.36	4	5.78	0.69	-1
12.0	0.00	0	0.40	0.00	0
13.5	1.94	39	31.53	1.24	4
14.4	0.91	1	1.96	0.51	0
14.9	0.86	34	43.02	0.79	-4
15.7	1.12	35	28.42	1.23	3
16.6	0.97	18	13.62	1.32	2
17.2	0.00	0	0.10	0.00	0
25.2	0.00	0	0.20	0.00	0
28.9	0.00	0	0.03	0.00	0
34.2	0.76	4	4.76	0.84	0
Height (m) of low blade reach					
4.0 – 5.1	0.42	6	12.67	0.47	-3
8.0 – 9.6	1.02	70	69.08	1.01	0
11.1 – 14.85	1.07	80	84.12	0.95	-2
15.7 – 17.2	1.06	53	42.14	1.26	5
25.2 – 34.2	0.74	4	4.99	0.80	0
Height (m) of high blade reach					
22.9	0.54	3	5.03	0.60	-1
25.3	0.36	4	5.78	0.69	-1
25.9	0.88	2	1.43	1.40	0
27.4	0.98	64	59.32	1.08	2
29.5	0.27	2	6.25	0.32	-2
32.0	0.00	0	0.10	0.00	0
32.3	0.75	1	1.39	0.72	0
32.6	0.97	18	13.62	1.32	2
33.5	1.12	35	28.42	1.23	3
33.6	0.91	1	1.96	0.51	0
34.4	0.86	34	43.02	0.79	-4
36.9	1.94	39	31.53	1.24	4
37.2	0.00	0	0.40	0.00	0
40.3	3.12	3	2.71	1.11	0
41.2	1.35	3	7.05	0.43	-2
44.9	0.00	0	0.03	0.00	0

48.6	0.00	0	0.20	0.00	0
52.0	0.76	4	4.76	0.84	0
Height (m) of high blade reach					
22.9 – 27.4	0.86	73	71.56	1.02	1
29.5 – 33.6	0.95	57	51.74	1.10	2
34.4	0.86	34	43.02	0.79	-4
36.9 – 52.0	1.69	49	46.69	1.05	1
Wind wall					
In zigzag pattern		18	14.82	1.21	1
Not in wind wall	1.01	185	185.96	0.99	0
In wind wall	0.94	10	12.23	0.82	-1
Position in string *					
End	1.48	70	48.81	1.43	10
Edge of gap	1.10	21	21.68	0.97	0
Interior	0.84	122	141.73	0.86	-9
Non-operational	0.00	0	0.64	0.00	0
Location in wind farm **					
Edge of farm	1.02	28	25.78	1.09	1
Edge of local cluster	1.87	41	22.74	1.80	9
Interior of wind farm	0.88	142	161.79	0.88	-9
Turbine congestion (no. in 300 m) *					
0 - 12	1.68	41	30.87	1.33	5
13 - 24	0.91	88	103.57	0.85	-7
25 - 36	1.11	58	46.44	1.25	5
37 - 72	0.65	26	32.01	0.81	-3
Elevation (m) [t]					
85 - 135	0.98	31	26.43	1.17	2
135 - 185	0.94	42	44.33	0.95	-1
185 - 235	1.26	36	35.42	1.02	0
235 - 285	1.35	18	14.53	1.24	2
285 - 335	1.17	43	34.89	1.23	4
335 - 385	1.02	25	22.51	1.11	1
385 - 535	0.55	18	34.80	0.52	-8
Slope grade (degrees) [t]					
0	0.74	63	78.72	0.80	-7
2 - 5	1.37	23	16.11	1.43	3
6 - 14	1.19	62	52.69	1.18	4
15 - 58	1.10	65	65.39	0.99	0
Physical relief [t]					
Peak	0.55	2	3.29	0.61	-1
Plateau	0.54	8	11.18	0.72	-1
Ridge crest	0.98	67	78.64	0.85	-5
Ridgeline	1.23	53	41.71	1.27	5
Slope	0.93	67	68.71	0.98	-1

Saddle	1.59	15	8.17	1.84	3
Ravine	0.63	1	1.26	0.79	0
Canyon **					
Not in canyon	0.82	148	173.62	0.85	-12
In canyon	2.00	65	39.38	1.65	12
Slope curvature feature					
Valley (concave trending)	0.85	43	45.09	0.95	-1
Ridge (convex trending)	1.05	170	167.91	1.01	1
Slope aspect *					
None (flat)	0.67	41	61.12	0.67	-9
North-facing	0.84	26	29.10	0.89	-1
Northeast	1.16	16	13.43	1.19	1
East	0.78	14	18.04	0.78	-2
Southeast	1.12	27	22.37	1.21	2
South	1.37	24	18.67	1.29	3
Southwest	1.61	6	3.86	1.56	1
West	1.14	9	8.16	1.10	0
Northwest	1.43	50	37.98	1.32	6
Slope aspect *					
None (flat)	0.67	41	61.12	0.67	-9
East-northeast	0.94	30	31.47	0.95	-1
South-southeast	1.22	51	41.03	1.24	5
West-southwest	1.29	15	12.02	1.25	1
North-northwest	1.15	76	67.08	1.13	4
Aspect of ridge relative to wind					
Flat	0.94	91	95.82	0.95	-2
Windward to NW or SW winds	0.88	46	51.74	0.89	-3
Windward & perpendicular	1.23	59	49.97	1.18	4
Windward to NW & SW winds	1.12	17	15.48	1.10	1
Edge index at tower base **					
No edge	0.49	4	7.38	0.54	-2
Some lateral edge	0.93	19	20.21	0.94	-1
Lots lateral edge	0.68	45	64.73	0.70	-9
Some vertical edge	1.09	74	68.93	1.07	2
Lots vertical edge	1.23	54	44.26	1.22	5
Lots vertical & lateral edge	2.78	17	7.49	2.27	4
Rock piles ≤50 m away					
None	0.95	154	158.10	0.97	-2
1	1.41	25	18.59	1.34	3
≥2	1.01	14	16.31	0.86	-1
Rodent control through 2001					
Unknown	0.39	1	3.28	0.31	-1
None	0.92	45	38.70	1.16	3
Control	1.30	74	69.40	1.07	2

