COMPARISON OF MORTALITY ESTIMATES IN THE ALTAMONT PASS WIND RESOURCE AREA WHEN RESTRICTED TO RECENT FATALITIES

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During another in a series of discussions we have had on the accuracy and precision of mortality estimates in the Altamont Pass Wind Resource Area (APWRA), we addressed the effect on mortality estimates due to error in estimating time since death of a found fatality. An effect of such error could be realized if the mortality estimator relied on estimates of time since death of each carcass rather than the number of days since the last fatality search, for example. We asked ourselves whether mortality estimates might be more reliable by restricting them to the 7-day period just preceding each fatality search, relying only on "fresh" carcasses rather than all the carcasses found since the last fatality search, which averaged 41 days from fall 2005 to fall 2007 in the APWRA (Altamont Pass Avian Monitoring Team 2008, Smallwood 2008). Not only would these fresh carcasses be more accurate in their estimated days since death, but the adjustments for scavenger removal would be much smaller and therefore much less of an influence on the mortality estimates (Smallwood 2007), and the cause of death would be more apparent.

We recognize that estimates of time since death are much more likely to be accurate when attributed to carcasses found within 7 days of death, and that uncertainty in the time-since-death estimates increases over periods longer than 7 days. Within 3 days since death, the fatality searchers might err in their estimates of time since death by about a day. Within a week of death, the fatality search crews might err by at most 3 days. On the other hand, between 1 and 3 months since death, fatality searchers might err in their estimates by two months or more, because it is often difficult to determine whether a carcass has been in the environment for 2 months or 4 months. Therefore, assuming a steady rate of carcass deposition from wind turbines over the average fatality search interval, we compared mortality estimates based on restricted ranges of days since the fatalities were estimated to have occurred before the fatality searches. If the scavenger removal functions in Smallwood (2007) are realistic, and if the fatality searchers are accurate in their estimates of time since death, then mortality estimates should not change when based on only 3 days preceding each fatality search, or when based on only 7 days preceding each search.

Because the fatality searchers typically estimated time since death as ranges of days, our comparisons were restricted to these ranges. Typical ranges were 0-3, 4-7, 8-30, 30-90, and 0-90 days since death. The average search interval was 41 days for data collected from fall 2005 to fall 2007, so we compared the mortality estimates from the average 41-days search interval to those from 0 to 3 days, 0 to 7 days, and 0 to 30 days before searches. Additionally, we estimated the number of carcasses that should have been found within each of these portions of the average search interval, given the total number we found over the two year monitoring period and assuming a steady rate of carcass deposition. For example, the 3 days preceding the fatality searches amounted to $3 \div 41 = 0.07317$, or 7.3% of the search interval. From the total number of fatalities found over the monitoring period, 7.3% should have been killed within 3 days of the fatality search, on average. This additional comparison of actual to expected numbers of fatalities attributed to portions of the average search interval served as another means to check on the accuracy of the scavenger removal functions in Smallwood (2007) and the fatality searchers' estimates of time since death.

Assuming a steady rate of carcass deposition from wind turbines within the average search interval, our objective was to check whether the numbers of fatalities found and the resulting mortality estimates were proportionally distributed across portions of the average search interval. Disproportionate mortality estimates or numbers of fatalities should indicate whether scavenger removal rates are incorrectly represented throughout the average search interval or whether fatality searchers have been unbiased in their estimates of days since death, though additional research would be needed to determine which explanation is true. We hope that our exploration will assist the Alameda County Scientific Review Committee (SRC) to better understand the strengths and weaknesses of existing mortality estimates, and to improve methodology.

METHODS

Data collection in the field, data management, and analytical assumptions have been described in other reports (Altamont Pass Avian Monitoring Team 2008, Smallwood 2007, 2008; Smallwood and Thelander 2004, 2005, 2008; Smallwood et al. 2007), so will not be described again here. One difference here is that we did not estimate mortality for Diablo Winds, nor did we include fatality records or searches that were from the Vasco Caves Regional Preserve. Our estimates were derived from all other old-generation wind turbines searched routinely from fall 2005 to fall 2007 by the Alameda County monitoring team, and can be extrapolated to 547.02 MW of rated capacity of the APWRA, although extrapolation of the estimates was not our aim in this report. Another difference was our exclusion of fatalities that were found incidentally to the standard fatality searches (see below). In this report we did not report the standard errors or confidence intervals of the mortality estimates, but instead restricted our comparisons to the averages among turbine strings.

