BIOLOGICAL EFFECTS OF REPOWERING A PORTION OF THE ALTAMONT PASS WIND RESOURCE AREA, CALIFORNIA: THE DIABLO WINDS ENERGY PROJECT

K. Shawn Smallwood

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EXECUTIVE SUMMARY

WEST, Inc. (2006) reported on the first year of fatality monitoring in the Diablo Winds Energy Project, which replaced 169 vertical axis wind turbines with 31 larger horizontal axis wind turbines in the Altamont Pass Wind Resource Area (APWRA). WEST, Inc. also compared bird utilization and mortality in the project area to utilization and mortality reported by Smallwood and Thelander (2004) across the APWRA. West, Inc. concluded mortality declined after Diablo Winds even though raptor utilization of the area increased. I reviewed the WEST, Inc. report, other reports of bird utilization and mortality at other wind farms, and I analyzed the Smallwood and Thelander data collected at the 169 wind turbines that were replaced.

I found WEST, Inc. inappropriately compared bird observations to 800 m to the data Smallwood and Thelander collected to 300 m. Recording birds seen to 800 m misses many of the birds that should have occurred between 300 and 800 m, but even so this practice artificially inflates the number of birds seen per unit time because the total area within an 800-m radius is seven times the area within a 300-m radius. I quantified the bias and adjusted the WEST, Inc. utilization estimates, revealing raptor activity in the study area decreased rather than increased after Diablo Winds.

The WEST, Inc. mortality estimator also is statistically biased because its adjustments for searcher detection error and scavenger removal rates were based on incorrect assumptions that inflated mortality estimates in the case of searcher detection error, and lowered estimates in the case of scavenger removal error. It was inappropriate to use rock dove as a surrogate for large birds and large raptors in searcher detection trials, and the same was true of scavenger removal trials. The mean number of days to carcass removal, which is the scavenger removal adjustment term used by WEST, Inc., turned out to increase systematically with the duration of the trial and with increasing sample size of carcasses used (until about 50 were used). Except for the case of large raptors, most carcasses deposited under wind turbines are quickly carried off by vertebrate scavengers, but when many carcasses are placed in the field at once vertebrate scavengers simply cannot carry them all away before some decompose to unattractive levels The remaining carcasses “mummify,” and will usually remain throughout the trial, so the more days used in the trial, the more these mummified carcasses will factor into the calculation of the mean days to carcass removal. I quantified these biases, and developed an alternative scavenger removal term.

Relying on all suitable reports I obtained of scavenger removal trials, I developed a simple model to predict the percentage of carcasses remaining each day following the commencement of a removal trial or of the next fatality search interval, assuming a steady state of carcass deposition by wind turbines. Adjusted mortality estimates caused by the new and replaced wind turbines indicated overall bird mortality was reduced 70% by the Diablo Winds Energy Project, and

raptor mortality was reduced 62%. Burrowing owl mortality was reduced 85%, and most of the total bird mortality reduction appeared to be among song birds. On the other hand, red-tailed hawk mortality increased nearly three-fold, and some species were killed by Diablo Winds that were not reported killed by the replaced turbines during Smallwood and Thelander's study, including golden eagle and bats. Differences in mortality were likely due to the reduced number of wind turbines, turbine siting, and the increased height above ground of the turbines, but additional research will be needed. Also, the repowering did not change the risk of collision for all raptors or all birds, perhaps because avian utilization of the Diablo Winds project site declined along with mortality between studies,[1] or perhaps because the utilization data are not reliably comparable.

My analysis of bird utilization and mortality data among the new and replaced wind turbines indicates a decline occurred in bird utilization over the last 8 years, but the Diablo Winds Energy Project is killing smaller numbers of birds than did the Flowind vertical axis turbines. I believe bird mortality could have been reduced further had the wind turbine siting and operations recommendations of Smallwood and Thelander (2004, 2005) been implemented, and I believe future repowering efforts in the APWRA can also reduce mortality more substantially by adopting the recommendations of Smallwood and Thelander (2004, 2005), Smallwood and Neher (2004), and Smallwood and Spiegel (2005a,b,c).

The mortality adjustments in this report include multiple uncertainties and potential statistical biases yet to be completely characterized. Directed research is needed to address these and other uncertainties. Furthermore, the first annual report of Diablo Winds fatalities is preliminary because the time period was short and the sample size of fatalities small. Several years of monitoring will be needed to make more robust comparisons of mortality before and after the project.

INTRODUCTION

In February 2005 FPL Energy completed the replacement of 169 Flowind F-17 and F-19 vertical axis wind turbines (Photo 1) with 31 Vestas V47 horizontal axis wind turbines (Photo 2). The Flowind wind turbines had totaled 21 MW of rated capacity, whereas the Vestas turbines total 20.46 MW of rated capacity. The Flowind turbines were 29.5 and 32.3 m in total height, with rotor diameters of 17.2 and 19.1 m between the F-17 and F-19 models, respectively. The Vestas V47 turbine is 50 m high at the hub for 24 of the turbines and 55 m for 7 turbines, and the maximum height of the blade reach is 73.5 m for 24 turbines and 78.5 m for the other 7 turbines. The Vestas V47 turbine has a rotor diameter of 47 m.

The 169 replaced Flowind turbines had been monitored for fatalities during the Smallwood and Thelander (2004) study, though mortality estimates were not reported separately for these wind turbines. WEST, Inc. (2006) reported the results of fatality searches at the Vestas V47 wind turbines during the period March 2005 through February 2006. Additionally, WEST, Inc. (2006)

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[1] The risk of collision is a ratio, so if both the numerator and denominator change in the same direction, then the ratio value remains the same. For example, 8 divided by 10 is 0.8, but then so is 4 divided by 5.

Photo 1. Flowind F-17 vertical axis wind turbines in the Altamont Pass Wind Resource Area prior to replacement in the Diablo Winds Energy Project.

Photo 2. Vestas V47 wind turbines in the foreground, and KCS56-100 wind turbines in the background.

reported the results of bird observations through the year, and compared their results to the results reported in Smallwood and Thelander (2004).

The purpose of this review is to improve upon the analysis in the WEST, Inc. (2006) report in order to generate a more reliable comparison of raptor utilization and wind turbine-caused mortality in the Diablo Winds Energy Project before and following the repowering effort.

BIRD UTILIZATION

WEST, Inc. (2006) reported their bird observation methods followed the methods of Smallwood and Thelander (2004a,b), but this report was not entirely correct. (As a clarification, the Smallwood and Thelander (2004a) citation appearing in WEST, Inc. (2006) should read Smallwood and Thelander (2005).) The bird utilization methods differed between Smallwood and Thelander (2004) and Smallwood and Thelander (2005), the former based on instantaneous sampling and geo-referencing of birds and the latter based on tracking of individual birds and no geo-referencing. The 2004 report used the frequencies of instantaneously mapped observations as the metric for hypothesis testing, whereas the 2005 report used minutes of observation as the metric. WEST, Inc. used some of the methods in the Smallwood and Thelander (2004) report, but not those of the 2005 report. WEST, Inc. (2006) deviated from both Smallwood and Thelander reports in the definitions of seasons they used. But most importantly, WEST, Inc. recorded birds during 360˚ visual scans out to 800 m, whereas the Smallwood and Thelander studies limited their observations to 300 m.

WEST, Inc. has routinely measured site utilization based on bird observations out to 800 m (Good et al. 2004, Johnson et al. 2006, WEST, Inc. 2006), and even beyond 800 m (Erickson et al. 2004). However, I have not encountered any other study outside the context of wind farms using 800 m as a maximum distance in point counts. Identifying raptors to species becomes difficult beyond 300-400 m, even by trained biologists using the best binoculars. Identifying small birds beyond 100 m is very difficult, and many songbirds occurring beyond 300 m will not be detected by the observers. This maximum distance issue is important because WEST, Inc. (2006:11) compared their measure of raptor use to the measures reported by Smallwood and Thelander (2004).

Fig. 1 illustrates the changes in geographic areas within circles of radii 300 m, 400 m, and 800 m, corresponding with search areas used by Smallwood and Thelander (2004, 2005) and WEST, Inc. during most of their studies among wind farms. Fig. 2 shows the area within the circle as a power function of circle radius. The area in a circle of 800 m radius is 4 times the area of a circle of 400-m radius, and 7.1 times the area of a circle of 300-m radius. Therefore, assuming birds continue to occur at the same per-hectare rate from within 300 m to within 800 m, then observers performing 360˚ visual scans out to 800 m should record 4 times more birds per hour than observed out to 400 m, and 7.1 times more birds per hour out to 300 m. This assumption should be realistic among studies with multiple observation points, because there is no reason to expect birds will be systematically less numerous at distances >300 m from the observers.

So far as I am aware, only three opportunities exist to quantify bias due to comparing bird utilization between wind turbine collision studies using such different maximum observation

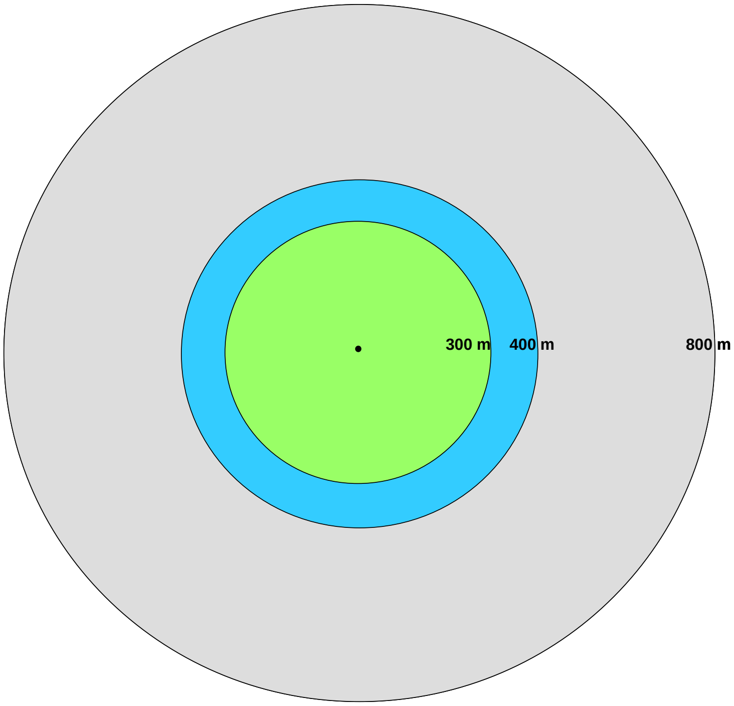

Figure. 1. Visual scans include increasingly larger areas as the search radius increases from the observation point (green dot in the center).