Intense control	0.89	93	101.63	0.92	-4
Rodent control through 2002					
Unknown	0.39	1	3.28	0.31	-1
None	1.13	41	31.34	1.31	5
Control	1.30	74	69.45	1.07	2
Intense control	0.83	97	108.94	0.89	-6
Cattle pats 40 m from turbines *					
0	1.74	26	13.79	1.89	8
1 - 9	0.91	68	72.89	0.93	-3
10 - 25	0.92	46	52.04	0.88	-4
>25	1.01	17	18.28	0.93	-1
Cattle pats at turbines					
0 - 2	1.03	21	17.14	1.22	2
3 - 9	0.81	43	48.31	0.89	-3
10 - 25	1.13	58	53.90	1.08	3
>25	1.10	35	37.65	0.93	-2
Cottontails 40 m from turbines					
No pellets	1.07	131	126.92	1.03	3
Some pellets	0.62	17	24.35	0.70	-5
Abundant pellets	1.24	9	5.73	1.57	2
Cottontails at turbines					
No pellets	1.10	132	124.90	1.06	5
Some pellets	0.66	18	24.06	0.75	-4
Abundant pellets	0.70	7	8.04	0.87	-1
Vegetation height (cm)					
0 - 10	0.70	19	25.44	0.75	-4
11 - 20	1.04	53	49.67	1.07	2
21 - 35	0.98	47	45.46	1.03	1
> 35	1.21	38	36.43	1.04	1
Pocket gopher clustering					
Obs/Exp in 15 m = 0	0.96	6	6.28	0.96	0
Obs/Exp in 15 m <1.5	0.86	9	10.42	0.86	-2
Obs/Exp in 15 m = 1.5-3.0	0.82	29	35.53	0.82	-7
Obs/Exp in 15 m >3	1.20	49	40.77	1.20	9
Ground squirrel clustering					
Obs/Exp in 15 m = 0	1.01	33	32.78	1.01	0
Obs/Exp in 15 m ≤1.14	0.94	34	36.05	0.94	-2
Obs/Exp in 15 m >1.14	1.08	26	24.17	1.08	2
Pocket gopher density ≤90 m *					
0 – 1.4/ha	1.25	40	32.01	1.25	9
1.41 – 3.5/ha	0.96	29	30.29	0.96	-1
>3.5/ha	0.79	24	30.54	0.79	-7
Ground squirrel density ≤90 m					
0/ha	0.91	15	16.56	0.91	-2

0.01 – 5.99/ha	1.16	63	54.41	1.16	9
≥6/ha	0.68	15	22.02	0.68	-8
Clustering of all burrows					
Obs/Exp in 15 m = 0-1.2	0.99	19	19.28	0.99	0
Obs/Exp in 15 m = 1.2-3.0	0.89	43	48.25	0.89	-6
Obs/Exp in 15 m >3	1.22	31	25.48	1.22	6
Density of all burrow systems *					
< 5/ha	1.26	45	35.82	1.26	10
5 – 9/ha	0.91	25	27.37	0.91	-3
> 9/ha	0.77	23	29.81	0.77	-7
Season of the year **					
Spring	0.26	11	41.81	0.26	-20
Summer	1.19	45	37.97	1.19	5
Fall	1.32	35	26.98	1.30	5
Winter	1.35	60	44.24	1.36	10

Appendix A3. Chi-square test statistics and derived measures of effect for American kestrel.

Variable & Attribute	**Obs ÷ Exp without rotor swept area**	**Observed**	**Expected**	**Obs ÷ Exp with rotor swept area**	**Accountable percent**
Turbine model **					
Micon	1.19	5	3.07	1.63	3
Bonus	0.60	10	20.71	0.48	-18
Danwin	0.00	0	0.54	0.00	-1
Flowind	0.41	1	2.12	0.47	-2
Windmatic	0.00	0	0.42	0.00	-1
Enertech	0.00	0	1.60	0.00	-3
KCS-56	1.11	33	27.02	1.22	10
KVS-33	11.35	7	1.95	3.58	9
Howden	0.00	0	0.75	0.00	-1
Nordtank	3.09	3	0.71	4.22	4
W.E.G.	0.00	0	0.11	0.00	0
Rated turbine power (kW) **					
40	0.00	0	1.60	0.00	-3
65	1.37	8	4.21	1.90	6
100	1.11	33	27.02	1.22	10
110	0.00	0	0.54	0.00	-1
120	0.64	7	11.92	0.59	-8
150	0.52	4	10.52	0.38	-11
250	0.00	0	0.50	0.00	-1
330	0.00	0	0.75	0.00	-1
400	11.35	7	1.95	3.58	9
Rotor diameter (m) **					
13.5 – 14.8	0.00	0	2.02	0.00	-3
16.0	1.55	8	3.78	2.12	7
17.2 – 17.8	1.07	34	28.75	1.18	9
19.1 – 19.5	0.60	7	12.84	0.54	-10
23.4 – 25.2	0.53	3	8.90	0.34	-10
31.4 – 33.2	7.92	7	2.70	2.59	7
Blade tip speed (kph) **					
136.77	0.00	0	0.42	0.00	-1
143.20	3.09	3	0.71	4.22	4
146.42	0.64	7	11.92	0.59	-8
148.03	0.00	0	1.60	0.00	-3
149.64	1.19	5	3.07	1.63	3
173.77	0.53	3	8.79	0.34	-10
180.21	11.35	7	1.95	3.58	9