Groups compared were the ranges of days since death routinely attributed to carcasses found by the monitoring team. These ranges reflected the monitoring team's confidence in estimating days since death. Ranges typically were 0 to 3 days, 4 to 7 days, <1 month, and after one month the ranges were much larger. We selected 3 days, 7 days, and 30 days to be our temporal boundaries around carcasses to be included in mortality estimates. In the 3-day group, we selected only those fatalities found by the monitoring team during standard searches and estimated to have occurred within 3 days prior to the fatality search. We adjusted the mortality estimates by the proportion of carcasses estimated to remain following scavenger removal over a 3 day period, as reported in Smallwood (2007). We also adjusted the estimates by the proportion of the monitoring period (i.e., fall 2005 to fall 2007) composed of 3 days before each search. The average search interval over the monitoring period was 41 days. Thus, if 20 searches were performed at a string over the 2.25 year period (20 searches averaging 41 days between searches equals 2.25 years), then 20 x 3 days = 60 days, or 7.3% of the entire monitoring period. The mortality metric was changed accordingly:

Unadjusted mortality, $M_U = \text{deaths} \div \text{MW} \div \left(\text{years} \times \sum 3\text{ day intervals}\right)$, Adjusted mortality, $M_A = \frac{M_U}{p \times R}$, and the values of R were taken from Day 3 in Appendix 1 of Smallwood (2007). The same approach was used for the 7-day group and the 30-day group, where 7 days before each search comprised 17.1% of the average 41-day search interval, and 30 days before each search comprised 73.2% of the average 41-day search interval. Essentially, we pretended as though 3 days, 7 days, and 30 days were the search intervals preceding each fatality search, so we adjusted the estimates for scavenger removal rates and fractions of the overall time period of the monitoring from 2005 to 2007.

Additionally, for each species we multiplied the number of fatalities tabulated over the monitoring period by the fraction of the average search interval composed of 3 days, 4-7 days, 8-30 days, and >30 days before the fatality searches. So if 100 fatalities of species A were found over the two year monitoring period, then the expected number of fatalities within 3 days of fatality searches would be $N \cdot 0.07317 = 7.3$ fatalities of species A. This expected number was compared to the number of fatalities determined to have occurred within the last 3 days.

RESULTS

Incidental fatality finds composed substantial portions of mortality estimates for some species. They contributed 34% of the mortality estimate of golden eagle, 40% of red-tailed hawk, 24% of great horned owl, and 32% of barn owl, but none of burrowing owl mortality estimates (Table 1; Fig. 1, left graph). Some species were only found incidentally, so excluding incidental finds from mortality estimates reduced the estimates. All bird mortality without incidental finds was only 72% of the estimate with the incidental finds (Table 1).

Compared to the estimates based on the average 41-day search interval, mortality of large raptors tended to increase when restricted to shorter periods, whereas mortality estimates of small-bodied raptors tended to decrease (Figure 1, Tables 1 and 2). Restricting the search interval to 3 days increased our estimate of golden eagle mortality 2.09 times (Table 2). It increased our estimated mean mortality of red-tailed hawks 1.28-fold (Table 2). Over only a 3 day period, the American kestrel mortality estimate declined to 6.6% of the estimate made over the entire search interval, and estimated burrowing owl mortality declined to 30% of the estimate made over the entire search interval. Overall, raptor mortality estimates from restricted portions of the search interval were 43% to 61% of the estimate from the complete search interval, and the all bird mortality estimates were 40% to 68% of the estimate from the complete search interval (Tables 1 and 2). Mortality estimates made from restricted intervals of 3 and 7 days prior to the fatality searches were considerably different from those made from the restricted interval of 30 days prior to the searches (Table 2; Figure 1, right graph).

