

**EFFECTS OF MONITORING DURATION AND INTER-ANNUAL VARIABILITY ON
PRECISION OF WIND-TURBINE CAUSED MORTALITY ESTIMATES IN THE
ALTAMONT PASS WIND RESOURCE AREA, CALIFORNIA**

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During a 20 July 2007 conference call, members of the Alameda County Scientific Review Committee (SRC) were noncommittal on measuring post-management mortality during the entire period following the effective date of the settlement agreement between the wind companies and Audubon society and Californians for Renewable Energy. Contrary to past discussions and agreements, some members of the SRC said they were inclined to begin measuring mortality only after the companies implement mitigation measures to reduce bird mortality. The feeling was that a portion of the settlement agreement program period would suffice, but it remained to be decided whether mortality would be measured over a 2-year period, 1 year, or even a fraction of a year. However, Smallwood and Thelander (2004, 2005) had recommended mortality be measured over a minimum of 3 years in order to reduce the influence of inter-annual variation in mortality on the estimate, and to detect at least one fatality at a larger number of wind turbine rows used in the estimate, i.e. to reduce the proportion of turbine rows with zero fatalities in the mortality calculation.

The purpose of this study was to examine bird fatality data collected during the Smallwood and Thelander study to assess the suitability of mortality estimates generated from a monitoring period of 3 years and less using current field methodology. Specifically, I selected data from 54 wind turbine rows (322 turbines with a combined rated capacity of 39.77 MW) that were monitored for more than 4 years. My objectives were to examine: (1) variation in the mean and standard error of annual estimates; and, (2) compare the means and standard errors of annual estimates to multi-annual estimates. A limitation of this study was its small sample size of wind turbines compared to

the monitoring plan currently underway in the Altamont Pass Wind Resource Area (APWRA). However, the trends observed in this study should indicate the trends to be expected with the larger sample size of turbines.

METHODS

From the 1,526 wind turbines searched for bird carcass from March 1998 through September 2002, referred to as Set 1, I selected the 54 turbine rows (322 turbines for a combined rated capacity of 39.77 MW) that were searched for at least 4 years. Within each turbine row I expressed unadjusted mortality (M_U) as the number of fatalities/MW/yr, where MW was the sum of the megawatts (MW) of rated power outputs for all of the wind turbines in the row surveyed. Although individual turbines killed birds, I used the wind turbine row as the study unit because I believed birds often sensed and reacted to the wind turbine row as a barrier or threat. I excluded from mortality estimates all fatalities estimated to have occurred >90 days before discovery, and I excluded carcasses found incidentally after all search rotations had ceased at a particular row. Carcasses found outside the search radius while searches were performed were included, because I assumed the likelihood of seeing carcasses outside the search radius would not vary significantly among turbine rows in the APWRA's short-stature grassland.

I adjusted the mortality estimate, M_A , for carcasses not found due to searcher detection error and scavenger removals as:

$$M_A = \frac{M_U}{p \times R}, \quad \text{eq 1}$$

where M_U was unadjusted mortality expressed as number of fatalities per MW of rated capacity per year, p was the proportion of turbine-caused bird fatalities found by searchers during searcher detection trials, R was the estimated proportion of carcasses remaining since the last fatality

search and was estimated by scavenger removal trials (Smallwood in press). I calculated its standard error, $SE[M_A]$, using the delta method (Goodman 1960):

$$SE[M_A] = \sqrt{\left(\frac{1}{p \times R} \times SE[M_U]\right)^2 \times \left(\frac{M_U}{p} \times \frac{-1}{R^2} \times SE[R]\right)^2 \times \left(\frac{M_U}{R} \times \frac{-1}{p^2} \times SE[p]\right)^2}. \quad \text{eq 2}$$

Searcher efficiency and scavenger removal trials were not performed in the APWRA during this study, so I instead used estimators of searcher detection and scavenger removal rates I developed (Smallwood in press) through synthesis of reported searcher detection and scavenger removal trials performed in wind farms throughout the US.

Search detection rates were 75% ($SE = 9.129\%$) for small raptors, and 100% ($SE = 0\%$) for large raptors, based on averages among reports of searcher detection trials in grasslands across the US (Smallwood in press). I used the following models to predict the proportion of carcasses remaining after each successive day into scavenger removal trials, or into the periods intervening fatality searches (see Smallwood in press for details):

Small raptors: $R_i = 121.86 - 34.54 \times \ln(i+1)$, $r^2 = 0.93$, $n = 6$, $SE = 0.040$, $P < 0.0001$

Large raptors: $R_i = 106.43 - 5.16 \times \ln(i+1)$, $r^2 = 0.23$, $n = 26$, $SE = 0.089$, $P < 0.05$,

where R_i was the percent of carcasses remaining on the i th day into the scavenger removal trial, and the parameter values were fitted using least squares regression. Assuming wind turbines will deposit carcasses at a steady state, for each species group I averaged the above model predictions across the number of days equaling the average number of days between fatality searches for all the turbines I used for this study:

$$R_C = \frac{\sum_{i=1}^{I-1} R_i}{I \times 100}, \quad \text{eq 3}$$

where R_C was the cumulative carcasses remaining, R_i was the percent of carcasses remaining by the i th day following the initiation of a scavenger removal trial and corresponding with the number of days since the last fatality search, and I was the average number of days between fatality searches among Set 1 turbines.