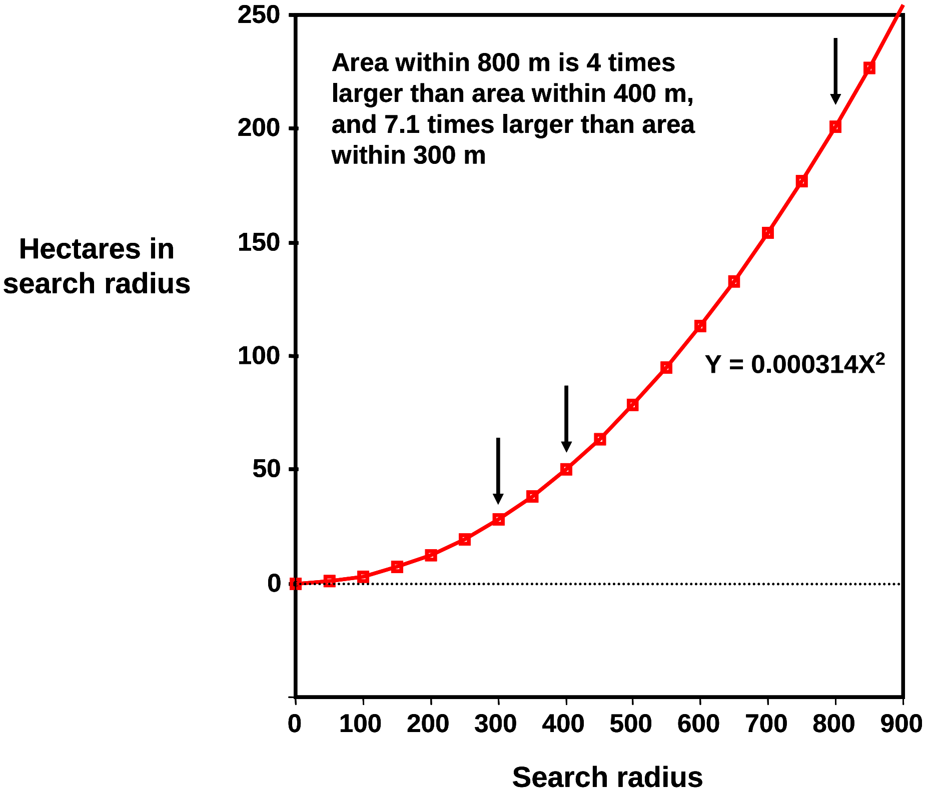

Figure 2. The number of hectares increases as a power function of search radius in utilization studies.

distances. WEST, Inc. reported birds per session out to both 400 and 800 m at Foote Creek Rim, Wyoming (Young et al. 2003), and out to 300 and 800 m at Windy Point Wind Energy Project (Johnson et al. 2006 [2]), as well as at the Diablo Winds project site where WEST, Inc. used an 800-m search radius and Smallwood and Thelander (2004, 2005) relied on a 300-m radius.

At Foote Creek Rim, Young et al. (2003) recorded 269 raptors within 400 m of the observation points. Multiplying this number by 4 yields 1,076 observations, which would be the number expected of a constant rate of raptor occurrence out to 800 m from the observation points. Instead of 1,076 raptor observations, however, Young et al. recorded only 841, which is a difference of 235, or 22% fewer. For some of the species observed during the study, Table 1 lists discrepancies between the numbers actually reported within 800 m and the numbers that should have been observed at 800 m based on the number observed at 400 m. Between 400 and 800 m, Young et al. missed large proportions of large-bodied, conspicuous birds, such as American white pelican (42%), turkey vulture (56%), and red-tailed hawk (41%), as well as many of the small birds, such as American kestrel (77%), cliff swallow (71%), and vesper sparrow (69%).

Table 1. Discrepancies between the numbers of birds reported to 800 m and the numbers that should have been observed to 800 m based on the numbers observed to 400 m and assuming a constant rate of occurrence of birds across areas that were visually scanned.

Species	**No. observed to 800 m**	**No. expected to 800 m based on no. observed to 400 m extrapolated to the area within 800 m**	**Percentage difference between numbers observed and expected**
American white pelican	42	73	-42%
Mountain plover	11	24	-54%
Golden eagle	394	434	-9%
Ferruginous hawk	37	51	-27%
Red-tailed hawk	156	263	-41%
Rough-legged hawk	23	24	-4%
Swainson’s hawk	22	36	-39%
Northern harrier	16	27	-41%
Prairie falcon	44	88	-50%
American kestrel	40	175	-77%
Turkey vulture	7	16	-56%
Common raven	133	177	-25%
Cliff swallow	50	170	-71%
Mountain bluebird	42	98	-57%
Horned lark	1915	4219	-55%
Brown-headed cowbird	10	27	-63%
Brewer’s blackbird	76	124	-39%
Vesper sparrow	9	29	-69%

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[2] Including the 11-page WEST, Inc. response to my comment letter on the project, prepared by W. Erickson, G. Johnson, and D. Strickland, and submitted 13 July 2006 to Curt Dryer, Klickitat County Planning Department.

At Windy Point, WEST, Inc. missed 75% of the raptors they should have observed out to 800 m, based on the number they reported out to 300 m (Fig. 3). WEST, Inc. reported seeing 1.8 times more raptors to 800 m than they did to 300 m, whereas they should have seen 7.1 times as many due to the 7.1-fold difference in spatial area that was scanned. At distances beyond 300 m raptors appear increasingly small, and are therefore increasingly difficult to detect. Also, the area being scanned for raptors increases faster than the increases in maximum search distance (fig. 2), so the airspace over each hectare searched will be examined by the observers less frequently during a given time interval.

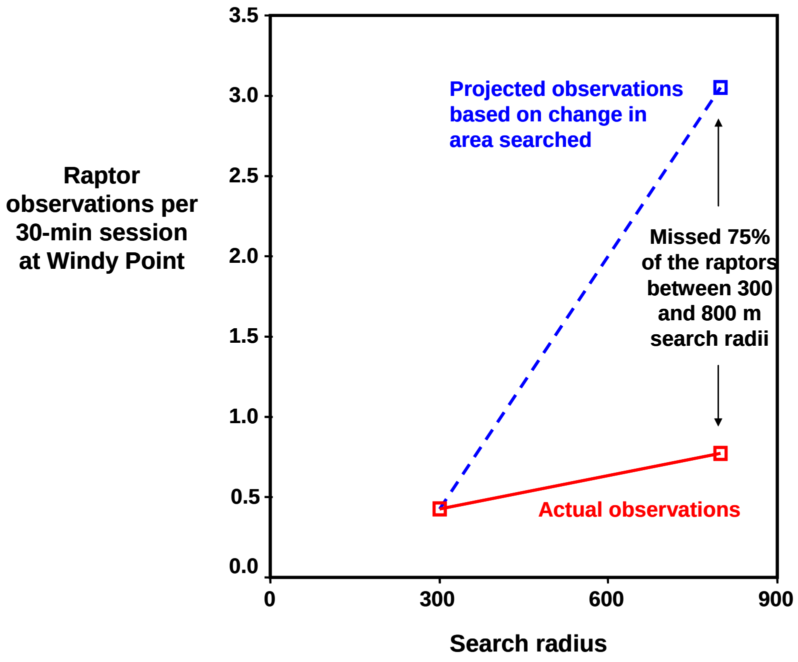

Figure 3. Actual observations of raptors did not change as much within 300- and 800-m search radii (red solid line) as they should have (blue dashed line) at the site of the proposed Windy Point Wind Energy Project, Klickitat County, Washington.

Despite these large differences in bird detections between the visual scan radii used, comparing numbers of detections between the WEST, Inc. study at Diablo winds and the earlier studies (Orloff and Flannery 1992, Smallwood and Thelander 2004, 2005) can mislead an uninformed reader to conclude raptor activity was greater during the WEST, Inc. study than during the earlier studies. Although a researcher scanning to 800 m for birds will miss many of the birds occurring between 400 and 800 m away because the birds are farther away, as pointed out above, that researcher still will see more birds per hour than if he restricted his search to 400 m for the simple reason that he increased the search area 400% (>700% when comparing between 300 and 800 m). Assuming birds are uniformly or randomly distributed among observation points, and assuming detection does not change with increasing search radii (the former assumption is reasonable, but the latter is not, as I will demonstrate in the paragraph below), observers should report 4 times as many birds per session within 800 m as compared to within 400 m.

In the Young et al. (2003) study, the number of raptors observed per session was 3.13 times greater to 800 m as compared to 400 m as a maximum distance. Compared to the detection rates of observations to 400 m, the detection rates to 800 m were 3.6 times greater for golden eagle, 2.4 times greater for red-tailed hawk, 221 times greater for Canada goose, and 1.8 times greater for horned lark. Overall, the Young et al. (2003) observations of birds to 400 m were 3.562 per 40-min session, whereas the bird observations to 800 m were 7.678 per 40-min session, so the rate reported at the shorter maximum distance was 46% of the rate reported at the longer distance.

The differences in utilization rates reported in Young et al. (2003) for Foote Creek Rim can be used to adjust the WEST, Inc. (2006) utilization rates for Diablo Winds so they can be compared more equitably to the rates measured at Diablo Winds by Smallwood and Thelander (2004, 2005), assuming equal abilities between observers. Young et al. (2003) detected raptors per session within 400 m at 32% of the rate detected within 800 m. A reasonably equitable comparison could be made between studies by multiplying the WEST, Inc. (2006) raptor utilization by 0.32, which is the percentage detection rate from the Young et al. study converted to a proportion. Thus, the WEST, Inc. (2006) estimate of raptor utilization in the Diablo Winds study area converts from 4.394 per 30-minute session to 1.406 raptors per 30-minute session (Fig. 4). I'll refer to this approach as the *Foote Creek Rim extrapolation*. This extrapolation, however, suffers two drawbacks. First, it is from one site to another. Second, the search radius at Foote Creek Rim was 400 m, whereas the search radius used by Smallwood and Thelander was 300 m.

Another way to adjust the WEST, Inc. estimate of utilization within 800 m to a comparable estimate within 300 m, is to divide the former by 7.1, which is the area within 800 m as a multiple of the area within 300 m. Using this approach, the WEST, Inc. (2006) estimate of raptor utilization in the Diablo Winds study area converts from 4.394 per 30-minute session to 0.619 raptors per 30-minute session (Fig. 4). The Smallwood and Thelander (2004) estimate of raptor utilization was 2.155 per 30-minute session, so it appears raptor activity was about 35% to 71% less during the WEST, Inc., study, and probably not greater as reported by WEST, Inc. (2006).

However, WEST, Inc. (2006) also compared their measured raptor utilization to that of Smallwood and Thelander (2004), which was measured across a much larger portion of the APWRA. To make a more resolute comparison between the studies, I selected only the behavior observation plots that overlapped the Diablo Winds project area. I selected the plots studied during 1998-2000 and reported by Smallwood and Thelander (2005), and I selected the plots studied during 2002-2003 and reported by Smallwood and Thelander (2004). During the 1998-2000 study, 658 sessions in the plots overlapping the Diablo Winds project area yielded 2.067 raptor observations per 30-min session. During the 2002-2003 study, 37 sessions yielded 3.243 raptor observations per 30-min session. Based on the Foote Creek Rim extrapolation, raptor utilization of the Diablo Winds project area was 32% to 66% lower during the WEST, Inc. (2006) study compared to the earlier studies. Based on a comparison of the on-site differences in search areas corresponding with the 300- and 800-m search radii, raptor utilization was 70% to 81% lower during the WEST, Inc. study. (Without ongoing monitoring at nearby sites lacking wind turbines, there is no way to determine why recorded raptor utilization declined in the APWRA.)