193.08	0.43	1	2.27	0.44	-2
194.69	0.00	0	0.39	0.00	-1
212.39	0.00	0	0.11	0.00	0
239.74	0.00	0	0.75	0.00	-1
246.18	1.11	33	27.02	1.22	10
Blade tip speed (kph)					
137.77 – 149.64	0.75	15	17.72	0.85	-5
173.77 – 194.69	1.23	11	13.40	0.82	-4
212.39 – 246.18	1.09	33	27.88	1.18	9
Seconds/sweep at blade tip **					
0.272583	1.11	33	27.02	1.22	10
0.343807	0.00	0	1.60	0.00	-3
0.374882	0.00	0	0.54	0.00	-1
0.403091	1.19	5	3.07	1.63	3
0.407945	0.00	0	0.42	0.00	-1
0.421219	3.09	3	0.71	4.22	4
0.447299	0.00	0	0.11	0.00	0
0.493765	0.00	0	0.75	0.00	-1
0.502071	0.64	7	11.92	0.59	-8
0.503748	0.49	1	1.73	0.58	-1
0.507659	0.53	3	8.79	0.34	-10
0.554769	0.00	0	0.39	0.00	-1
0.694529	11.35	7	1.95	3.58	9
Seconds/sweep at blade tip					
0.2726	1.11	33	27.02	1.22	10
0.3438 – 0.4938	0.84	8	7.21	1.11	1
0.5021 – 0.6945	0.92	18	24.77	0.73	-11
Rotor plane (m^2) swept/s **					
1498.8	0.00	0	1.60	0.00	-3
1518.1	0.00	0	0.42	0.00	-1
1660.5	0.49	1	1.73	0.58	-1
1718.4	3.09	3	0.71	4.22	4
1795.7	1.19	5	3.07	1.63	3
1859.3	0.00	0	0.39	0.00	-1
2141.4	0.64	7	11.92	0.59	-8
2780.4	0.00	0	0.54	0.00	-1
3049.7	0.53	3	8.79	0.34	-10
3286.5	1.11	33	27.02	1.22	10
4014.2	0.00	0	0.11	0.00	0
4487.2	11.35	7	1.95	3.58	9
5645.9	0.00	0	0.75	0.00	-1
Rotor plane (m^2) swept/s *					
1499 - 1859	0.79	9	7.92	1.14	2
2141	0.64	7	11.92	0.59	-8

2780 - 3287	1.01	36	36.35	0.99	-1
4014 - 5646	7.41	7	2.82	2.49	7
Tower type [t]					
Vertical axis	0.41	1	2.12	0.47	-2
Tubular	0.80	18	25.93	0.69	-13
Lattice	1.17	40	30.96	1.29	15
Tower type, outside canyons					
Vertical axis	0.42	1	2.14	0.47	-2
Tubular	0.88	13	16.75	0.78	-8
Lattice	1.10	36	31.11	1.16	10
Tower type, inside canyons **					
Vertical axis	0.00	0	0.05	0.00	-1
Tubular	0.65	5	8.10	0.62	-34
Lattice	3.09	4	0.85	4.69	35
Tower height (m)					
14.0	1.30	2	1.39	1.44	1
18.5	0.92	20	18.43	1.09	3
24.0	0.00	0	0.54	0.00	-1
24.6	1.28	33	26.41	1.25	11
25.2	0.54	3	8.73	0.34	-10
29.5	0.49	1	1.73	0.58	-1
32.3	0.00	0	0.39	0.00	-1
36.9	0.00	0	0.06	0.00	0
43.1	0.00	0	1.32	0.00	-2
Tower height (m)					
14.0	1.30	2	1.39	1.44	1
18.5	0.92	20	18.43	1.09	3
24.0 – 25.2	1.14	36	35.68	1.01	1
29.5 – 32.3	0.41	1	2.12	0.47	-2
36.9 – 43.1	0.00	0	1.38	0.00	-2
Rotor orientation to wind					
Faces wind	0.89	29	35.07	0.83	-10
Away from wind	1.21	29	21.81	1.33	12
Vertical axis	0.41	1	2.12	0.47	-2
Blade color scheme [t]					
White	0.92	53	56.89	0.93	-7
Black stripes	12.38	3	0.76	3.93	4
Red stripes	0.00	0	0.04	0.00	0
Red tips	1.98	1	0.46	2.20	1
Green tips	3.24	2	0.85	2.36	2
Perch guard					
None	0.99	58	58.42	0.99	-1
Wire netting	1.56	1	0.58	1.71	1
Derelict turbines					