All mortality estimates represented mortality caused directly by wind turbines, and did not include fatalities caused by electrocution on the power collection system, collisions with overhead power lines, or collisions with automobiles traveling the wind turbine service roads. A potential source of error was the proportion of turbine rows where 0 fatalities were recorded, but where scavengers might have removed carcasses prior to the searches, or where the searches missed carcasses. These 0-values were not adjusted for searcher detection and scavenger removal errors because 0 divided by p or R equals 0.

For each raptor species, I estimated mortality and 80% confidence intervals for each year since fatality monitoring began at the turbine row, as well as for the first 2 years, middle 2 years, and last 2 years, the first 3 years, and last 3 years, and for the first 4 years. Collection of the first year of data began in April through August of 1998, depending on the turbine row, and continued to the same date in 1999. The last year of data started in 2001 and ended in one of the first 5 months of 2002, depending on the turbine row.

RESULTS AND DISCUSSION

For each of the target species of the Alameda County avian mortality reduction program, variation in 80% CI half-widths in the mortality estimates declined with increasing number of years used to generate the mortality estimate (Figure 1). Some portion of this reduction in variation was forced by the simple fact that fewer estimates were made with each annual increase in number of years, but an examination of the graphs in Figure 1 indicate the 80% CI half-widths of estimates

generated from 2- and 3-year periods were not trending toward the same level observed for 80% CI half-widths generated annually. Furthermore, the 80% CI half-widths declined with number of years used to generate the mortality estimate.

The 80% CI half-width was a logistic function of average annual mortality, so the larger the mean mortality estimate, the larger the confidence interval (Figure 2). As the number of years used to generate the estimate increased, both the mean and 80% CI half-width tended to reduce, as Smallwood and Thelander (2004, 2005) had generally predicted (Figure 3). Note that the estimates from 1-year periods span the entirety of the range of estimated mean mortality of each species. The precision of the estimates from 1-year periods varied from year to year, most dramatically for the small-bodied raptor species, i.e., American kestrel and burrowing owl (Figure 4).

The 80% CI half-widths derived from 1-year periods could be relatively small during a particular year, but at least half were larger than those derived from 2-, 3-, and 4-year periods (Figures 5-9). Furthermore, the multi-year estimates tended to be more consistent than the estimates derived from 1-year periods. This difference was less noticeable for American kestrel and burrowing owl (Figures 5 and 6), but was pronounced for golden eagle and red-tailed hawk (Figures 7 and 8).

Figure 9 demonstrates the increase in 80% CI half-widths caused by combining all four target species for use as an indicator of the effectiveness of the Alameda County avian mortality reduction program. If the carcasses of all 4 species were generally of the same body size, and were treated by scavengers similarly and detected at equal rates by fatality searchers, then their numbers could be combined prior to mortality adjustments and use of the Delta Method for combining error estimates for all terms in the calculation of adjusted mortality. Because these species represent two very different body size classes, their carcass numbers need to be processed for mortality estimates

separately, and their overall error estimates cannot be combined until after separate estimates are made. For this reason, the 80% CI half-widths in Figure 9 are large, and they will be large in the baseline and post-management mortality estimates compared by the SRC at the end of the Alameda County avian mortality reduction program, regardless of the duration of the monitoring period used to generate the mortality estimates. In the case of combine species, the large combined 80% CI half-widths of the mortality estimates derived from this subset of the baseline data indicate the SRC may be unable to detect any difference in mortality between the baseline and post-management mortality estimates. The combined 80% CI half-widths derived from the entire baseline data set would have to be much smaller, which is conceivable given the larger sample size of wind turbine rows. However, after estimating new mortality estimates from the entire baseline data set, Thelander and I found the estimates included large 80% CI half-widths (manuscript in press), likely due to the fact many turbine rows were searched only for a half-year period.

Based on the results of the analyses presented herein, and based on the assumption the ongoing monitoring methods will continue without modification, I recommend the minimum fatality monitoring period be at least three years over which post-management mortality is estimated. Mortality estimates from one-year periods are too variable from year to year, and half their confidence intervals too large, to be relied upon for comparing post-management mortality to baseline mortality. It is unlikely any differences in mortality will be detected based on a short-duration monitoring period, and even if a difference was detected, the difference would be regarded by many as the product of either a high- or low-mortality period due to inter-annual variation in relative abundance and/or mortality. I also recommend not pooling the four target species for deciding whether raptor mortality has been reduced by half.

REFERENCES

Smallwood, K. S. In press. Estimating wind turbine-caused bird mortality. Journal undisclosed until further notice.

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Smallwood, K. S. and C. Thelander. 2005. Bird mortality at the Altamont Pass Wind Resource Area, March 1998 – September 2001 Final Report. National Renewable Energy Laboratory, NREL/SR-500-36973. Golden, Colorado, USA.