My results indicated more care will be needed in future comparisons of bird utilization rates between studies. Utilization rates recorded from different search radii will need adjustments. Comparisons of utilization rates before and after repowering should include data collected in the immediate area of the repowering project, and not from disparate study areas. Adjustments need to be made for any biases introduced by differences in duration between observation sessions used at different studies, e.g. between 10-minute, 20-minute, and 30-minute sessions. Furthermore, comparisons of utilization between studies should be adjusted by the average viewable areas from the observation points because some study sites are relatively flat whereas others are hilly. In hilly areas, an increasingly larger proportion of the visual scan areas will not be visible as the search radius increases. Another significant aspect of my analysis of utilization rates was how the revised estimates factor into the calculation of collision risk. This aspect will be addressed below, under **Risk of Collision**.

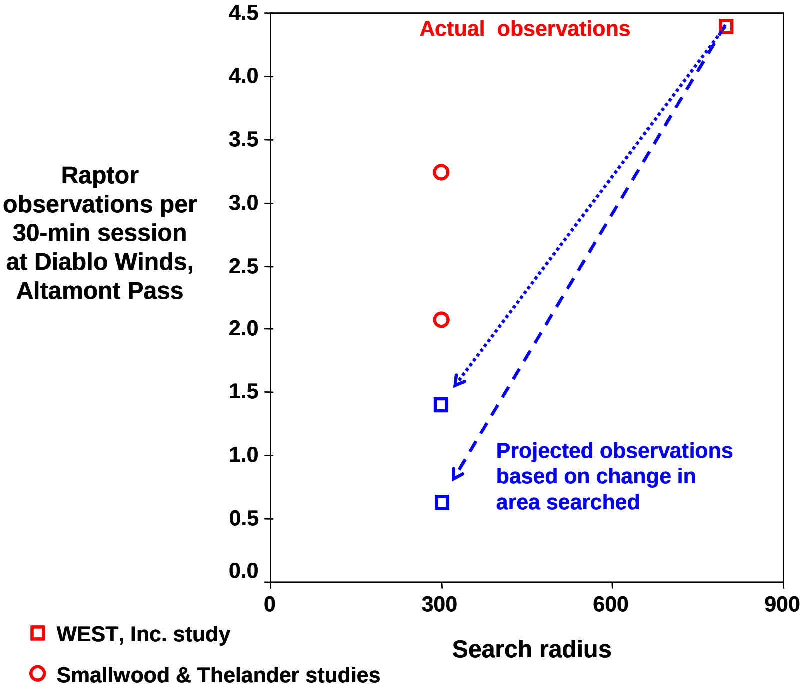

Figure 4. At Diablo Winds, WEST, Inc. inflated raptor utilization 300% (dotted line, based the Foote Creek Rim extrapolation) to 700% (dashed line, based on 7.1-fold difference in areas scanned) by comparing the number seen within 800 m to those seen during earlier studies within 300 m. By adjusting the WEST, Inc. utilization estimate to an area equal to that used in the earlier studies, the conclusion that more raptors were seen per session during the WEST, Inc. study reversed to the conclusion that fewer were seen.

FATALITY SEARCHES

WEST, Inc. (2006) used a 75-m fatality search radius, which was larger than the 50-m search radius used by Smallwood and Thelander (2004, 2005). This difference was appropriate because the Vestas V47 wind turbine is a larger turbine, and is likely to throw birds farther from the tower base. The lateral reach of the Vestas V47 blades is nearly 15 m greater than the Flowind

F-17 blades, and the greater inertia in the Vestas' blades likely threw carcasses an unknown additional distance from the turbine. The proportion of carcasses thrown beyond 75 m from the wind turbines cannot be estimated reliably without actually looking for carcasses at distances >75 m from the turbines.

The average interval between searches was 30 days in the WEST, Inc. study at the Vestas V47 turbines, and 38 days in the Smallwood and Thelander study at the 169 Flowind turbines (not 50 or 90 days as claimed in WEST, Inc. 2006:11). The difference of 8 days between the studies requires an adjustment to the scavenger removal rates applied to the Smallwood and Thelander data in order to compare mortality estimates, and will be addressed in the following section.

CHOICE OF MORTALITY ESTIMATOR AND ASSUMPTIONS

Most investigators estimating wind turbine-caused mortality have used the following formula to adjust for the fatalities not found due to scavenger removal and searcher detection error:

$$M_A = \frac{M_U}{R \times p}, \qquad \text{eqn. 1}$$

where M_U is unadjusted mortality expressed as either number of fatalities per wind turbine per year or number of fatalities per MW of rated capacity per year, R is the proportion of carcasses remaining since the last fatality search,[3] and is estimated by scavenger removal trials, and p is the proportion of carcasses found by fatality searchers during searcher detection trials. Additional adjustments could be incorporated into eqn. 1, such as background mortality (M_B), crippling bias (M_C), and search radius bias (M_S):

$$M_A = \frac{M_U}{R \times p} - M_B + M_C + M_S\ . \qquad \text{eqn. 1b}$$

Background mortality is the natural rate of fatalities, or the rate not caused by wind turbines or their infrastructure. Crippling bias refers to the number of animals injured by the wind turbines but which die elsewhere, undetected. Search radius bias refers to the number of animals thrown by the wind turbines outside the search area, and are not detected. Attempts to estimate M_B, M_C, and M_S also would require adjustments by R and p. I did not attempt to incorporate these terms in the analysis that follows because they are either unknown in their magnitudes or relatively small.

WEST, Inc. (2006) used the following formula to estimate wind turbine-caused mortality in their Diablo Winds Project study area, consistent with the formula they have used in most of their reports of bird and bat collisions:

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[3] The proportion of carcasses remaining can be converted to the percentage remaining simply by multiplying the proportion by 100%, and the percentage remaining can be converted to the proportion remaining by dividing by 100.

$$M_A = \frac{\bar{c}}{\left(\frac{\bar{t} \times p}{I}\right) \cdot \left(\frac{e^{I/\bar{t}} - 1}{e^{I/\bar{t}} - 1 + p}\right)}, \qquad \text{eqn. 2}$$

where $\bar{c}$ is the average number of carcasses observed per year, $\bar{t}$ is the mean number of days until carcass removal, p is the observer efficiency rate, and I is the search interval in days. WEST, Inc. (2006) reported "this formula has been independently verified by Shoenfeld (2004)." Shoenfeld (2004) did not appear in the WEST, Inc. (2006) reference list, but I was able to track it down anyway. My review of Shoenfeld (2004) revealed it was not really a verification of the WEST, Inc. formula, but rather a critique of a formula previously used by West, Inc. Shoenfeld (2004) found the previous WEST, Inc. formula to be statistically biased, resulting in mortality estimates that were about 23% low. He suggested improvements, which WEST, Inc. adopted for use in their 2006 report on Diablo Winds.

WEST, Inc. (2006) did not list the underlying assumptions or possible biases of eqn. 2, but Shoenfeld (2004) provided some discussion of them. He pointed out that $\bar{t}$ and p are estimated from common field experiments involving small samples of carcasses, so knowledge of these parameters may be incomplete. He concluded bias can probably be found in how these parameters relate to the number of carcasses found and to the estimated number killed, but he did not attempt to characterize the bias.

Shoenfeld (2004) assumed all wind turbine-killed birds fall to the ground, and eqn. 2 certainly reflects this assumption, but this assumption is false. Whereas some injured birds are found at and near wind turbines, some unknown number of others likely is never found and their eventual deaths never factored into the mortality estimate. This type of bias is referred to as *crippling bias*. For example, the Diablo Winds turbines caused a serious wing injury to a golden eagle, which was later euthanized (WEST, Inc. 2006). This particular golden eagle ended up in the fatality search area and was counted as a fatality, but others die elsewhere and are never recorded as wind turbine-caused fatalities. Smallwood and Thelander also found injured birds, most of which perished sometime after they were found. Some unknown number of birds survive long enough to die outside the fatality search areas, and some unknown number likely survive for extended periods, though debilitated by their injuries. Therefore, all mortality estimates are conservative to an unknown degree. Until remote detection of turbine collisions is achieved, the contribution of crippling bias to mortality estimates will remain unknown.

There are other potential biases in eqn. 2 Shoenfeld (2004) did not discuss in depth. Probably the most critical biases result from design and implementation of scavenger removal trials and searcher efficiency trials. Whereas these biases can affect mortality estimates calculated from both eqns. 1 and 2, I will show below how the mean days to carcass removal (eqn. 2) appears more prone to bias than does the proportion of carcasses remaining (eqn. 1).

Placing all or many of the trial carcasses in the field at once can result in *scavenger swamping*, similar to the phenomenon of predator swamping well described in the ecological literature. WEST, Inc. placed all 20 carcasses among 31 wind turbines on October 5, 2005 for the fall trial, and all 22 carcasses on December 5, 2005 for the winter trial. The available vertebrate scavengers in the area had only a few days to snatch up carcasses before they decomposed to the point of being unattractive as food. Once remaining carcasses are filled with maggots or dried to the hardness of leather, they will unlikely be picked up by coyotes, foxes and other vertebrate scavengers, and turkey vultures will feed on them in place, leaving bones and feathers. Scavenger swamping will bias mortality estimates low by leaving carcasses in the field longer than if they had been deposited at a frequency more consistent with the steady state of carcass deposition from wind turbine collisions.

Scavenger swamping can increase the likelihood that some of the trial carcasses will escape early detection or removal by vertebrate scavengers. These carcasses will essentially mummify. Only a few mummified carcasses are needed to substantially increase the mean number of days to carcass removal because they will last as long as the trial is performed. To the 1, 2 or 3 days attributed to the removals of most bird carcasses, each mummified carcass will likely add the total number of days in the trial to the calculation of the mean number of days to carcass removal. Therefore, scavenger removal trials including mummified carcasses should increasingly reduce the mortality estimate the longer the trial lasts. For example, 30 carcasses used in a field trial will average 2 days to carcass removal if all 30 carcasses are removed in 2 days, but if 4 (13%) of the carcasses mummify and remain until the end of a 15-day trial, then the mean days to carcass removal becomes 3.7 days, almost twice as long. Leaving these same 4 mummified carcasses until the end of a 60-day trial will shift the mean days to carcass removal to 9.7 days, almost 5 times as long. The consequence of this mummification bias, which can be exacerbated by scavenger swamping, is lower mortality estimates generated from longer-duration scavenger removal trials.