Operating & away from derelict	1.07	58	54.88	1.06	5
Derelict	0.00	0	1.84	0.00	-3
Next to derelict	0.39	1	2.27	0.44	-2
Height (m) of low blade reach *					
4.0	0.41	1	2.12	0.47	-2
5.1	1.30	2	1.39	1.44	1
8.0	11.35	7	1.95	3.58	9
8.9	0.00	0	0.75	0.00	-1
9.6	1.10	20	16.43	1.22	6
11.1	0.00	0	0.40	0.00	-1
11.8	0.00	0	1.60	0.00	-3
12.0	0.00	0	0.11	0.00	0
13.5	0.54	3	8.73	0.34	-10
14.4	0.00	0	0.54	0.00	-1
14.9	0.64	7	11.92	0.59	-8
15.7	1.27	11	7.87	1.40	5
16.6	1.55	8	3.77	2.12	7
17.2	0.00	0	0.03	0.00	0
25.2	0.00	0	0.06	0.00	0
28.9	0.00	0	0.01	0.00	0
34.2	0.00	0	1.32	0.00	-2
Height (m) of low blade reach **					
4.0 – 5.1	0.76	3	3.51	0.85	-1
8.0 – 9.6	1.42	27	19.13	1.41	13
11.1 – 14.85	0.48	10	23.30	0.43	-23
15.7 – 17.2	1.37	19	11.67	1.63	12
25.2 – 34.2	0.00	0	1.38	0.00	-2
Height (m) of high blade reach *					
22.9	1.30	2	1.39	1.44	1
25.3	0.00	0	1.60	0.00	-3
25.9	0.00	0	0.40	0.00	-1
27.4	1.10	20	16.43	1.22	6
29.5	0.49	1	1.73	0.58	-1
32.0	0.00	0	0.03	0.00	0
32.3	0.00	0	0.39	0.00	-1
32.6	1.55	8	3.77	2.12	7
33.5	1.27	11	7.87	1.40	5
33.6	0.00	0	0.54	0.00	-1
34.4	0.64	7	11.92	0.59	-8
36.9	0.54	3	8.73	0.34	-10
37.2	0.00	0	0.11	0.00	0
40.3	0.00	0	0.75	0.00	-1
41.2	11.35	7	1.95	3.58	9
44.9	0.00	0	0.01	0.00	0

48.6	0.00	0	0.06	0.00	0
52.0	0.00	0	1.32	0.00	-2
Height (m) of high blade reach					
22.9 – 27.4	0.94	22	19.82	1.11	4
29.5 – 33.6	1.20	20	14.33	1.40	10
34.4	0.64	7	11.92	0.59	-8
36.9 – 52.0	1.25	10	12.93	0.77	-5
Wind wall					
In zigzag pattern		7	4.10	1.71	5
Not in wind wall	0.99	50	51.51	0.97	-3
In wind wall	1.09	2	3.39	0.59	-2
Position in string					
End	1.22	17	13.52	1.26	6
Edge of gap	1.14	6	6.01	1.00	0
Interior	0.92	36	39.26	0.92	-6
Non-operational	0.00	0	0.18	0.00	0
Location in wind farm					
Edge of farm	1.30	10	7.21	1.39	5
Edge of local cluster	1.47	9	6.36	1.42	4
Interior of wind farm	0.89	40	45.24	0.88	-9
Turbine congestion (no. in 300 m)					
0 - 12	1.18	8	8.55	0.94	-1
13 - 24	1.16	31	28.69	1.08	4
25 - 36	0.76	11	12.87	0.86	-3
37 - 72	0.82	9	8.87	1.02	0
Elevation (m) *					
85 - 135	1.36	12	7.32	1.64	8
135 - 185	0.32	4	12.28	0.33	-14
185 - 235	0.76	6	9.81	0.61	-6
235 - 285	1.63	6	4.02	1.49	3
285 - 335	0.78	8	9.67	0.83	-3
335 - 385	1.03	7	6.23	1.12	1
385 - 535	1.75	16	9.64	1.66	11
Slope grade (degrees) [t]					
0	0.90	21	21.81	0.96	-1
2 - 5	1.93	9	4.46	2.02	8
6 - 14	1.18	17	14.59	1.16	4
15 - 58	0.73	12	18.11	0.66	-10
Physical relief [t]					
Peak	0.00	0	0.91	0.00	-2
Plateau	0.98	4	3.10	1.29	2
Ridge crest	1.16	22	21.78	1.01	0
Ridgeline	1.51	18	11.55	1.56	11
Slope	0.50	10	19.03	0.53	-15