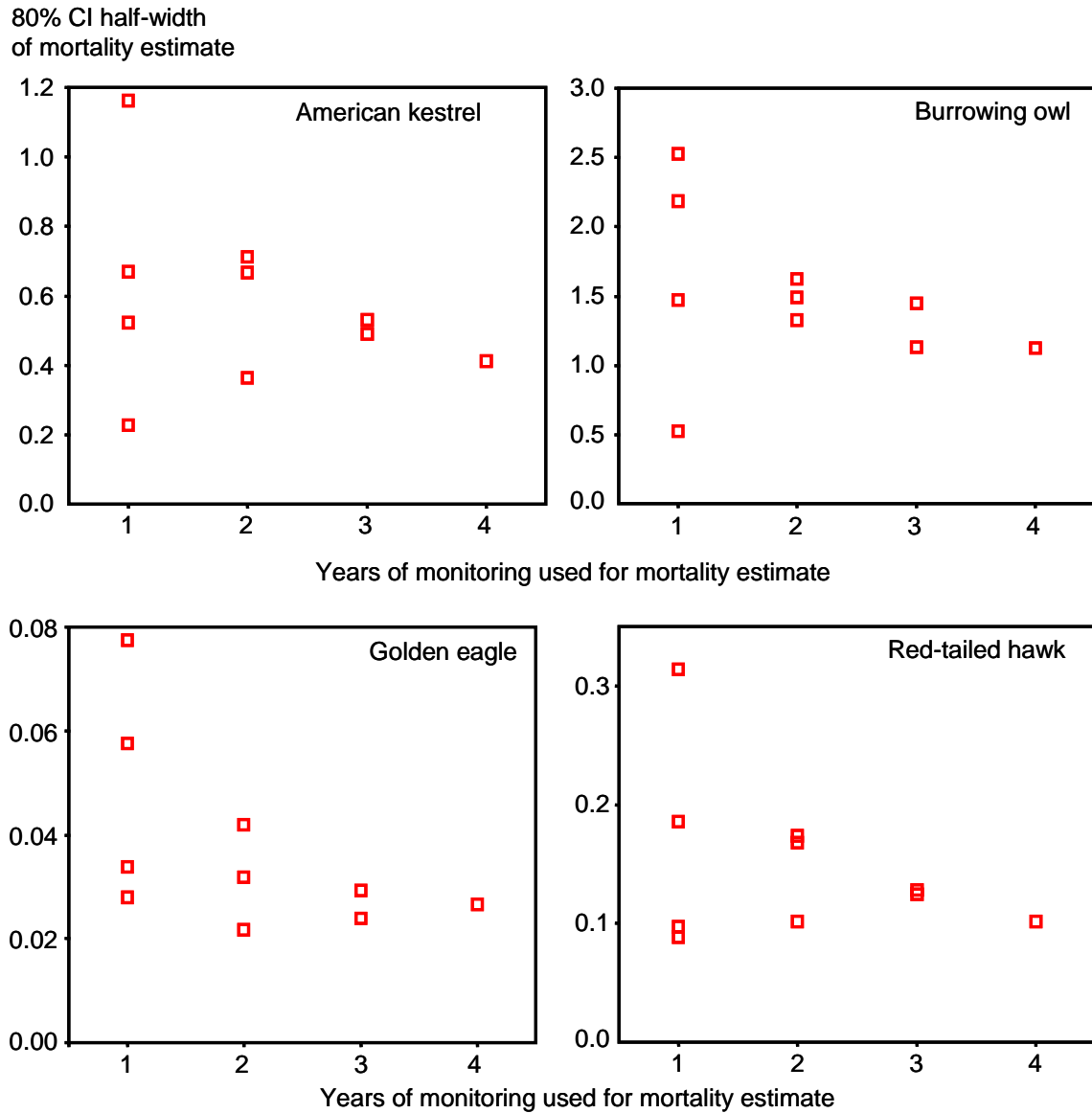