Frozen bird carcasses are often used by WEST, Inc., and were used in their Diablo Winds scavenger removal trial. Kerns (2005) reported faster removal of fresh carcasses compared to frozen carcasses. The freezing of carcasses can alter the delivery of odor and the attractiveness of tissue. This practice likely increases the mean time to carcass removal, thereby also biasing the mortality estimate low. Additionally, placing whole carcasses in removal trials falsely mimics the deposition of most wind turbine-killed birds, which are typically cut in half or dismembered. Pieces of birds are easier for vertebrate scavengers to pick up and remove. Furthermore, the wounds sustained by blade strikes likely dispense odors alerting mammalian scavengers, common ravens, turkey vultures and other birds to the urgent availability of fresh food. The placement of whole carcasses likely reduces the pool of available scavenger species as well as the number of detections by scavengers, thus inflating the average time to removal and reducing the mortality estimate. A solution is to cut some fresh bird carcasses in half, and to cut one or both wings off, prior to placing the carcasses and carcass parts in the field.

Another bias in scavenger removal trials is the use of inappropriate species, such as species that are exceptionally attractive to vertebrate scavengers, that are more or less visible or odiferous, or that do not occur in the area. WEST, Inc. routinely uses rock doves as surrogates of large raptors, but large raptors are not removed at rates similar to the removal of other birds such as rock doves. Using rock doves as large raptor surrogates likely biases mortality estimates high. Using game hens or chickens also will likely bias the mortality estimates high, as will be demonstrated below. (Note that WEST, Inc. did not use game hens or chickens, but I included them in my analysis to make the point that species vary in their scavenger removal rates.)

Fitting the best model or mathematical function to the scavenger removal data can be hindered by arbitrary termination of scavenger removal trials, which is referred to as right-censoring of data. Right-censoring of data hides part of the scavenger removal pattern that can be fit by a model, but this practice is common because budgets have not covered trials lasting as long as some of carcasses are detectable. Right-censoring of data was less in this study than in most other WEST, Inc. studies, because they ran the trial out to 62 days, but relatively large percentages of medium-sized birds remained at the end of the trial. The problem of right-censored data could be eliminated by running scavenger removal trials until all carcasses degrade to the point of becoming undetectable.

Mortality estimates can be biased low due to left-censoring of data, meaning wind turbines or turbine strings represented by zero-values may have, in truth, caused fatalities that were scavenged before the fatality searchers visited the turbines. Or, turbines or turbine strings may be attributed zero fatalities because the searchers missed carcasses that were present. Turbines or turbine strings assigned zero-values will not be adjusted by scavenger removal rates or searcher detection bias unless these turbines are lumped with others to arrive at a pooled estimate of mortality. In the case of Smallwood and Thelander’s (2004, 2005) study, mortality was estimated for each turbine string separately because the turbines were given unequal sampling efforts. All turbine strings with zero fatalities were estimated to have caused zero mortality because 0 divided by scavenger removal and searcher detection terms yields 0. Left-censoring of data can bias mortality estimates low.

Another problem arises when the searchers switch to multiple-day or weekly search intervals following the first week of daily carcass searches. By doing so, carcasses found after the daily search schedule cannot be identified with the exact number of days since the initiation of the trial. Although WEST, Inc. (2006) did not explain how they handled this problem, it appears they took the middle number of days between multi-day searches as the day associated with a carcass removal. A carcass removed during a 7-day period between days 34 and 41 would be arbitrarily associated with day 37.5, but the actual day of removal could have been day 34 or day 41. Such 7-day ranges of possible removals introduce considerable sources of error in the model fit. An alternative to this variable monitoring interval would have been to check on the carcasses every day.

Inexplicably, scavenger removal rates are assumed exponential in the WEST, Inc. mortality estimator. However, any thresholds of carcass attractiveness to vertebrate scavengers will likely result in a non-constant rate of carcass removal, and not an exponential rate.

Another potential bias to the estimator is *searcher swamping*. By deploying 20 carcasses among 31 turbines on 10-11 May 2005, 20 carcasses on 4-5 October 2005 and 30 carcasses on 17-18 January 2006, the searchers most likely became aware they were being tested. Encountering 20 or 30 carcasses during a single rotation is too great a deviation from the normal carcass discovery rate of one or two per search rotation to go unnoticed. If the searchers are tipped off to the trial, they will probably heighten their vigilance, reduce their rate of missed carcasses, and bias the mortality estimate low. The alternative to searcher swamping would have been to deposit one or two carcasses per search rotation throughout the period of monitoring.

The *search radius bias* results from birds thrown by the wind turbine blades beyond the boundary of the fatality search area. Strong gusts of wind can also boost bird carcasses beyond the search radius. Some, but probably not all, carcasses beyond the search radius are spotted by fatality searches from within the search radius. Any carcasses landing outside the search area and going undetected will bias the corresponding mortality estimates low. Eqn. 2 did not account for search radius bias.

Background mortality is another potential source of error in the WEST, Inc. (2006) estimates of wind turbine-caused mortality, and one WEST, Inc. chose not to account for due to lack of data in the APWRA. Inadvertently including background mortality in estimates of wind turbine-caused mortality will inflate the collision-caused mortality estimates. However, the published estimates of background mortality indicate this error is likely small.

Table 2 summarizes the potential sources of error in the mortality estimator represented by eqn. 2. Most of these sources of error would bias the mortality estimate low, a few will bias the estimate high, and others will add imprecision with unknown bias. Not all were discussed in the preceding text. Most will affect mortality estimates calculated from eqn. 1, as well. It is important to understand that most of these potential sources of error have not been quantified, nor have most been addressed in mortality estimators used by researchers of bird or bat collisions in wind farms. The estimates of mortality calculated from both eqns. 1 and 2 remain relatively crude, burdened by high uncertainties. Directed field research will be needed to quantify most of these sources of error.

In the analysis that follows I summarized the available estimates of searcher detection error, and I quantified one important bias in eqn. 2 – scavenger removal.

SCAVENGER REMOVAL

Methods

Mean time to removal

For reports that presented mean time to removal both seasonally and averaged among seasons, only the latter estimates were used in this analysis. I used mean time to removal specific to one season when no average was reported among seasons. Data on rock doves were from Kerlinger et al. (2000), Erickson et al. (2000, 2003), Johnson et al. (2002, 2003), Young et al. (2003), and WEST, Inc. (2006). Data from other medium- and large-sized birds were from Kerlinger et al. (2000), Erickson et al. (2000, 2003, 2004), and Johnson et al. (2003). Data on small birds were from Kerlinger et al. (2000), Erickson et al. (2000, 2003, 2004), Johnson et al. (2002, 2003), Young et al. (2003), Anderson et al. (2005), and WEST, Inc. (2006).

Mean time to removal was related to the duration of the scavenger removal trial, and multiple functions tested for best fit. Best fit was determined by the coefficient of determination (r^2), the root mean square error (RMSE), the P-value, sample size (d.f.), whether the Y-intercept was reasonably close to 100% of carcasses remaining (keeping in mind that 1 was added to the predictor variable in most model fits), whether the residuals were homoscedastic when plotted against the predictor variable, and interpretability of the model.

Table 2. Potential biases in adjustment terms used in mortality estimators.

Bias in mortality estimators	**Likely affect on WEST, Inc. mortality estimator, eqn. 2**
Crippling bias	Biased low to unknown degree
Search radius bias	Biased low to unknown degree
Background mortality	Slightly biased high
$\bar{t}$ and *p* are derived from small samples of carcasses in field experiments, usually performed concurrently	Added uncertainty
Scavenger swamping	Biased low to unknown degree
Some carcasses not removed by vertebrate scavengers mummify and increase mean days to carcass removal	Biased low
Use of inappropriate species misrepresents levels of detection and/or attractiveness to scavengers	Biased high in some cases, but could also bias low
Frozen or thawed carcasses less attractive to vertebrate scavengers	Biased low to unknown degree
Whole carcasses may not mimic dismembered carcasses, and are more difficult to detect or to remove	Biased low to unknown degree
Right-censored data, i.e., terminating trial before all carcasses removed	Added uncertainty
Left-censored data, i.e., findings of 0 fatalities not adjusted	Biased low
Long search intervals in scavenger removal trials hamper best-fits of the alternative mathematical functions	Added uncertainty
The use of mean time to removal assumes exponential rate of carcass removal, whereas the pattern of removal appears not to be exponential	Added uncertainty
Seasonal variation in scavenger activity	Added uncertainty
Site variation in scavenger activity	Added uncertainty
Searchers made aware of detection trials might be more vigilant	Biased low
Searcher swamping can alert searchers to the trial	Biased low
Inappropriate species used in searcher detection trials can be more or less conspicuous, or can alert searchers to the trial	Biased low
Marking carcasses can alert searchers to the detection trial	Biased low
Searchers typically rely on multiple cues when detecting wind turbine-killed birds, but volitionally placed whole carcasses may not provide those cues	Biased high
Detection trials performed away from the wind turbines will alert searchers to the trial	Biased low
Seasonal variation in carcass detection by searchers	Added uncertainty
Site variation in carcass detection, e.g., due to vegetation height	Added uncertainty

Proportion of carcasses remaining

I obtained percentages of bird carcasses remaining in scavenger removal trials from tables in reports, when available, but sometimes I had to take them from graphs.[4] Estimates from graphs were measured by ruler. Estimates for small birds were taken from Kerlinger et al. (2000), Kerlinger (2002), Erickson et al. (2000, 2003, 2004), Johnson et al. (2002, 2003), Young et al. (2003), Kerns and Kerlinger (2004), Anderson et al. (2005), Kerlinger et al. (2006), and WEST et al. (2006). Estimates for medium and large birds were taken from Orloff and Flannery (1992), Kerlinger et al. (2000), Erickson et al. (2000, 2003, 2004), Johnson et al. (2002, 2003), Schmidt et al. (2003), Young et al. (2003), Kerns (2005), Anderson et al. (2005), Koford et al. (2005), and Kerlinger et al. (2006). Estimates for rock doves were taken from Johnson et al. (2002), Young et al. (2003), and WEST, Inc. (2006). Estimates for chickens and game hens were taken from Howell and DiDonato (1991), Orloff and Flannery (1992), and Anderson et al. (2005). Orloff and Flannery (1992) reported data on small raptors and on medium and large raptors. Other reports with medium and large raptor data included Howell and Noone (1992) and WEST, Inc. (2006), the latter of which had a sample size of 3. Howell and Noone (1992) also reported generally on raptors. All of the raptor data were from the Altamont Pass and the Solano wind farms.

Means were taken from data spanning multiple seasons within a year. Generally, summary representations of percent of carcasses remaining were used per study site. These data were plotted and examined visually to select mathematical functions to attempt to fit to the data. Model fits were assessed using the same standards as used for mean time to carcass removal, as discussed above.