As the search interval was restricted to smaller portions of the entire period, the number of species with estimates of 0 mortality increased, or another way of saying the same thing, as the search interval increased, the number of species found dead increased (Figure 2, left graph). This pattern correlated with mortality of all bird species grouped together (Figure 2, right graph). Of the bird species documented to have been found under wind turbines during the two-year monitoring period, 60% were not found within the 3 days preceding the fatality searches, so only

40% of the species contributed to the overall bird mortality estimate, and the overall estimate was 41% of that from all species found over the entire monitoring period.

Assuming a steady rate of carcass deposition from wind turbines throughout the search interval, disproportionately more large-bodied raptors were attributed to death within 3 days and older than 30 days before the fatality searches (Table 3, Figure 3). The number of fatalities estimated to have been killed within 3 days was 238% of the expected number of golden eagles, and 158% of the expected number of red-tailed hawk fatalities. The number of fatalities estimated to have been killed between 4 and 7 days and between 8 and 30 days was usually smaller than the number expected, and the number estimated to have been killed between 30 days and the last fatality search was much larger than expected for most bird species (Table 3; Figure 3, right graph). American kestrels stood out as unusual among bird species because the number of estimated to have been killed within 3 days of the fatality search was only 27% of the expected number, and the percentage of the expected actually found increased with increasingly older spans of days before the fatality search. In other words, there were many fewer than the expected number of American kestrels estimated to have been killed within 3 days and many more than the expected number estimated to have been killed between 30 and an average of 41 days prior to the search.

DISCUSSION

Because disproportionate numbers of golden eagle and red-tailed hawk carcasses were considered fresh, our estimates of golden eagle and red-tailed hawk mortality increased substantially after restricting our search interval to the 3 days preceding each search. The searchers found 238% and 158% of the expected numbers of golden eagle and red-tailed hawk carcasses estimated to have died the previous 3 days, and these discrepancies resulted in mortality estimates that were 209% and 128% of the non-restricted mortality estimates, respectively. Applied APWRA-wide, the restricted 3-day search interval would increase golden eagle mortality from 68 per year to 142 per year, and it would increase red-tailed hawk mortality from 399 per year to 511 per year. Restricting the search interval to 3 days can make a substantial difference in mortality estimates of large raptors. Either the estimates of days since death of large raptors have been biased too recent, or large raptor carcasses have been removed over the average 41-day search interval at rates that were higher than previously estimated. At this time, we do not know which explanation for the discrepancy is true, or whether both explanations are true. However, there remains the possibility that more golden eagles and red-tailed hawks are being killed at wind turbines than previously thought.

On the other hand, the number of American kestrel carcasses estimated to have been killed within 3 days of the searches was 27% of the expected number, resulting in a mortality estimate derived from this interval that was only 7% of the unrestricted search interval. Although the number of burrowing owls estimated to have been killed within 3 days of the searches was about equal the expected number, burrowing owl mortality over this restricted search interval was only 30% of the estimate from the unrestricted interval. The difference in mortality estimates was caused by the much faster scavenger removal rate attributed to American kestrels and burrowing owls over the longer 41-day search interval (Smallwood 2007). It would appear likely that the scavenger removal function used to adjust the mortality estimates of American kestrels and burrowing owls have introduced artificial inflations. The most likely cause of these inflations is the assumption stemming from conventional scavenger removal trials that carcass removal equates with searchers no longer able to detect the fatality, but the fatality searchers have been finding feather piles of American kestrels and burrowing owls in the APWRA. It may be that detection probability actually increases with feather piles compared to intact carcasses.

Given the increasing omissions of bird species from mortality estimates made for multi-species groups, we conclude that the most representative search interval is the complete time period between searches. Using the entire search interval dampens the effects of the error in estimating the number of day since death. However, given the likely inflation of small raptor mortality estimates due to the frequent discovery of feather piles (72% of American kestrel carcasses and 83% of burrowing owl carcasses), we also conclude that more research is needed to more accurately estimate carcass removal rates of small raptors and the number of days since death of carcasses represented by feather piles. Also, more research is needed to determine whether golden eagle and red-tailed hawk carcasses are disappearing from the search areas at faster rates than measured to date.