Saddle	1.53	4	2.26	1.77	3
Ravine	2.26	1	0.35	2.87	1
Canyon					
Not in canyon	1.00	50	48.09	1.04	3
In canyon	1.00	9	10.91	0.83	-3
Slope curvature feature					
Valley (concave trending)	1.00	14	12.49	1.12	3
Ridge (convex trending)	1.00	45	46.51	0.97	-3
Slope aspect					
None (flat)	0.94	16	16.93	0.95	-2
North-facing	0.47	4	8.06	0.50	-7
Northeast	1.31	5	3.72	1.34	2
East	1.01	5	5.00	1.00	0
Southeast	1.04	7	6.20	1.13	1
South	2.06	10	5.17	1.93	8
Southwest	0.00	0	1.07	0.00	-2
West	1.37	3	2.26	1.33	1
Northwest	0.93	9	10.52	0.86	-3
Slope aspect					
None (flat)	0.94	16	16.93	0.95	-2
East-northeast	1.14	10	8.72	1.15	2
South-southeast	1.47	17	11.37	1.50	10
West-southwest	0.93	3	3.33	0.90	-1
North-northwest	0.71	13	18.58	0.70	-9
Aspect of ridge relative to wind					
Flat	1.04	28	26.54	1.05	2
Windward to NW or SW winds	0.96	14	14.33	0.98	-1
Windward & perpendicular	1.05	14	13.84	1.01	0
Windward to NW & SW winds	0.71	3	4.29	0.70	-2
Edge index at tower base					
No edge	0.89	2	2.05	0.98	0
Some lateral edge	1.06	6	5.60	1.07	1
Lots lateral edge	0.98	18	17.93	1.00	0
Some vertical edge	0.96	18	19.09	0.94	-2
Lots vertical edge	0.91	11	12.26	0.90	-2
Lots vertical & lateral edge	2.36	4	2.08	1.93	3
Rock piles ≤50 m away					
None	1.04	39	36.86	1.06	5
1	1.45	6	4.34	1.38	4
≥2	0.00	0	3.80	0.00	-8
Rodent control through 2001					
Unknown	1.40	1	0.91	1.10	0
None	1.03	14	10.72	1.31	6
Control	0.70	11	19.22	0.57	-14

Intense control	1.14	33	28.15	1.17	8
Rodent control through 2002					
Unknown	1.40	1	0.91	1.10	0
None	1.29	13	8.68	1.50	7
Control	0.70	11	19.24	0.57	-14
Intense control	1.05	34	30.18	1.13	6
Cattle pats 40 m from turbines					
0	0.96	4	3.87	1.03	0
1 - 9	0.95	20	20.43	0.98	-1
10 - 25	1.07	15	14.59	1.03	1
>25	1.06	5	5.12	0.98	0
Cattle pats at turbines [t]					
0 - 2	0.87	5	4.80	1.04	0
3 - 9	1.40	21	13.54	1.55	17
10 - 25	0.69	10	15.11	0.66	-12
>25	0.90	8	10.55	0.76	-6
Cottontails 40 m from turbines					
No pellets	1.05	36	35.57	1.01	1
Some pellets	0.78	6	6.83	0.88	-2
Abundant pellets	0.98	2	1.61	1.24	1
Cottontails at turbines					
No pellets	0.98	33	35.00	0.94	-5
Some pellets	0.91	7	6.74	1.04	1
Abundant pellets	1.42	4	2.25	1.78	4
Vegetation height (cm)					
0 - 10	1.32	10	7.13	1.40	7
11 - 20	0.91	13	13.92	0.93	-2
21 - 35	0.67	9	12.74	0.71	-8
> 35	1.37	12	10.21	1.18	4
Pocket gopher clustering					
Obs/Exp in 15 m = 0	0.00	0	1.22	0.00	-7
Obs/Exp in 15 m <1.5	1.49	3	2.02	1.49	5
Obs/Exp in 15 m = 1.5-3.0	0.87	6	6.88	0.87	-5
Obs/Exp in 15 m >3	1.14	9	7.89	1.14	6
Ground squirrel clustering [t]					
Obs/Exp in 15 m = 0	0.79	5	6.34	0.79	-7
Obs/Exp in 15 m ≤1.14	0.57	4	6.98	0.57	-17
Obs/Exp in 15 m >1.14	1.92	9	4.68	1.92	24
Pocket gopher density ≤90 m *					
0 – 1.4/ha	1.94	12	6.20	1.94	32
1.41 – 3.5/ha	0.34	2	5.86	0.34	-21
>3.5/ha	0.68	4	5.91	0.68	-11
Ground squirrel density ≤90 m					
0/ha	1.25	4	3.21	1.25	4

0.01 – 5.99/ha	1.14	12	10.53	1.14	8
≥6/ha	0.47	2	4.26	0.47	-13
Clustering of all burrows					
Obs/Exp in 15 m = 0-1.2	0.54	2	3.73	0.54	-10
Obs/Exp in 15 m = 1.2-3.0	1.18	11	9.34	1.18	9
Obs/Exp in 15 m >3	1.01	5	4.93	1.01	0
Density of all burrow systems					
< 5/ha	1.30	9	6.93	1.30	12
5 – 9/ha	1.13	6	5.30	1.13	4
> 9/ha	0.52	3	5.77	0.52	-15
Season of the year *					
Spring	0.75	12	15.78	0.76	-7
Summer	0.77	11	14.33	0.77	-6
Fall	0.70	7	10.19	0.69	-6
Winter	1.61	27	16.70	1.62	18

Appendix A4. Chi-square test statistics and derived measures of effect for burrowing owl.