To test certain hypotheses, the percent of carcasses remaining was used for predictive model development when these data were associated with a month of the year or a season. Months of the year were grouped into seasons, and all annual or multi-season scavenger removal estimates were omitted from this effort. Residuals from the best-fit models were saved and compared seasonally to test whether season of the year affected scavenger removal rates.

As an alternative to mean number of days to removal as an adjustment to wind turbine-caused mortality, I estimated the percentage of carcasses remaining at each fatality search interval, assuming a steady state of carcass deposition by wind turbine collisions:

$$R_C = \frac{\sum_{I}^{i=1} R_i}{I \times 100}, \qquad \text{eqn. 3}$$

where R_C is the cumulative carcasses remaining, R_i is the percent of carcasses remaining by the ith day following the initiation of a scavenger removal trial, and I is the duration of a scavenger removal trial corresponding with the fatality search interval used during a mortality monitoring

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[4] Percentages were collected rather than proportions because percentages were more commonly available and are easier to interpret. Percentages can be converted to proportions by dividing them by 100.

effort. Thus, the expected percentage of bird carcasses remaining by the next fatality search should be R_C corresponding with the fatality search interval, I.

Results and Discussion

Mean time to removal

Mean days to removal was a function of the number of days in the scavenger removal trial (Table 3, Figs. 5 and 6). The best-fit function was the S-curve:

$$\bar{t} = e^{a+b/d} \;, \qquad \text{eqn. 4}$$

where t is the mean time to removal, d is the number of days since the scavenger removal trial began, and a and b are fitted parameters. However, sample sizes were small, and the model estimated for medium- and large-sized birds included chickens and rock doves, which can bias the models. The inclusion of chickens likely steepened the early portion of the estimated curve.

Table 3. Logistic growth curve models fitted to mean time to removal of carcasses deployed in scavenger removal trials at wind farms.

Model	**r^2**	**RMSE**	**n**	**P-value**	**a**	**b**
Medium and large birds	0.91	0.32	16	<0.0001	4.2000	-27.4795
Rock dove	0.91	0.29	4	< 0.05	4.3294	-29.7639
Small birds	0.60	0.40	9	<0.05	2.9297	-14.1678

The relationship between mean time to removal and duration of the scavenger removal trial indicates the duration of the scavenger removal trial can also influence wind turbine-caused mortality estimates. For example, applying the parameter estimates in Table 3 to the model in eqn. 4, a 62-day trial would predict an average 43 days to carcass removal of medium to large birds, but a 14-day trial would predict only an average of 9 days to carcass removal. These predictions can also be seen in Fig. 6. Assuming 100% searcher detection in order to hold this term constant, as well as a 30-day search interval, then the WEST, Inc. (2006) mortality estimator would multiply unadjusted mortality of medium and large birds by 1.38 based on a 62-day trial and by 3.46 for a 14-day trial. This range of multipliers is relatively large. Thus, the WEST, Inc. (2006) mortality estimator is a function of the duration of the scavenger removal trial, and the longer the trial the lower the mortality estimate.

In the past, WEST, Inc. has relied on 14-day scavenger removal trials (Johnson et al. 2002), and more recently they used 28-day trials (Erickson et al. 2000, Johnson et al. 2003, Young et al. 2003), 30-day trials (Erickson et al. 2003), and 40-day trials (Erickson et al. (2004). At Diablo Winds they extended their trial period to 62 days, an apparent increase in the duration of scavenger removal trials over the last 6 years. By increasing their trial durations they also increased their mean time to carcass removal estimates, and they correspondingly underestimated mortality.

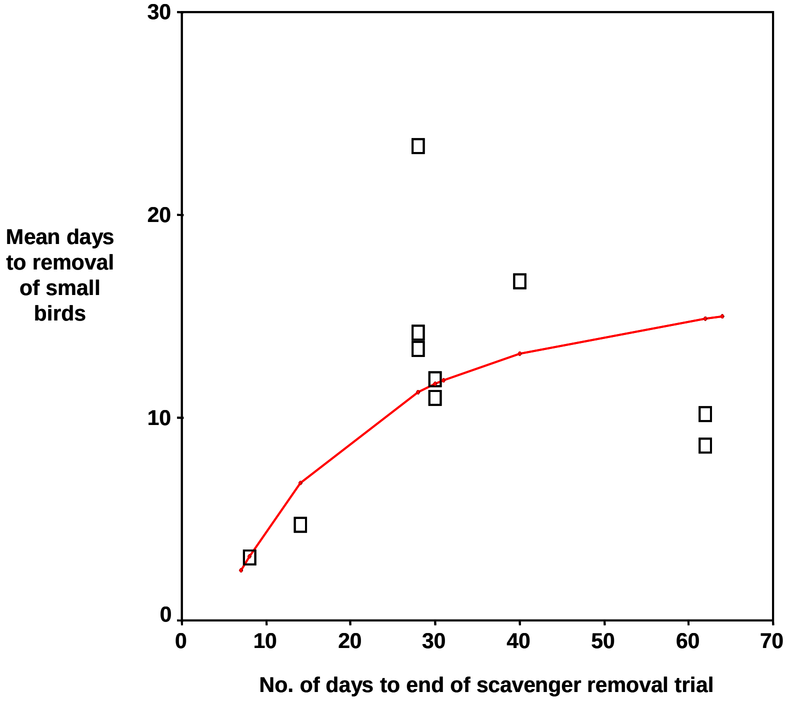

Figure 5. Logistic growth curve fitted to reports of mean days to small bird carcass removal as a function of the number of days to the end of the carcass removal trial.

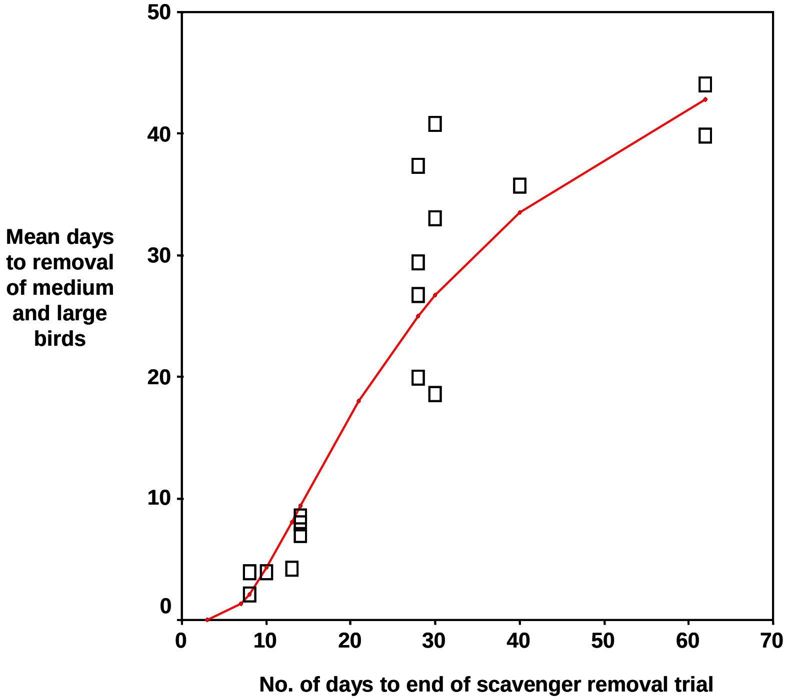

Figure 6. Logistic growth curve fitted to reports of mean days to medium and large bird carcass removal as a function of the number of days to the end of the carcass removal trial.

Using WEST, Inc.'s (2006) estimated searcher efficiency of 0.76 for medium and large birds, and applying my predicted average time to removal of carcasses during scavenger trials, their mortality estimator would adjust their raw estimate of 0.64 birds/MW/year to 1.03 birds/MW/year based on their 62-day trial, whereas a 14-day trial would yield a predicted adjusted mortality estimate of 2.89 birds/MW/year. Thus, by extending their scavenger removal trial from 14 days used elsewhere to 62 days used at Diablo Winds, WEST, Inc. reduced their medium/large-sized bird mortality estimate by about 65%.

The sample size of carcasses in scavenger removal trials explained much of the remaining variation in mean days to carcass removal after accounting for trial duration (Fig. 3). Table 4 summarizes the logistic growth curves estimated from the relationship. The fit was best for small birds, but it also was significant for all birds. This relationship indicates scavenger swamping likely significantly biased mean time to carcass removal, as well as the mortality estimator in eqn. 2. As illustrated in Fig. 7, the difference between the observed and predicted mean days to carcass removal increased rapidly between 0 and 50 carcasses used in the trial. This pattern indicates local vertebrate scavengers remove increasingly smaller percentages of trial carcasses from samples ranging up to about 50 or more.[5] Scavenger swamping also likely would bias the mortality estimator in eqn. 1 by inflating the percentage of carcasses remaining at the end of the trial, but the more limited value range of this adjustment metric (i.e., 0 to 1) will also limit the impact of the bias.

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[5] The time it takes for a carcass to decompose to the point of being unattractive to vertebrate scavengers will vary by species, and according to local conditions and time of year. Within only a few days the carcass removal rate should be nearly constant, but even over this time period it is conceivable the rate could drop off dramatically once the local scavengers have had their fill. A large number of trial carcasses placed at once within a relatively small area will be a windfall of food for the local vertebrate scavengers, many of which will remove carcasses as quickly as they are capable. Common ravens would likely detect the carcasses quickly, and will take off with the smaller carcasses, whereas foxes, coyotes, and other mammalian carnivores will remove carcasses as they come across the windfall while patrolling their home ranges. Ground squirrels likely will pull one or two into each of the nearby burrow systems. After this initial assault on the carcasses, however, these same scavengers will be busy either processing their new food, or digesting it. By the time they return to the windfall of carcasses, the remaining carcasses will have decomposed, some to the point of being unattractive to the types of scavengers that normally would remove entire carcasses. By this time, turkey vultures will be the more likely vertebrate scavenger to feed on the carcasses, but they leave the bones and feathers in place.

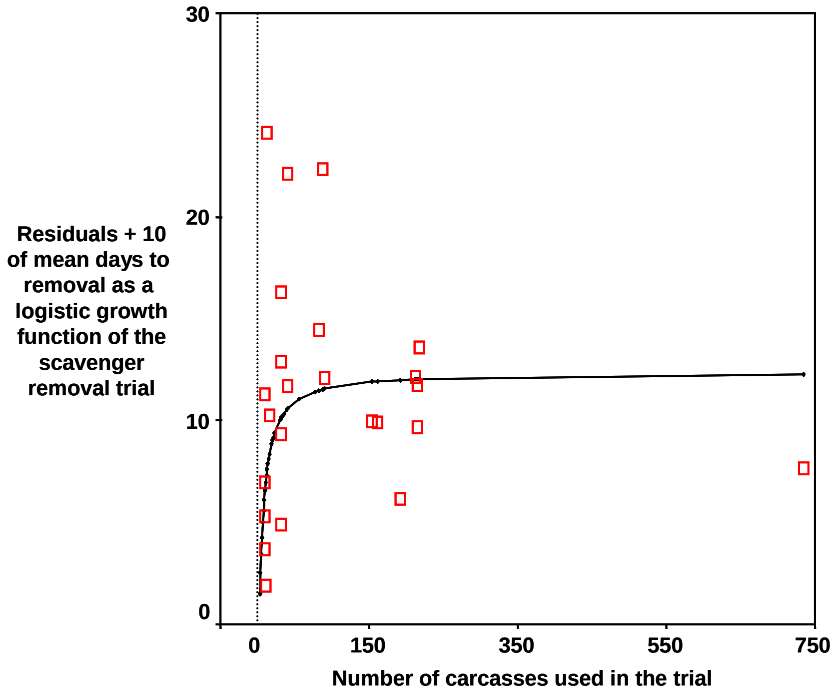

Figure 7. Logistic growth curve residuals related to sample size of carcasses used in the removal trial.