Another implication of our results relates to how mortality is estimated. There has been recent consideration of relying on a new estimator, which adjusts the values of individual fatalities by scavenger removal rates. Thus, the estimated number of days since death of each fatality would be used to estimate the likelihood that the carcass would have remained in the face of removal of carcasses by scavengers. This approach would differ from the conventional approach of attributing carcass removal rates to the average search interval, thus not factoring in estimates of days since death except as a screening tool used to exclude carcasses that had unlikely been deposited since the last fatality search. The new approach would assume the estimates of time since death are reasonably accurate and precise, even though the reported ranges of days since death suggest they are highly imprecise in most cases. Our results herein suggest the estimates of days since death are also inaccurate, and appear to be biased toward fewer days since death for large raptors and more days since death for most bird species. The new approach would likely inflate mortality estimates for most species, and wildly so for some species. It would also need to carry a very large, additional error term through the calculation of mortality, resulting in large uncertainty ranges.

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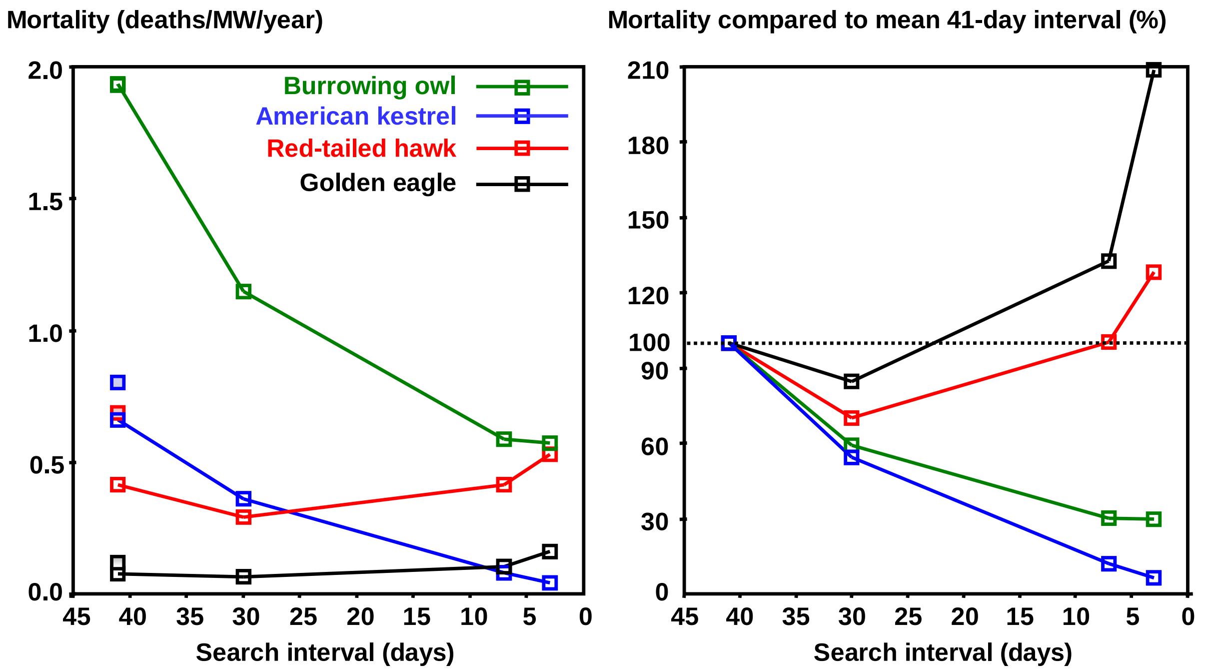

Figure 1. Shifts in mortality estimates of 4 target raptor species in response to restrictions on the portion of the entire search interval used to make the estimates, where the shifts are depicted in original units (left graph) and percentages of the estimates derived from the average 41-day search intervals (right graph). The estimates from the complete search interval are to the left of each graph (mean 41 days), and the estimates from the 3 days immediately prior to each search are to the right of each graph.