Variable & Attribute	Obs ÷ Exp without rotor swept area	Observed	Expected	Obs ÷ Exp with rotor swept area	Accountable percent
Turbine model **					
Micon	1.63	8	3.59	2.23	6
Bonus	1.60	31	24.22	1.28	10
Danwin	0.00	0	0.63	0.00	-1
Flowind	3.54	10	2.48	4.04	11
Windmatic	0.00	0	0.50	0.00	-1
Enertech	1.67	6	1.87	3.21	6
KCS-56	0.40	14	31.59	0.44	-25
KVS-33	0.00	0	2.28	0.00	-3
Howden	0.00	0	0.88	0.00	-1
Nordtank	0.00	0	0.83	0.00	-1
W.E.G.	0.00	0	0.13	0.00	0
Rated turbine power (kW) **					
40	1.67	6	1.87	3.21	6
65	1.17	8	4.92	1.63	4
100	0.40	14	31.59	0.44	-25
110	0.00	0	0.63	0.00	-1
120	1.72	22	13.94	1.58	12
150	1.90	17	12.30	1.38	7
250	3.96	2	0.58	3.44	2
330	0.00	0	0.88	0.00	-1
400	0.00	0	2.28	0.00	-3
Rotor diameter (m) **					
13.5 – 14.8	1.37	6	2.37	2.53	5
16.0	1.32	8	4.42	1.81	5
17.2 – 17.8	0.59	22	33.62	0.65	-17
19.1 – 19.5	1.76	24	15.02	1.60	13
23.4 – 25.2	1.36	9	10.41	0.86	-2
31.4 – 33.2	0.00	0	3.16	0.00	-5
Blade tip speed (kph) **					
136.77	0.00	0	0.50	0.00	-1
143.20	0.00	0	0.83	0.00	-1
146.42	1.72	22	13.94	1.58	12
148.03	1.67	6	1.87	3.21	6
149.64	1.63	8	3.59	2.23	6
173.77	1.37	9	10.28	0.88	-2
180.21	0.00	0	2.28	0.00	-3

193.08	2.91	8	2.66	3.01	8
194.69	4.62	2	0.45	4.43	2
212.39	0.00	0	0.13	0.00	0
239.74	0.00	0	0.88	0.00	-1
246.18	0.40	14	31.59	0.44	-25
Blade tip speed (kph) **					
137.77 – 149.64	1.55	36	20.73	1.74	22
173.77 – 194.69	1.81	19	15.67	1.21	5
212.39 – 246.18	0.40	14	32.60	0.43	-27
Seconds/sweep at blade tip **					
0.272583	0.40	14	31.59	0.44	-25
0.343807	1.67	6	1.87	3.21	6
0.374882	0.00	0	0.63	0.00	-1
0.403091	1.63	8	3.59	2.23	6
0.407945	0.00	0	0.50	0.00	-1
0.421219	0.00	0	0.83	0.00	-1
0.447299	0.00	0	0.13	0.00	0
0.493765	0.00	0	0.88	0.00	-1
0.502071	1.72	22	13.94	1.58	12
0.503748	3.34	8	2.02	3.95	9
0.507659	1.37	9	10.28	0.88	-2
0.554769	4.62	2	0.45	4.43	2
0.694529	0.00	0	2.28	0.00	-3
Seconds/sweep at blade tip **					
0.2726	0.40	14	31.59	0.44	-25
0.3438 – 0.4938	1.25	14	8.43	1.66	8
0.5021 – 0.6945	1.79	41	28.97	1.42	17
Rotor plane (m^2) swept/s **					
1498.8	1.67	6	1.87	3.21	6
1518.1	0.00	0	0.50	0.00	-1
1660.5	3.34	8	2.02	3.95	9
1718.4	0.00	0	0.83	0.00	-1
1795.7	1.63	8	3.59	2.23	6
1859.3	4.62	2	0.45	4.43	2
2141.4	1.72	22	13.94	1.58	12
2780.4	0.00	0	0.63	0.00	-1
3049.7	1.37	9	10.28	0.88	-2
3286.5	0.40	14	31.59	0.44	-25
4014.2	0.00	0	0.13	0.00	0
4487.2	0.00	0	2.28	0.00	-3
5645.9	0.00	0	0.88	0.00	-1
Rotor plane (m^2) swept/s **					
1499 - 1859	1.81	24	9.27	2.59	21
2141	1.72	22	13.94	1.58	12

2780 - 3287	0.55	23	42.51	0.54	-28
4014 - 5646	0.00	0	3.29	0.00	-5
Tower type **					
Vertical axis	3.54	10	2.48	4.04	11
Tubular	1.49	39	30.32	1.29	13
Lattice	0.50	20	36.20	0.55	-23
Tower type, outside canyons **					
Vertical axis	3.93	10	2.31	4.32	14
Tubular	1.57	25	18.09	1.38	13
Lattice	0.54	19	33.60	0.57	-27
Tower type, inside canyons					
Vertical axis	0.00	0	0.08	0.00	-1
Tubular	1.10	14	13.50	1.04	3
Lattice	0.46	1	1.42	0.70	-3
Tower height (m) **					
14.0	0.00	0	1.63	0.00	-2
18.5	0.70	18	21.55	0.84	-5
24.0	0.00	0	0.63	0.00	-1
24.6	1.06	32	30.88	1.04	2
25.2	1.38	9	10.21	0.88	-2
29.5	3.34	8	2.02	3.95	9
32.3	4.62	2	0.45	4.43	2
36.9	0.00	0	0.08	0.00	0
43.1	0.00	0	1.54	0.00	-2
Tower height (m) **					
14.0	0.00	0	1.63	0.00	-2
18.5	0.70	18	21.55	0.84	-5
24.0 – 25.2	1.11	41	41.73	0.98	-1
29.5 – 32.3	3.54	10	2.48	4.04	11
36.9 – 43.1	0.00	0	1.62	0.00	-2
Rotor orientation to wind **					
Faces wind	1.05	40	41.02	0.98	-1
Away from wind	0.68	19	25.51	0.74	-9
Vertical axis	3.54	10	2.48	4.04	11
Blade color scheme					
White	1.02	69	66.53	1.04	4
Black stripes	0.00	0	0.89	0.00	-1
Red stripes	0.00	0	0.05	0.00	0
Red tips	0.00	0	0.53	0.00	-1
Green tips	0.00	0	0.99	0.00	-1
Perch guard					
None	1.01	69	68.32	1.01	1
Wire netting	0.00	0	0.68	0.00	-1
Derelict turbines [t]					