Table 4. Logistic growth curve models of residuals + 10 from the models in Table 3 related to sample size of carcasses used in the trial. The value ten was added to the residuals to eliminate negative values for the purpose of model fitting.

Model	**r^2**	**RMSE**	**n**	**P-value**	**a**	**b**
All birds	0.17	0.54	23	<0.05	2.5174	-6.3769
Small birds	0.64	0.34	8	<0.01	2.7496	-11.1947

Proportion of carcasses remaining

Percentages of carcasses remaining were fitted by mathematical functions best representing the pattern in the data (Figs. 8-12). In most cases the best-fit model was logarithmic:

$$R_i = a + b \cdot \ln(D_i + 1) \,, \qquad \text{eqn. 5}$$

where R_i was the percent of carcasses remaining on the *i*th day, D_i was the *i*th day into the scavenger removal trial (1 was added to avoid error results when taking the natural log of 0), and *a* and *b* were fitted parameters. The best-fit models are presented in Table 5. Table 6 presents the best-fit models for all estimates resolved to season of the year. The residuals from the models in Table 6 were used to test whether other reported variables affected scavenger removal rates.

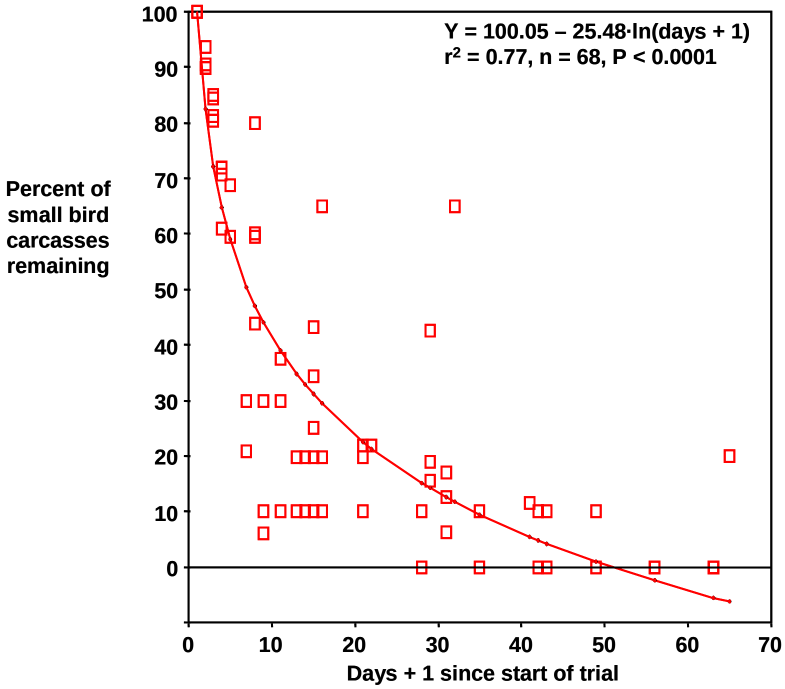

Figure 8. The percentage of small, nonraptor bird carcasses remaining at trial's end as a logarithmic function of trial duration.

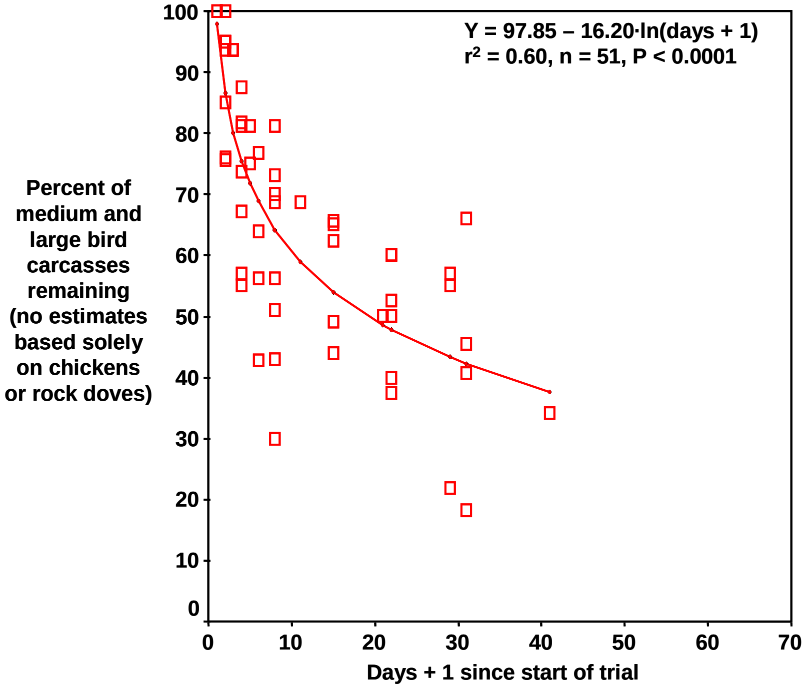

Figure 9. The percentage of medium and large, nonraptor bird carcasses remaining at trial's end as a logarithmic function of trial duration.

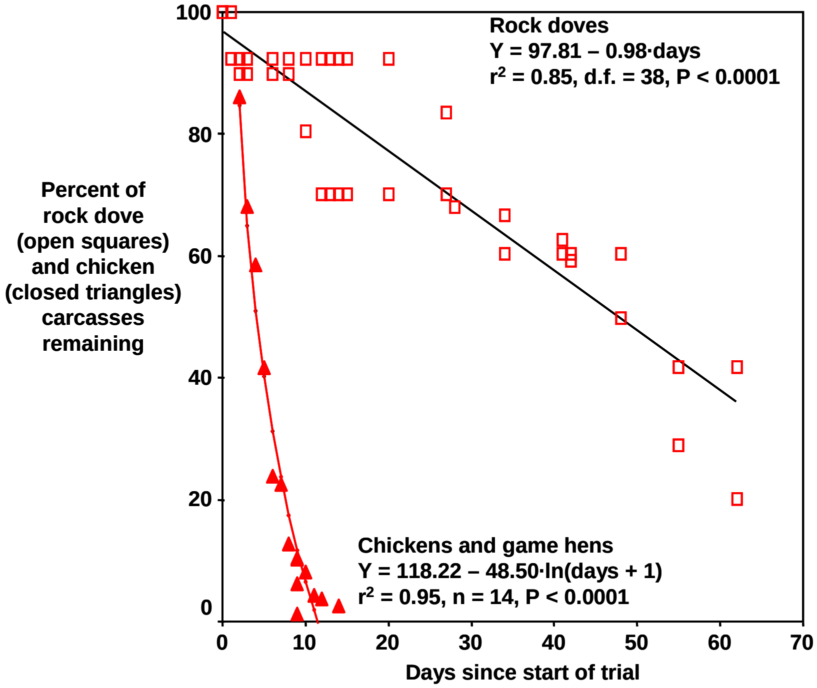

Figure 10. The percentage of rock dove carcasses remaining at trial's end as a linear function of trial duration, and the percentage of chicken/game hen carcasses remaining as a logarithmic function of trial duration.

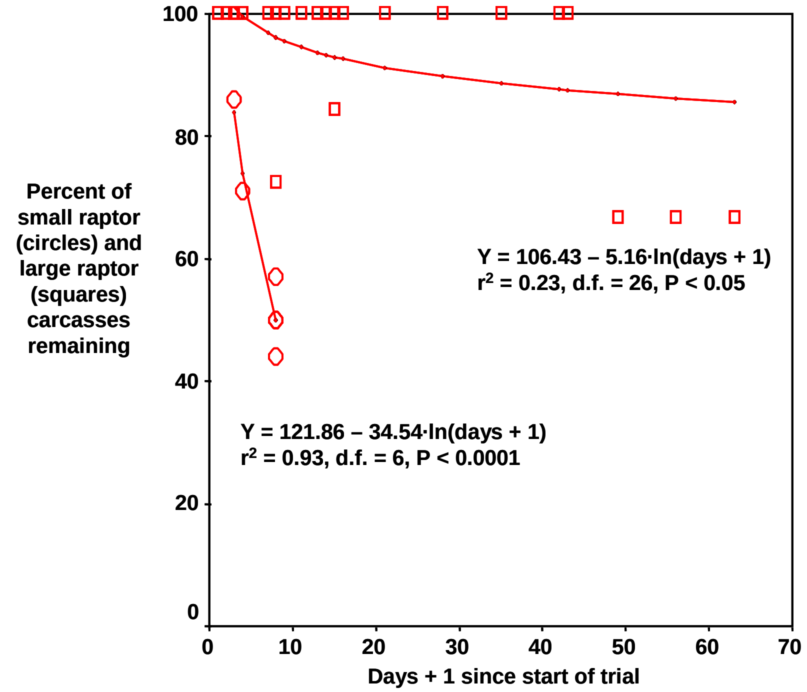

Figure 11. The percentages of small and large raptor carcasses remaining at trial's end as logarithmic functions of trial duration.

Table 5. Summary of best-fit models of the percent of carcasses remaining regressed on the number of days since the start of the scavenger removal trial.

Group	Model	r^2	n	P-value	a	b
Small birds	Logarithmic	0.77	68	<0.0001	100.05	-25.48
Medium/large birds	Logarithmic	0.60	51	<0.0001	97.85	-16.20
Chickens/game hens	Logarithmic	0.95	14	<0.0001	118.22	-48.50
Rock doves	Linear	0.85	38	<0.0001	97.81	-0.98
Small raptors	Logarithmic	0.93	6	<0.0001	121.86	-34.54
Large raptors	Logarithmic	0.23	26	<0.05	106.43	-5.16

Table 6. Summary of best-fit models of the percent of carcasses remaining regressed on the number of days since the start of the scavenger removal trial, but only for estimates associated with season of the year.