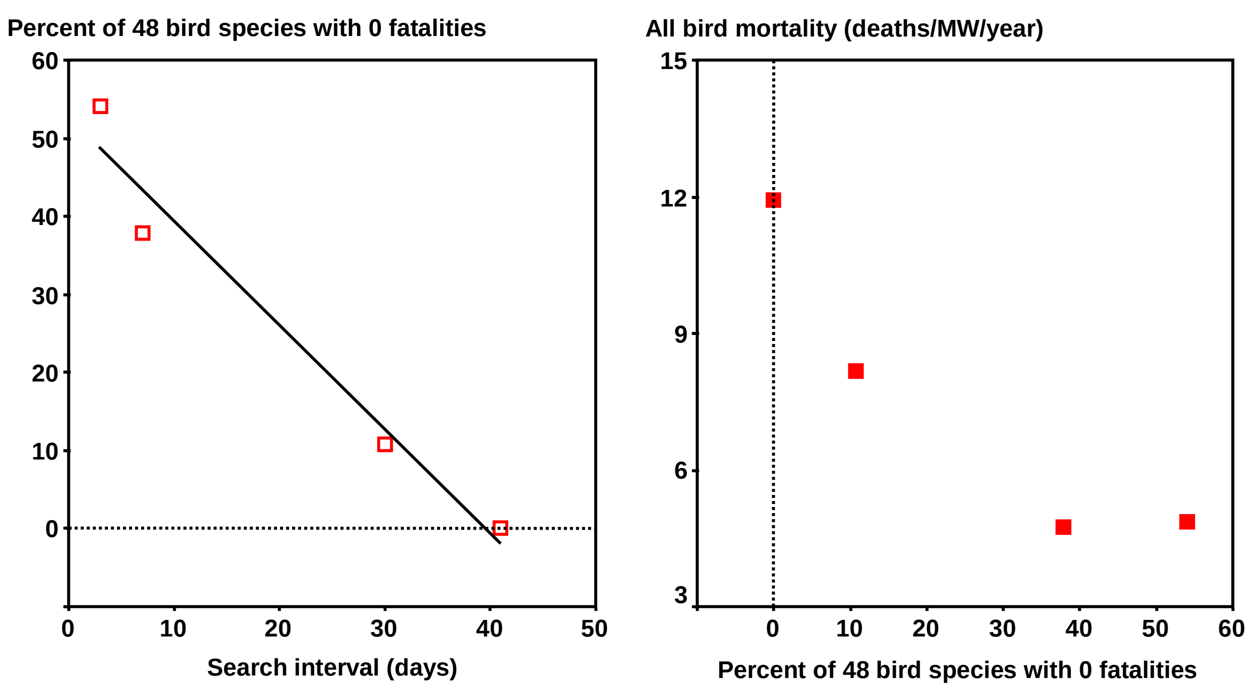

Figure 2. The percent of bird species with 0 mortality increased with smaller portions of the entire search interval used (left graph), and correlated with overall bird mortality (right graph).