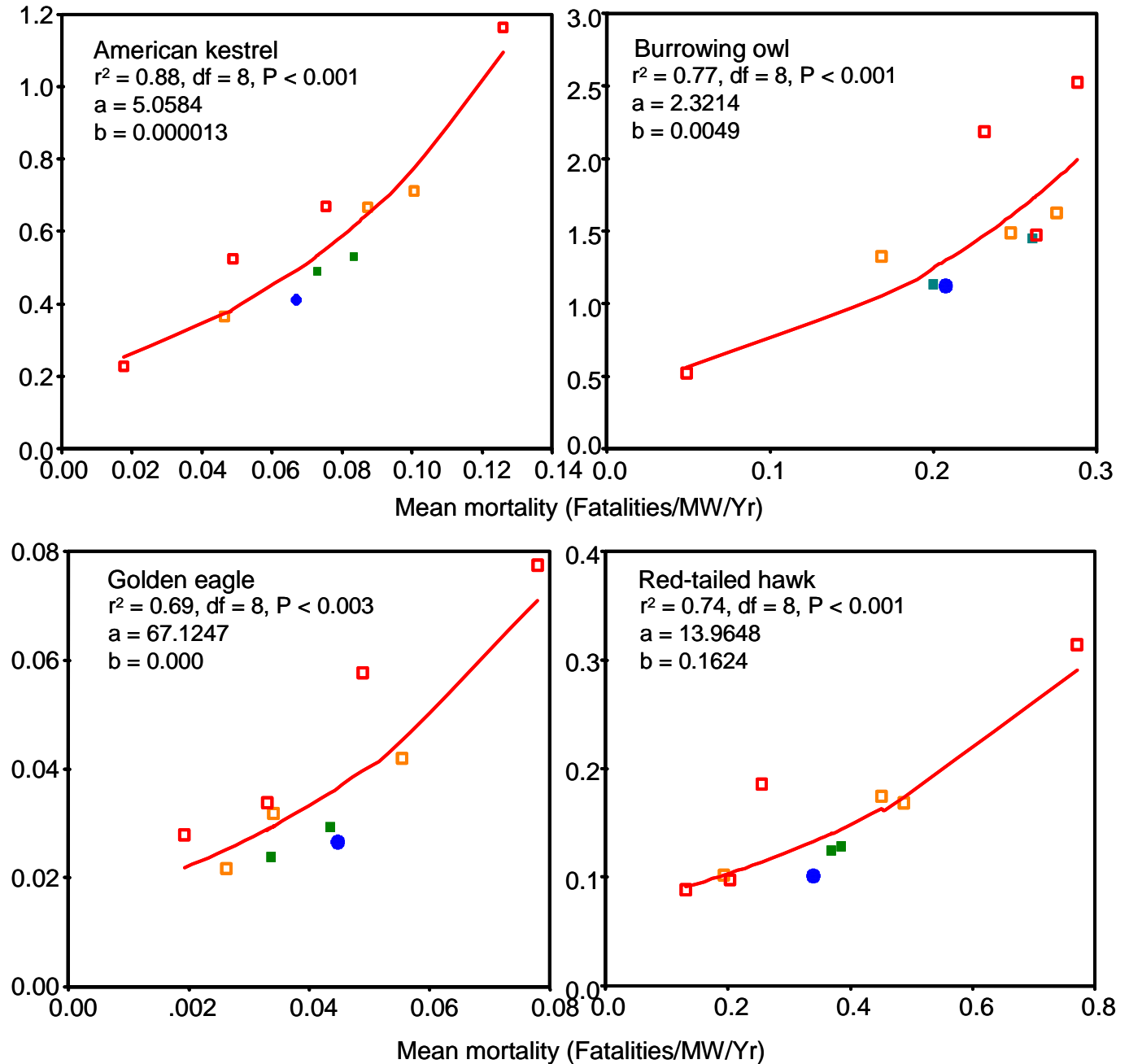