Group	Model	r^2	n	P-value	a	b
Small birds	Logarithmic	0.66	78	<0.001	96.87	-23.62
Medium/large birds	Logarithmic	0.50	79	<0.0001	114.83	-18.00
Rock doves	Linear	0.83	41	<0.0001	97.85	-0.98
Small raptors	Logarithmic	0.93	7	<0.001	121.85	-34.54
Large raptors	Logarithmic	0.07	36	>0.05	101.75	-4.27

The models summarized in Table 5 predict the percentage of carcasses remaining on any given number of days since the carcasses were deposited in the study area. However, assuming that wind turbines operate consistently from day to day and assuming that birds/bats fly in similar manners and frequencies each day, wind turbine collisions have a similar probability of depositing carcasses on the ground from one day to the next. In addition to the carcasses that may have been deposited 30 days ago, the analyst needs to consider the number deposited 29 days ago, 28 days ago, and so on until 1 and 0 days ago. In this case, the percentage of carcasses remaining after 30 days would be predicted using the parameter values in Table 5 applied to eqn. 5, and the same steps would be used to predict percentages of carcasses remaining after 29 days, 28 days, and so on until 1 and 0 days ago. These predictions can then be combined in eqn. 3 to arrive at the cumulative percentage of carcasses remaining over the last 30 days, or R_C. Table 7 and Fig. 12 present the estimates of the cumulative percentages of carcasses remaining on any of 53 days since the last fatality search.

As an example, we can estimate the percentage of small raptor carcasses remaining after a 3-day interval between fatality searches. The small raptor parameter values in Table 5 applied to the model in eqn. 5 would predict the following percentage of carcasses remaining after 1 day (D_i = 1):

$$R_1 = 121.86 - 34.54 \cdot \ln(1+1) = 97.9\% .$$

After 2 days in the field, R_2 = 83.9%, and after 3 days in the field, R_3 = 74.0%. Plugging these predictions into eqn. 3 results in the following estimate of the cumulative percentage of carcasses remaining at the end of the 3-day interval since the last fatality search (or, at the end of a 3-day scavenger removal trial):

$$R_C = \frac{97.9 + 83.9 + 74.0}{3 \times 100} = 85.3\% \, .$$

This value is 0.3% larger than the value appearing in Table 7 because the values in Table 7 were rounded to the nearest 0.5%.

Thus, Table 7 and Fig. 12 can be used to predict the percentage of carcasses remaining after each fatality search interval during fatality monitoring, assuming a steady state of carcass deposition by the wind turbines. For example, the percentage of small-bodied raptor carcasses remaining after each 15-day search interval of a hypothetical monitoring program would be 0.51, which is obtained by going to the cell in the small raptor column of Table 7 and corresponding with 15 days since the last search.

Table 7. Daily predictions of percentages of carcasses remaining since the last search, based on model predictions in Table 5 applied to eqn. 3.

Days since last search	**Percentage of carcasses remaining**					
	Small nonraptor birds	**Large nonraptor birds**	**Small raptors**	**Large raptors**	**Chickens and game hens**	**Rock doves**
1	82	87	98	100	85	97
2	77	83	91	100	75	96
3	73	81	85	100	67	96
4	70	78	81	99	60	95
5	67	77	76	99	54	95
6	64	75	73	98	49	94
7	61	73	70	98	45	94
8	59	72	67	98	41	93
9	57	71	64	97	37	93
10	55	69	61	97	33	92
11	54	68	59	97	30	92
12	52	67	57	96	28	91
13	51	66	55	96	26	91
14	49	66	53	96	24	90
15	48	65	51	96	22	90
16	47	64	50	95	21	89
17	45	63	48	95	20	89
18	44	62	46	95	19	89
19	43	62	45	95	18	88
20	42	61	43	95	17	88
21	41	60	42	94	16	87
22	40	60	41	94	15	87
23	39	59	40	94	14	86
24	38	59	38	94	14	86
25	38	58	37	94	13	85

26	37	58	36	93	13	85
27	36	57	35	93	12	84
28	35	57	34	93	12	84
29	34	56	33	93	11	83
30	34	56	32	93	11	83
31	33	55	31	93	11	82
32	32	55	30	93	10	82
33	32	54	29	92	10	81
34	31	54	28	92	10	81
35	30	54	27	92	10	80
36	30	53	27	92	9	80
37	29	53	26	92	9	79
38	29	52	25	92	9	79
39	28	52	25	92	9	78
40	27	52	24	92	8	78
41	27	51	23	92	8	77
42	26	51	23	91	8	77
43	26	51	22	91	8	76
44	25	50	22	91	8	76
45	25	50	21	91	7	75
46	24	50	21	91	7	75
47	24	49	20	91	7	74
48	23	49	20	91	7	74
49	23	49	20	91	7	73
50	22	48	19	91	7	73
51	22	48	19	91	7	72
52	22	48	18	90	6	72
53	21	48	18	90	6	71

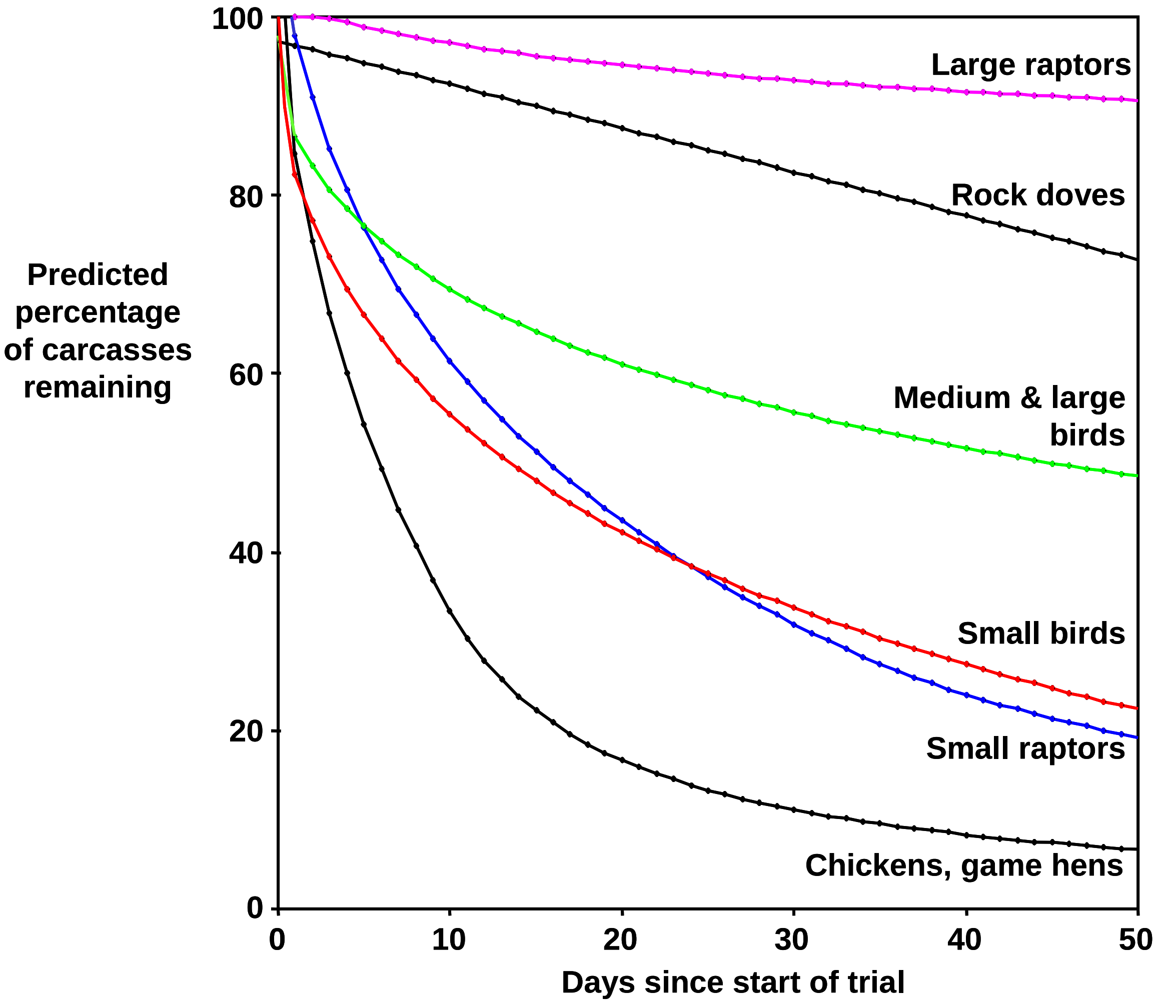

Figure 12. Estimated percentages of carcasses remaining each day into a scavenger removal trial or fatality search rotation (eqn. 3), and assuming a steady state frequency of bird collisions at wind turbines.

SEARCHER DETECTION

Data on searcher detection rates were collected from Orloff and Flannery (1992), Kerlinger et al. (2000, 2006), Johnson et al. (2002, 2003),Young et al. (2003), Erickson et al. (2000, 2003, 2004), Anderson et al. (2004, 2005), Koford et al. (2005), and WEST, Inc. (2006). Vegetation stature was categorized based on descriptions of the study areas in the reports. Short-stature vegetation included annual grassland and short-mid grass prairie. Intermediate stature vegetation included grassland and shrub-steppe, small shrubs and grass, small shrubs, mowed within forest, and forest clearings. Taller-stature vegetation included mixed grass prairie and sagebrush shrubland, wheat, wheat and grassland, hayfield, ruderal, creosote bush, brittlebrush, scalebroom, and wetland, grassland and forest.

Searcher detection varied by species group (ANOVA F = 24.87, d.f. = 5, 127, P < 0.001), and mean percentage of volitionally placed carcasses were highest for large raptors (100%), large nonraptor birds (80%), medium-sized raptors (79%), medium-sized nonraptor birds (78%), small raptors (75%), and small nonraptor birds (51%). Among small birds, percent searcher detection differed significantly by stature of the vegetation cover in the search area (ANOVA F = 13.12, d.f. = 2, 51, P < 0.001), and was least in short-stature vegetation (mean = 43%), and greater in intermediate (mean = 65%) and relatively tall vegetation (mean = 60%). Among medium- and large-sized nonraptor birds, searcher detection tended to differ (ANOVA F = 2.89, d.f. = 2, 57, P = 0.064), and was least in short-stature vegetation (mean = 76%), intermediate in tallest stature vegetation (mean = 82%), and greatest in intermediate stature vegetation (mean = 91%).

MORTALITY ESTIMATES OF DIABLO WINDS AND REPLACED WIND TURBINES

Table 8 presents the scavenger removal and searcher detection adjustments I applied to the pre- and post-repowering of the Diablo Winds Energy Project, resulting in the mortality estimates in Table 8, right columns, and in Table 9.

Table 8. Adjustment terms applied to eqn. 1 for estimating mortality pre- and post-construction of the Diablo Winds Energy Project. Under Search Detection, the WEST, Inc. (2006) column is presented as a comparison to the averages among studies, which are the adjustments I used.