Operating & away from derelict	0.94	60	64.19	0.93	-6
Derelict	2.08	5	2.16	2.32	4
Next to derelict	1.35	4	2.66	1.51	2
Height (m) of low blade reach **					
4.0	3.54	10	2.48	4.04	11
5.1	0.00	0	1.63	0.00	-2
8.0	0.00	0	2.28	0.00	-3
8.9	0.00	0	0.88	0.00	-1
9.6	0.57	12	19.22	0.62	-10
11.1	0.00	0	0.46	0.00	-1
11.8	1.67	6	1.87	3.21	6
12.0	0.00	0	0.13	0.00	0
13.5	1.38	9	10.21	0.88	-2
14.4	0.00	0	0.63	0.00	-1
14.9	1.72	22	13.94	1.58	12
15.7	0.20	2	9.21	0.22	-10
16.6	1.33	8	4.41	1.81	5
17.2	0.00	0	0.03	0.00	0
25.2	0.00	0	0.07	0.00	0
28.9	0.00	0	0.01	0.00	0
34.2	0.00	0	1.54	0.00	-2
Height (m) of low blade reach **					
4.0 – 5.1	2.16	10	4.11	2.44	9
8.0 – 9.6	0.54	12	22.38	0.54	-15
11.1 – 14.85	1.53	37	27.25	1.36	14
15.7 – 17.2	0.62	10	13.65	0.73	-5
25.2 – 34.2	0.00	0	1.62	0.00	-2
Height (m) of high blade reach **					
22.9	0.00	0	1.63	0.00	-2
25.3	1.67	6	1.87	3.21	6
25.9	0.00	0	0.46	0.00	-1
27.4	0.57	12	19.22	0.62	-10
29.5	3.34	8	2.02	3.95	9
32.0	0.00	0	0.03	0.00	0
32.3	4.62	2	0.45	4.43	2
32.6	1.33	8	4.41	1.81	5
33.5	0.20	2	9.21	0.22	-10
33.6	0.00	0	0.63	0.00	-1
34.4	1.72	22	13.94	1.58	12
36.9	1.38	9	10.21	0.88	-2
37.2	0.00	0	0.13	0.00	0
40.3	0.00	0	0.88	0.00	-1
41.2	0.00	0	2.28	0.00	-3
44.9	0.00	0	0.01	0.00	0

48.6	0.00	0	0.07	0.00	0
52.0	0.00	0	1.54	0.00	-2
Height (m) of high blade reach *					
22.9 – 27.4	0.66	18	23.18	0.78	-8
29.5 – 33.6	1.03	20	16.76	1.19	5
34.4	1.72	22	13.94	1.58	12
36.9 – 52.0	0.96	9	15.12	0.60	-9
Wind wall *					
In zigzag pattern		0	4.80	0.00	-7
Not in wind wall	1.15	68	60.24	1.13	11
In wind wall	0.10	1	3.96	0.25	-4
Position in string **					
End	2.09	33	15.81	2.09	25
Edge of gap	1.13	7	7.02	1.00	0
Interior	0.61	28	45.91	0.61	-26
Non-operational	4.43	1	0.21	4.86	1
Location in wind farm					
Edge of farm	0.55	5	8.43	0.59	-5
Edge of local cluster	0.70	5	7.44	0.67	-4
Interior of wind farm	1.12	59	52.91	1.12	9
Turbine congestion (no. in 300 m)					
0 - 12	1.52	12	10.00	1.20	3
13 - 24	1.15	36	33.55	1.07	4
25 - 36	0.83	14	15.05	0.93	-2
37 - 72	0.54	7	10.37	0.68	-5
Elevation (m) **					
85 - 135	1.65	17	8.56	1.99	12
135 - 185	1.65	24	14.36	1.67	14
185 - 235	2.48	23	11.47	2.00	17
235 - 285	0.46	2	4.71	0.43	-4
285 - 335	0.00	0	11.30	0.00	-16
335 - 385	0.38	3	7.29	0.41	-6
385 - 535	0.00	0	11.27	0.00	-16
Slope grade (degrees)					
0	0.98	27	25.50	1.06	2
2 - 5	0.92	5	5.22	0.96	0
6 - 14	0.77	13	17.07	0.76	-6
15 - 58	1.25	24	21.18	1.13	4
Physical relief					
Peak	0.00	0	1.05	0.00	-2
Plateau	1.06	5	3.57	1.40	2
Ridge crest	1.01	22	25.10	0.88	-5
Ridgeline	0.58	8	13.32	0.60	-8
Slope	1.26	29	21.94	1.32	10