Figure 1. Effect of monitoring duration on confidence interval of mortality estimates (fatalities/MW/year).

80% CI half-width
of mortality estimate



Years of monitoring

- 4
- 3
- 2
- 1

$$Y = e^{a+b/X}$$

Figure 2. Precision of the mortality estimate is a logistic function of mean mortality. Note the multi-annual mortality estimates tend toward lower mean mortality and improved precision (smaller 80% CI half-widths).

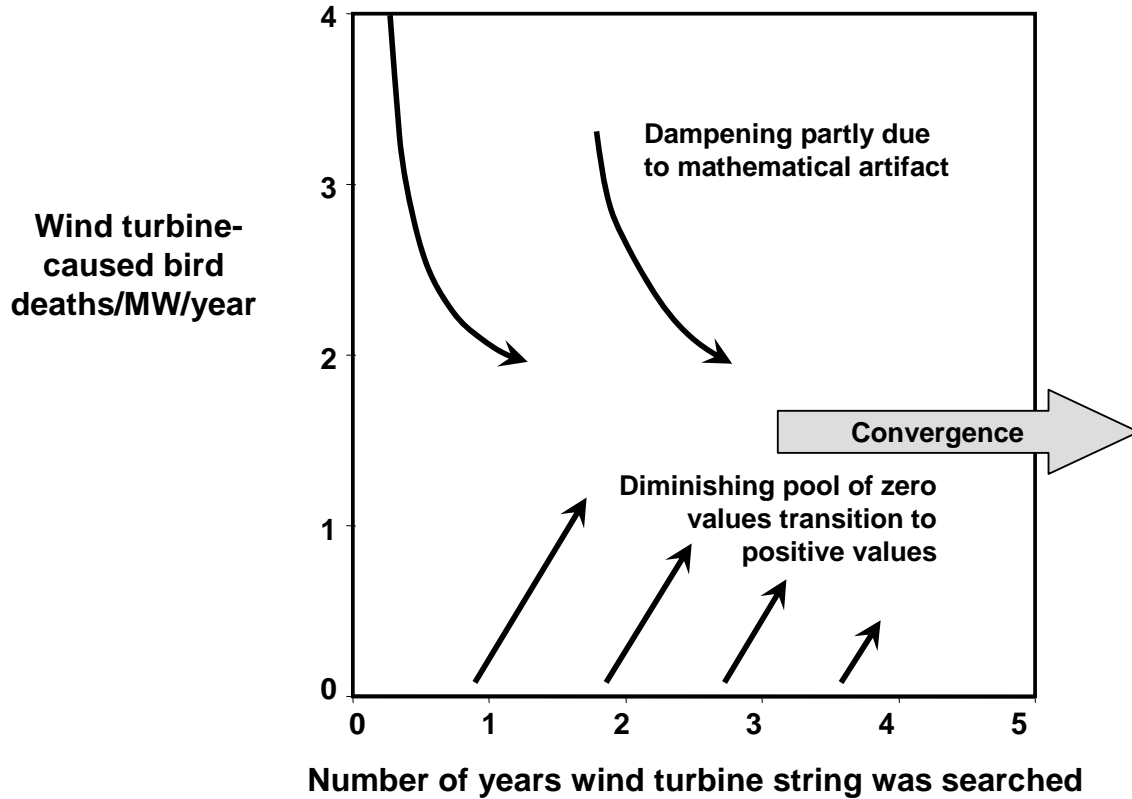


Figure 3. The variation about average annual mortality estimates was expected to reduce and the average was expected to trend toward a more middle value as the number of years used to generate the estimate increases. The figure was slightly modified from Smallwood and Thelander (2004), and was generally supported by the patterns shown in Figures 1 and 2.

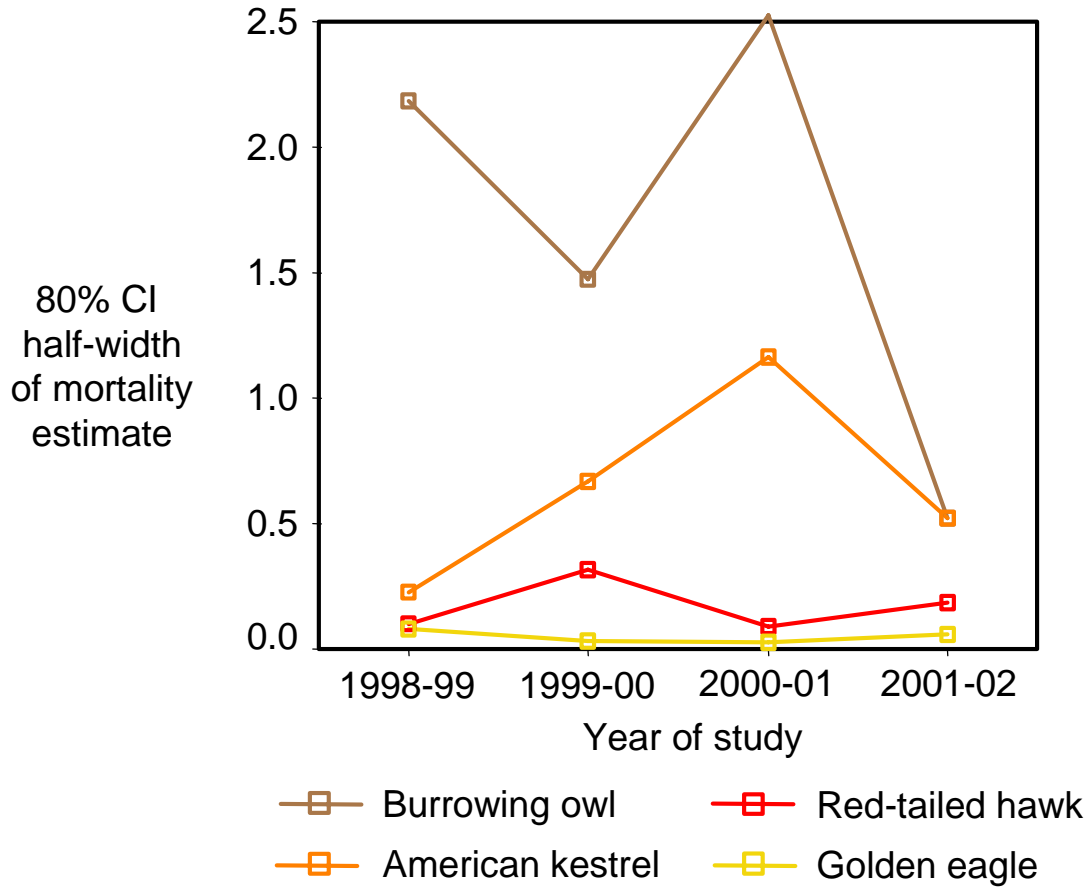


Figure 4. Inter-annual variation in the 80% CI half-width of mortality estimates generated from 1-year periods.