	Proportion of carcasses remaining		**Search detection (%)**		**Mortality, deaths/MW/year**	
Group	**30 days, after Diablo Winds**	**38 days, before Diablo Winds**	**WEST, Inc. (2006)**	**Mean among studies**	**Before Diablo Winds**	**After Diablo Winds**
Small birds	0.34	0.29	44	43	4.8605	1.0029
Medium/large birds	0.56	0.52	76	79	0.5587	0.4806
Chickens/game hens	0.11	0.09	---	74	---	---
Rock doves	0.83	0.79	44	81	0.0855	0.1491
Small raptors	0.32	0.25	44	75	1.4065	0.2036
Large raptors	0.93	0.92	44	89	0.2043	0.4135

Overall, the first year of operations of Diablo Winds appears to have reduced wind turbine collision-caused bird mortality by 70%. Most of this reduction was contributed by song birds. However, it must be remembered that the fatality search frequencies were too long to precisely estimate the mortality of small birds both before and after construction of Diablo Winds; much uncertainty remains in song bird mortality estimates during both fatality monitoring periods. Burrowing owl mortality declined 85%, whereas red-tailed hawk experienced a near three-fold increase in mortality. Diablo Winds also killed some species that were not found killed during previous fatality searches by Smallwood and Thelander (2004, 2005), including golden eagle, turkey vulture, and loggerhead shrike, but the repowered project also did not kill some species previously found, including barn owl, American kestrel, mallard, cliff swallow, European starling, Brewer’s blackbird, and horned lark.

Table 9. Summary of fatalities found and adjusted mortality estimates by species.

	Fatalities		Mortality (deaths/MW/year)	
Species	**Before Diablo Winds**	**After Diablo Winds**	**Before Diablo Winds**	**After Diablo Winds**
Turkey vulture	0	1	0.0000	0.0591
Golden eagle	0	1	0.0000	0.0591
Red-tailed hawk	3	5	0.1063	0.2953
American kestrel	1	0	0.0636	0.0000
Barn owl	3	0	0.1340	0.0000
Burrowing owl	10	1	1.3429	0.2036
Mallard	2	0	0.3146	0.0000
Ring-billed gull	1	0	0.1586	0.0000
Gull sp.	0	2	0.0000	0.2210
Rock dove	2	2	0.0855	0.1491
Cliff swallow	2	0	0.4076	0.0000
Loggerhead shrike	0	1	0.0000	0.3343
European starling	4	0	0.5700	0.0000
Blackbird sp.	1	0	0.4291	0.0000
Brewer’s blackbird	1	0	0.3661	0.0000
Western meadowlark	8	1	2.5067	0.3343
Horned lark	1	0	0.0781	0.0000
House finch	2	1	0.5069	0.3343
Medium-sized bird	0	1	0.0000	0.1105
Total birds	**41**	**16**	**7.0700**	**2.1004**
Bats	0	4	---	---

The mortality estimate for all birds appears similar between the reported estimate in WEST, Inc. (2006) and in Table 9 above. The similarity is coincidental because the estimators and the underlying assumptions differed substantially. The mortality estimates were increased by replacing mean time to carcass removal with percent of carcasses remaining after the number of days corresponding with the fatality search interval. On the other hand, mortality estimates were reduced by replacement of the WEST, Inc. searcher detection rates with more robust, literature-based searcher detection rates.

RISK OF COLLISION

In its reports of bird collisions with wind turbines, WEST, Inc. has often reported a risk index based on a ratio including bird utilization and mortality estimates. Smallwood and Thelander (2004, 2005) also reported collision risk based on these measures. The collision risk estimator (CR) is characterized in the following equation:

$$CR = \frac{M_A}{U}, \qquad \text{eqn. 6}$$

where M_A is the mortality estimate adjusted by scavenger removal rate and searcher detection error, and U is the utilization rate adjusted for a 400-m radius study area. Table 10 summarizes estimates of collision risk (last two rows) for raptors and all birds.

In Table 10 the index of collision risk indicates repowering did not affect collision risk after adjusting WEST, Inc.'s mortality and utilization estimates. The ranges of adjusted WEST, Inc. estimates were obtained by using two approaches to adjust the WEST, Inc. utilization estimates. One approach used the Foote Creek Rim extrapolation, described under the earlier section on utilization. The other approach used the differences in areas corresponding with the 300- and 800-m search radii between the Smallwood and Thelander and WEST, Inc. studies.

In Table 10 the adjusted WEST, Inc. collision risk estimates completely overlapped with the collision risk estimates based on data collected during the NREL and CEC studies. Whereas the repowering reduced mortality of all raptors and all birds, the risk of collision apparently did not change. One explanation for these differences in trend is that raptor and bird utilization of the Diablo Winds project site declined at the same magnitudes between studies, and this explanation is supported by the data. Another explanation is that the error in comparing utilization measured within 300- and 800 m search radii is too great to reliably compare utilization as well as estimates of collision risk. More research will be needed to determine whether collision risk changed, and this research will need to be comparable in methodology to the earlier NREL and CEC studies.

Table 10. Summary of collision risk estimates before and after Diablo Winds Energy Project.

	Collision risk			
Comparison	**WEST, Inc. estimates**	**NREL study, 1998-2000**	**CEC study, 2001-2003**	**Adjusted WEST Inc. estimates**
Raptors observed / 30 min	4.3940	2.0670	3.2430	0.6190 to 1.4060 [a]
Birds observed / 30 min	47.1190	32.974	---	6.5967 to 21.8150 [a]
Raptors killed / MW / year	0.5600	1.6468	---	0.6171
Birds killed / MW / year	2.1200	7.0700	---	2.1004
Raptor collision risk	0.1274	0.7967	0.5078	0.4389 to 0.9969 [a]
Bird collision risk	0.0450	0.2144	---	0.0963 to 0.3184 [a]

[a] The adjustments were based on both the empirical extrapolation from Young et al. (2003) and the differences in area between circles of 300 and 800 m radii, as explained in the text.

RECOMMENDATIONS

The WEST, Inc. mortality estimator includes multiple sources of potential error, and two statistical biases are addressed quantitatively in this report. More research is needed of the potential biases in the mortality estimators' adjustment terms (Table 11).

I recently observed a common raven remove a road-killed sparrow in whole from the roadway. The raven carried the sparrow carcass to a utility pole where the raven consumed it. Given Kerns' (2005) conclusion that common ravens learn quickly of the availability of wind turbine-killed carcasses, and Smallwood and Thelander's (2004, 2005) reports of frequent flights of common ravens within 50 m of wind turbines, it is reasonable to conclude many small birds may quickly disappear from fatality search areas due to the foraging habits of common ravens alone. The fatality search intervals used both before and after Diablo Winds were excessively long for precisely estimating the mortality of small-bodied birds. I suggest the only way to precisely estimate small-bodied bird mortality would be to perform fatality searches every day or perhaps every 2 or 3 days.

With more consistent and thorough reporting of study sites and trial methods, I could have tested more hypotheses of how scavenger removal rates and searcher detection rates related to the factors in Table 11. These scavenger removal and searcher detection trials are obviously very important to estimating mortality with acceptable accuracy and precision. Many of the trials I read about in reports appeared to have been performed in a perfunctory manner, without any apparent effort to reduce large uncertainties surrounding the trials' results. As recommended earlier, directed research is needed to reduce the areas of uncertainty listed in Table 11. Performing scavenger removal and searcher detection trials in cookbook fashion from one wind project to the next will not reduce these uncertainties in a timely manner, and some of these uncertainties will never be reduced this way.

Despite all the remaining uncertainties in mortality estimates, the weight of the evidence indicates the Diablo Winds repowering effort substantially reduced bird mortality. Burrowing owl mortality declined sharply. However, the increase in red-tailed hawk mortality is troubling, and needs to be monitored closely, and additional mitigation measures considered. The species-specific differences in mortality shifts due to repowering were forewarned by Smallwood and Thelander (2004, 2005), but the overall reduction in mortality was also predicted in the Smallwood and Thelander reports. The first year of mortality monitoring at Diablo Winds supports the Smallwood and Thelander (2004, 2005) recommendation that repowering the APWRA be given the highest priority among multiple alternative measures or solutions to the bird collision problem, other than a complete shutdown of the APWRA.

I did not see any evidence indicating Diablo Winds incorporated any of the wind turbine siting or operations recommendations in Smallwood and Thelander (2004, 2005), and which were available to the project owners in preliminary form prior to the release of the 2004 and 2005 reports. Nevertheless, overall bird mortality was reduced by the project during its first year of operations. I believe bird mortality could be reduced even more substantially, however, by careful siting of the wind turbines in future repowering efforts, and by implementing the recommended changes in operations described in Smallwood and Thelander (2004, 2005), Smallwood and Neher (2004), and Smallwood and Spiegel (2005a,b,c).

Table 11. Potential biases in adjustment terms used in mortality estimators, and whether these biases were addressed in this report.

Bias in mortality estimators	**Estimator affected**	**Quantitatively addressed in this report?**
Crippling bias	eqns. 1 & 2	No
Search radius bias	eqns. 1 & 2	No
Background mortality	eqns. 1 & 2	No
$\bar{t}$ and p are derived from small samples of carcasses in field experiments, usually performed concurrently	eqn. 2, but also eqn. 1 for p	No
Some carcasses escape period of attractiveness to vertebrate scavengers, and their mummification increases mean days to carcass removal	eqn. 2	Yes
Use of inappropriate species misrepresents levels of detection and/or attractiveness to scavengers	eqns. 1 & 2	Yes
Frozen or thawed carcasses less attractive to vertebrate scavengers	eqns. 1 & 2	No
Whole carcasses may not mimic dismembered carcasses, and are more difficult to detect or to remove	eqns. 1 & 2	No
Scavenger swamping	eqns. 1 & 2	Probably
Right-censored data, i.e., terminating trial before all carcasses removed	eqns. 1 & 2	Some
Left-censored data, i.e., findings of 0 fatalities not adjusted	eqns. 1 & 2	No
Long search intervals in scavenger removal trials hamper best-fits of the alternative mathematical functions	eqns. 1 & 2	No
The use of mean time to removal assumes exponential rate of carcass removal, whereas the pattern of removal appears not to be exponential	eqn. 2	Yes
Seasonal variation in scavenger activity	eqns. 1 & 2	No
Site variation in scavenger activity	eqns. 1 & 2	No
Searchers made aware of searcher detection trials might be more vigilant	eqns. 1 & 2	Some
Searcher swamping can alert searchers to the trial	eqns. 1 & 2	No
Inappropriate species used in searcher detection trials can be more or less conspicuous, or can alert searchers to the trial	eqns. 1 & 2	No
Marking carcasses can alert searchers to the detection trial	eqns. 1 & 2	No
Searchers typically rely on multiple cues when detecting wind turbine-killed birds, but volitionally placed whole carcasses may not provide those cues	eqns. 1 & 2	No
Detection trials performed away from the wind turbines will alert searchers to the trial	eqns. 1 & 2	No
Seasonal variation in carcass detection by searchers	eqns. 1 & 2	No
Site variation in carcass detection, e.g., due to vegetation height	eqns. 1 & 2	No

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