Saddle	1.00	3	2.61	1.15	1
Ravine	1.96	1	0.40	2.49	1
Canyon					
Not in canyon	0.92	54	56.24	0.96	-3
In canyon	1.43	15	12.76	1.18	3
Slope curvature feature **					
Valley (concave trending)	1.53	25	14.61	1.71	15
Ridge (convex trending)	0.84	44	54.39	0.81	-15
Slope aspect					
None (flat)	0.95	19	19.80	0.96	-1
North-facing	1.10	11	9.43	1.17	2
Northeast	0.89	4	4.35	0.92	-1
East	1.20	7	5.84	1.20	2
Southeast	0.51	4	7.25	0.55	-5
South	2.11	12	6.05	1.98	9
Southwest	0.83	1	1.25	0.80	0
West	0.39	1	2.65	0.38	-2
Northwest	0.88	10	12.30	0.81	-3
Slope aspect					
None (flat)	0.95	19	19.80	0.96	-1
East-northeast	1.07	11	10.19	1.08	1
South-southeast	1.18	16	13.29	1.20	4
West-southwest	0.53	2	3.89	0.51	-3
North-northwest	0.98	21	21.73	0.97	-1
Aspect of ridge relative to wind [t]					
Flat	0.83	26	31.04	0.84	-7
Windward to NW or SW winds	1.53	26	16.76	1.55	13
Windward & perpendicular	0.96	15	16.19	0.93	-2
Windward to NW & SW winds	0.41	2	5.01	0.40	-4
Edge index at tower base					
No edge	0.76	2	2.39	0.84	-1
Some lateral edge	1.06	7	6.55	1.07	1
Lots lateral edge	0.60	13	20.97	0.62	-12
Some vertical edge	1.36	30	22.33	1.34	11
Lots vertical edge	1.13	16	14.34	1.12	2
Lots vertical & lateral edge	0.50	1	2.43	0.41	-2
Rock piles ≤50 m away					
None	0.91	51	54.88	0.93	-6
1	1.46	9	6.46	1.39	4
≥2	1.45	7	5.66	1.24	2
Rodent control through 2001 **					
Unknown	2.40	2	1.06	1.88	1
None	0.82	13	12.54	1.04	1
Control	1.90	35	22.48	1.56	18

Intense control	0.56	19	32.92	0.58	-20
Rodent control through 2002 *					
Unknown	2.40	2	1.06	1.88	1
None	0.43	5	10.15	0.49	-7
Control	1.89	35	22.50	1.56	18
Intense control	0.71	27	35.29	0.77	-12
Cattle pats 40 m from turbines [t]					
0	0.00	0	5.71	0.00	-9
1 - 9	1.03	32	30.18	1.06	3
10 - 25	1.16	24	21.55	1.11	4
>25	1.29	9	7.57	1.19	2
Cattle pats at turbines					
0 - 2	0.47	4	7.10	0.56	-5
3 - 9	0.68	15	20.00	0.75	-8
10 - 25	1.18	25	22.32	1.12	4
>25	1.59	21	15.59	1.35	8
Cottontails 40 m from turbines					
No pellets	0.99	50	52.55	0.95	-4
Some pellets	0.96	11	10.08	1.09	1
Abundant pellets	1.33	4	2.37	1.69	3
Cottontails at turbines					
No pellets	0.93	46	51.71	0.89	-9
Some pellets	1.41	16	9.96	1.61	9
Abundant pellets	0.72	3	3.33	0.90	-1
Vegetation height (cm)					
0 - 10	0.89	10	10.53	0.95	-1
11 - 20	1.14	24	20.56	1.17	5
21 - 35	0.96	19	18.82	1.01	0
> 35	0.93	12	15.08	0.80	-5
Pocket gopher clustering [t]					
Obs/Exp in 15 m = 0	0.53	1	1.89	0.53	-3
Obs/Exp in 15 m <1.5	2.23	7	3.14	2.23	14
Obs/Exp in 15 m = 1.5-3.0	0.65	7	10.70	0.65	-13
Obs/Exp in 15 m >3	1.06	13	12.28	1.06	3
Ground squirrel clustering					
Obs/Exp in 15 m = 0	0.51	5	9.87	0.51	-17
Obs/Exp in 15 m ≤1.14	1.11	12	10.85	1.11	4
Obs/Exp in 15 m >1.14	1.51	11	7.28	1.51	13
Pocket gopher density ≤90 m					
0 – 1.4/ha	0.75	7	9.29	0.75	-8
1.41 – 3.5/ha	1.36	12	8.79	1.36	12
>3.5/ha	0.90	8	8.87	0.90	-3
Ground squirrel density ≤90 m					
0/ha	0.20	1	4.99	0.20	-14

0.01 – 5.99/ha	1.22	20	16.38	1.22	13
≥6/ha	1.06	7	6.63	1.06	1
Clustering of all burrows					
Obs/Exp in 15 m = 0-1.2	1.21	7	5.80	1.21	4
Obs/Exp in 15 m = 1.2-3.0	1.10	16	14.53	1.10	5
Obs/Exp in 15 m >3	0.65	5	7.67	0.65	-10
Density of all burrow systems					
< 5/ha	0.74	8	10.79	0.74	-10
5 – 9/ha	1.21	10	8.24	1.21	6
> 9/ha	1.11	10	8.98	1.11	4
Season of the year **					
Spring	0.16	3	18.83	0.16	-23
Summer	1.83	30	17.10	1.75	19
Fall	0.84	10	12.15	0.82	-3
Winter	1.20	24	19.92	1.20	6