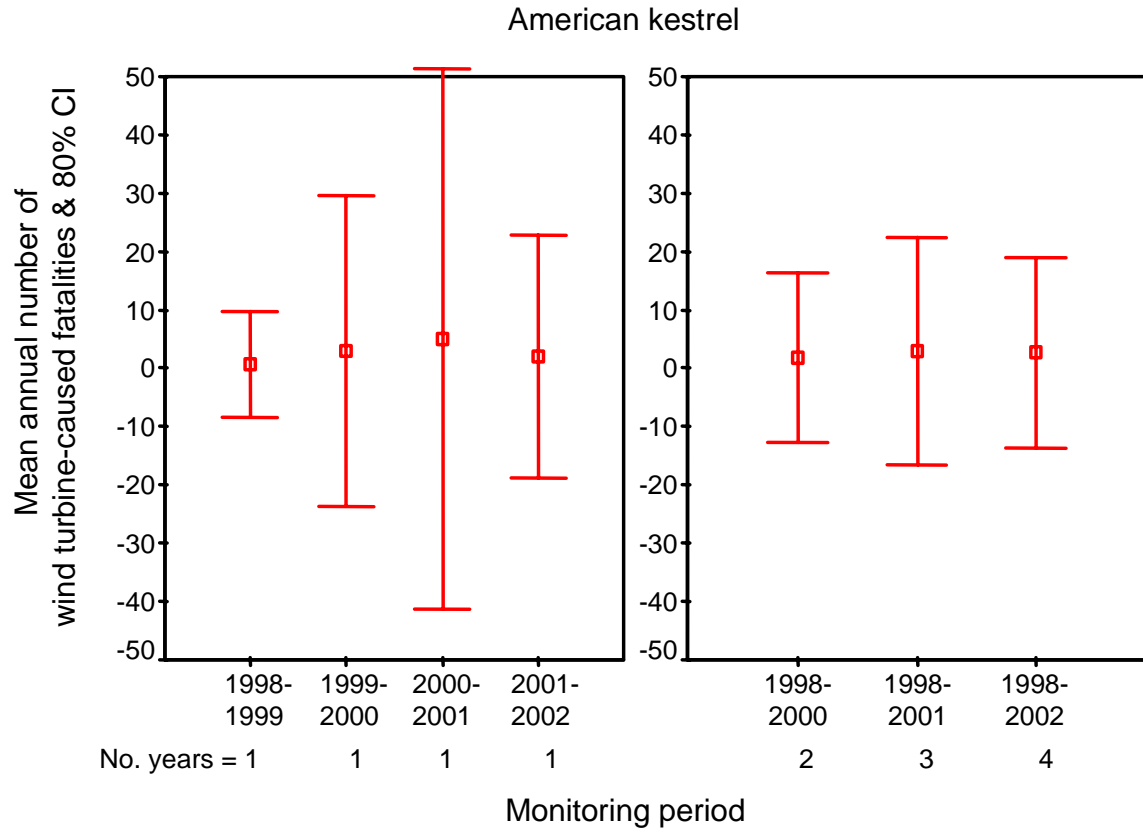


Figure 5. Average annual mortality estimates and 80% CI generated from one-year (left graph) versus multi-year (right graph) periods, where average annual estimates were the number of fatalities across the 39.77 MW of the wind turbines used in this study.

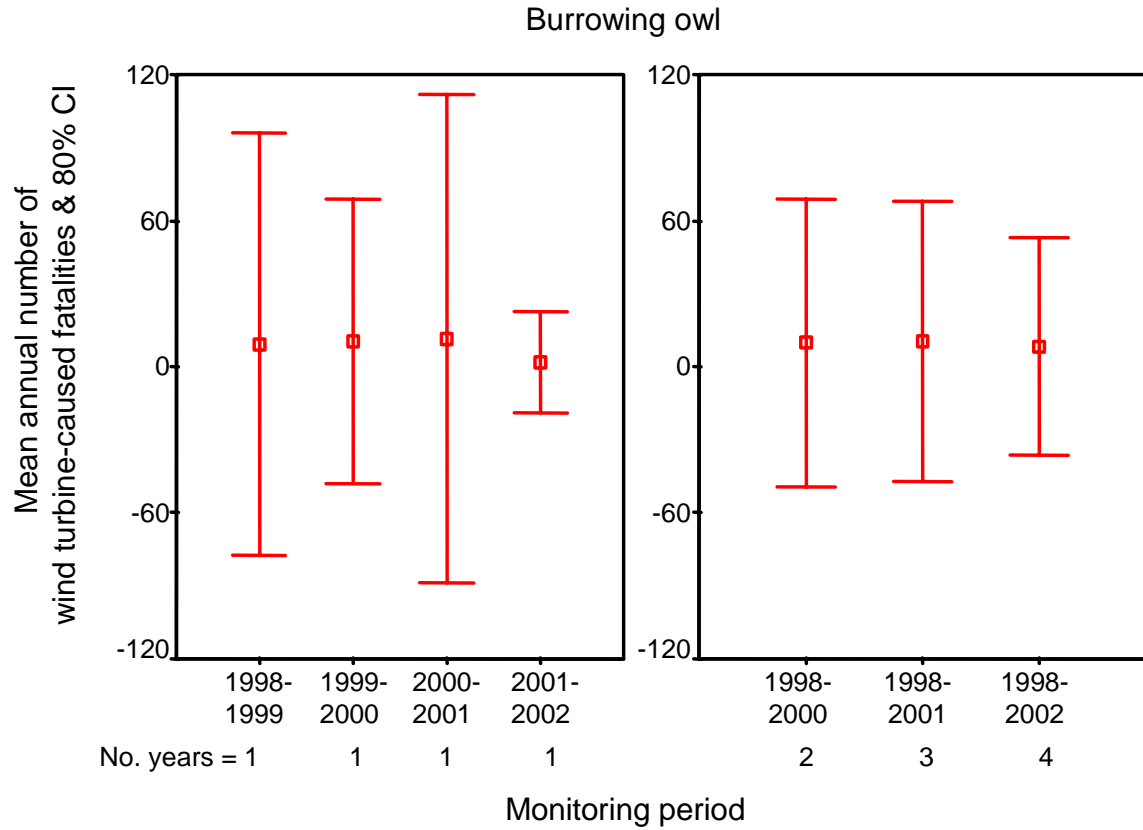


Figure 6. Average annual mortality estimates and 80% CI generated from one-year (left graph) versus multi-year (right graph) periods, where average annual estimates were the number of fatalities across the 39.77 MW of the wind turbines used in this study.