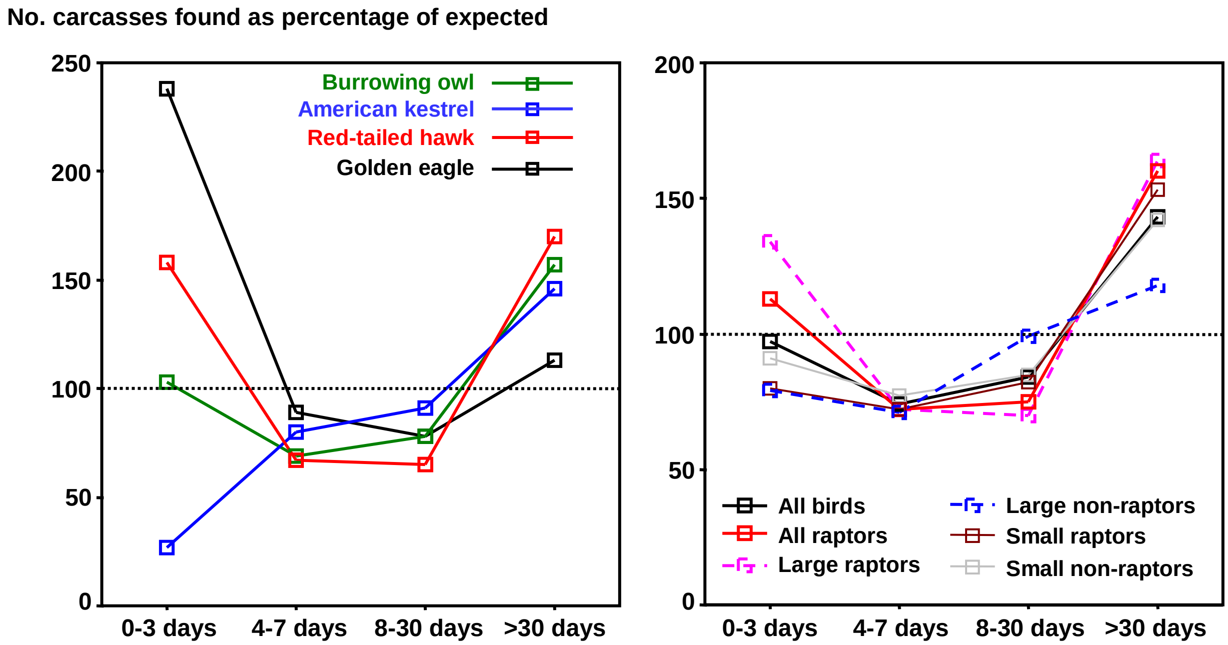

Figure 3. The number of fatalities found as a percentage of the number expected to have been killed within ranges of days preceding the fatality searches, assuming a steady rate of carcass deposition from wind turbines. Target raptor species are depicted in the left graph, and groups of birds based on taxonomic groupings and body size are depicted in the right graph.

Table 1. Mortality estimates from restricted portions of the entire search interval (30, 7, and 3 days) compared to the estimates from the entire search interval (mean 41 days) with and without fatalities found incidentally.

	Mortality (Deaths/MW/year) caused within the preceding:				
	Mean 41 days				
Species/Group	**All data, including incidentals**	**Only standard searches**	**30 days**	**7 days**	**3 days**
Turkey vulture	0.01800	0.01538	0.01522	0.01341	0.03098
Golden eagle	0.11761	0.07762	0.06567	0.10296	0.16211
Red-tailed hawk	0.68778	0.41339	0.29027	0.41530	0.53029
Ferruginous hawk	0.00126	0.00000	0.00000	0.00000	0.00000
Swainson's hawk	0.00099	0.00000	0.00000	0.00000	0.00000
Red-shouldered hawk	0.00056	0.00056	0.00075	0.00000	0.00000
Buteo sp.	0.03043	0.03043	0.00000	0.00000	0.00000
Northern harrier	0.00603	0.00603	0.00815	0.02765	0.00000
White-tailed kite	0.00067	0.00000	0.00000	0.00000	0.00000
Hawk sp.	0.00179	0.00000	0.00000	0.00000	0.00000
Raptor sp.	0.00424	0.00424	0.00260	0.00000	0.00000
Prairie falcon	0.00246	0.00119	0.00080	0.00000	0.00000
Great horned owl	0.05812	0.04417	0.05031	0.09547	0.04206
Barn owl	0.25583	0.14299	0.10543	0.07880	0.06095
Owl sp.	0.00024	0.00000	0.00000	0.00000	0.00000
American kestrel	0.80167	0.65844	0.35949	0.07879	0.04320
Burrowing owl	1.93222	1.93441	1.14674	0.58752	0.57321
Great blue heron	0.00133	0.00000	0.00000	0.00000	0.00000
Great egret	0.05141	0.00000	0.00000	0.00000	0.00000
Sandhill crane	0.00275	0.00275	0.00343	0.00000	0.00000
Wild turkey	0.00168	0.00168	0.00104	0.00000	0.00000
Mallard	0.12220	0.10905	0.08413	0.10897	0.00000
Gull sp.	0.11501	0.10087	0.09705	0.02370	0.04984
California gull	0.01163	0.01163	0.01448	0.04759	0.10007
Duck sp.	0.01782	0.01097	0.00720	0.00000	0.00000
Common raven	0.16237	0.12706	0.08169	0.02340	0.00000
American crow	0.05573	0.02381	0.01520	0.00000	0.00000
Rock pigeon	1.46320	1.07652	1.02370	1.19408	1.48313
Black-necked stilt	0.04198	0.04198	0.04556	0.00000	0.00000
Killdeer	0.01150	0.01150	0.01249	0.01020	0.00000
White-throated swift	0.05367	0.01432	0.01554	0.00000	0.00000
Western tanager	0.00404	0.00404	0.00439	0.00000	0.00000
Tree swallow	0.00426	0.00000	0.00000	0.00000	0.00000
Cliff swallow	0.03536	0.00000	0.00000	0.00000	0.00000
American pipit	0.00598	0.00598	0.00649	0.01550	0.03023
Bluebird sp.	0.09320	0.09320	0.08527	0.00000	0.00000
Mountain bluebird	0.06185	0.06185	0.02525	0.03794	0.00000

Rock wren	0.01632	0.00000	0.00000	0.00000	0.00000
House wren	0.00857	0.00857	0.00930	0.02222	0.04332
Northern flicker	0.02799	0.02799	0.00000	0.00000	0.00000
Swainson's thrush	0.01537	0.01537	0.01668	0.00000	0.00000
Loggerhead shrike	0.32506	0.25152	0.25474	0.03059	0.00000
Horned lark	0.53148	0.49896	0.34949	0.00000	0.00000
Hammond's flycatcher	0.00534	0.00534	0.00580	0.00000	0.00000
Say's phoebe	0.02060	0.02060	0.00000	0.00000	0.00000
Mourning dove	0.56680	0.37762	0.33794	0.09642	0.08190
Dove sp.	0.06513	0.06513	0.05433	0.00000	0.00000
European starling	3.39327	2.23045	1.29779	0.44284	0.54500
Northern mockingbird	0.01707	0.00000	0.00000	0.00000	0.00000
Scrub jay	0.00161	0.00000	0.00000	0.00000	0.00000
Western meadowlark	3.14874	2.32843	1.58425	1.00064	0.94893
Red-winged blackbird	0.25527	0.19468	0.20595	0.20522	0.00000
Brewer's blackbird	0.35423	0.26940	0.26706	0.08366	0.13295
Brown-headed cowbird	0.05260	0.05260	0.00000	0.00000	0.00000
Blackbird sp.	0.38482	0.35730	0.13833	0.00000	0.00000
Lincoln sparrow	0.00534	0.00534	0.00580	0.00000	0.00000
Sparrow sp.	0.01429	0.00000	0.00000	0.00000	0.00000
Cockatiel	0.02234	0.00000	0.00000	0.00000	0.00000
Unidentified bird sp.	0.29468	0.19964	0.07229	0.00000	0.00000
Bats	0.09608	0.06526	0.07082	0.05345	0.10422
All birds	16.61179	11.93502	8.16810	4.74288	4.85816
All raptors	3.92230	3.32884	2.04544	1.39989	1.44280
Four target raptors	3.53927	3.08386	1.86217	1.18456	1.30882

Table 2. Mortality estimates from restricted portions of the entire search interval (30, 7, and 3 days) as percent of the estimate from the entire search interval (mean 41 days), where the fatalities used were found during standard searches only.