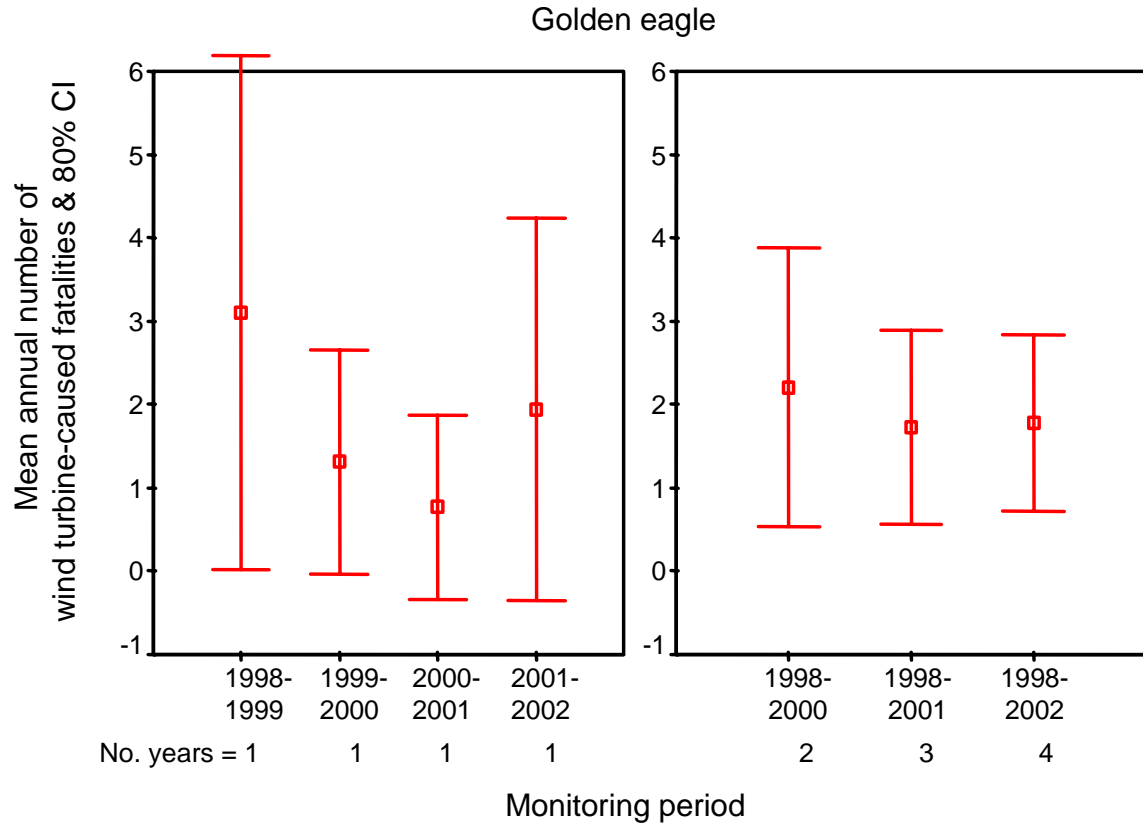


Figure 7. Average annual mortality estimates and 80% CI generated from one-year (left graph) versus multi-year (right graph) periods, where average annual estimates were the number of fatalities across the 39.77 MW of the wind turbines used in this study.

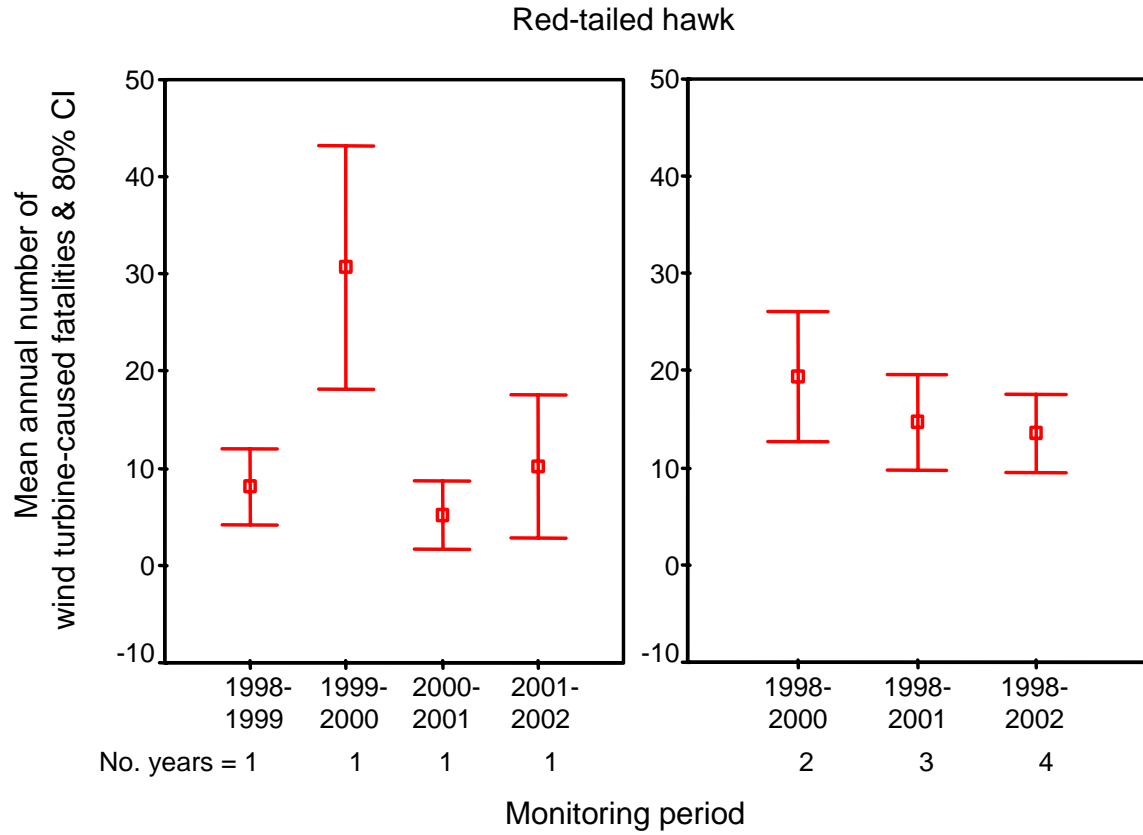


Figure 8. Average annual mortality estimates and 80% CI generated from one-year (left graph) versus multi-year (right graph) periods, where average annual estimates were the number of fatalities across the 39.77 MW of the wind turbines used in this study.

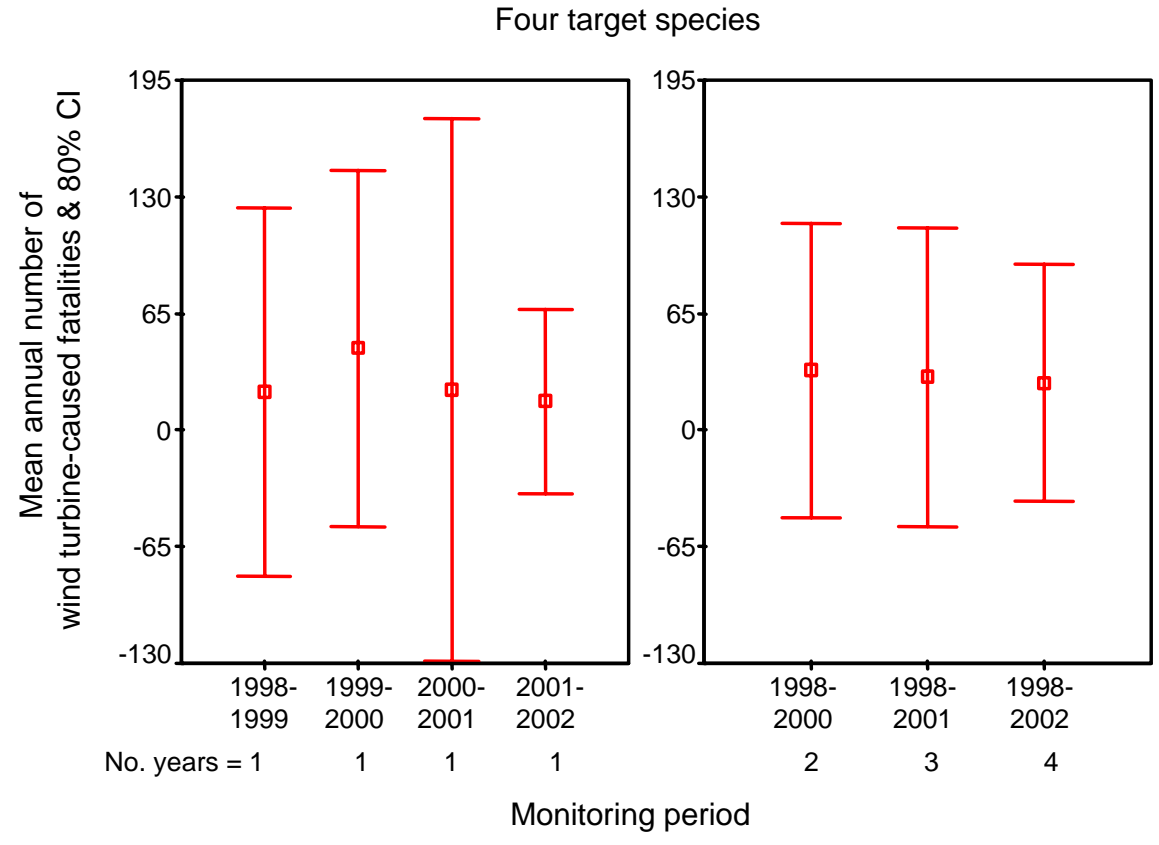


Figure 9. Average annual mortality estimates and 80% CI generated from one-year (left graph) versus multi-year (right graph) periods, where average annual estimates were the number of fatalities across the 39.77 MW of the wind turbines used in this study.