	Mortality as percent of average 41 day search when restricted to using fatalities caused within the preceding:		
Species/Group	**30 days**	**7 days**	**3 days**
Turkey vulture	99	87	201
Golden eagle	85	133	209
Red-tailed hawk	70	100	128
Red-shouldered hawk	135	0	0
Buteo sp.	0	0	0
Northern harrier	135	459	0
Raptor sp.	61	0	0
Prairie falcon	67	0	0
Great horned owl	114	216	95
Barn owl	74	55	43
American kestrel	55	12	7
Burrowing owl	59	30	30
Sandhill crane	124	0	0
Wild turkey	62	0	0
Mallard	77	100	0
Gull sp.	96	23	49
California gull	124	409	860
Duck sp.	66	0	0
Common raven	64	18	0
American crow	64	0	0
Rock pigeon	95	111	138
Black-necked stilt	109	0	0
Killdeer	109	89	0
White-throated swift	109	0	0
Western tanager	109	0	0
American pipit	109	259	505
Bluebird sp.	91	0	0
Mountain bluebird	41	61	0
House wren	109	259	505
Northern flicker	0	0	0
Swainson's thrush	109	0	0
Loggerhead shrike	101	12	0
Horned lark	70	0	0
Hammond's flycatcher	109	0	0
Say's phoebe	0	0	0
Mourning dove	89	26	22
Dove sp.	83	0	0
European starling	58	20	24

Western meadowlark	68	43	41
Red-winged blackbird	106	105	0
Brewer's blackbird	99	31	49
Brown-headed cowbird	0	0	0
Blackbird sp.	39	0	0
Lincoln sparrow	109	0	0
Unidentified bird sp.	36	0	0
Bats	109	82	160
All birds	68	40	41
All raptors	61	42	43
Four target raptors	60	38	42

Table 3. Numbers of fatalities found as percentages of those expected from restricted portions of the entire search interval (30, 7, and 3 days), assuming steady rates of carcass deposition from wind turbines, where the fatalities used were found during standard searches only.

Species/Group	Total fatalities	Fatalities found as percent of expected number within:			
		0-3 days	4-7 days	8-30 days	>30 days
Turkey vulture	5	273	0	107	75
Golden eagle	23	238	89	78	113
Red-tailed hawk	138	158	67	65	170
Red-shouldered hawk	1	0	0	178	0
Buteo sp.	8	0	0	0	373
Northern harrier	3	0	683	59	0
Raptor sp.	2	0	0	89	186
Prairie falcon	2	0	0	89	186
Great horned owl	17	241	121	94	66
Barn owl	56	24	55	76	186
American kestrel	51	27	80	91	146
Burrowing owl	119	103	69	78	157
Sandhill crane	1	0	0	178	0
Wild turkey	2	0	0	89	186
Mallard	7	0	146	76	160
Gull sp.	14	98	0	115	106
California gull	1	1367	0	0	0
Duck sp.	2	0	0	89	186
Common raven	16	0	64	89	163
American crow	4	0	0	134	93
Rock pigeon	212	84	77	99	114
Black-necked stilt	1	0	0	178	0
Killdeer	2	0	513	89	0
White-throated swift	2	0	0	178	0
Western tanager	1	0	0	178	0
American pipit	1	1367	0	0	0
Bluebird sp.	3	0	0	119	124
Mountain bluebird	7	0	146	25	266
House wren	1	1367	0	0	0
Northern flicker	1	0	0	0	373
Swainson's thrush	1	0	0	178	0
Loggerhead shrike	10	0	103	143	37
Hammond's flycatcher	1	0	0	178	0
Horned lark	14	0	0	102	160
Say's phoebe	1	0	0	0	373
Mourning dove	19	72	54	131	59
Dove sp.	7	0	0	127	106
European starling	107	115	48	87	143
Western meadowlark	131	104	110	67	165
Red-winged blackbird	12	0	256	119	31

Brewer's blackbird	11	248	93	97	68
Brown-headed cowbird	1	0	0	0	373
Blackbird sp.	13	0	0	82	201
Lincoln sparrow	1	0	0	178	0
Unidentified bird sp.	11	0	0	65	237
Bats	3	911	0	59	0
All small raptors	170	80	72	82	153
All large raptors	255	134	72	70	164
Four target raptors	331	124	71	74	158
All raptors	425	113	72	75	160
All small non-raptors	359	91	77	85	142
All medium & large non-raptors	259	79	71	99	118
All birds	1043	97	74	84	143