

Inter-turbine Comparisons of Fatality Rates in the Altamont Pass Wind Resource Area

K. Shawn Smallwood

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The Alameda County Scientific Review Committee (SRC) and other interested parties have sought to arrive at several conclusions which could be facilitated by (1) use of the individual wind turbine as a sampling unit, and (2) integration of utilization rate estimates. For example, the SRC would like to know the relative effectiveness of turbine removals and relocations. It would also like to know whether fatality rate changes can be explained by changes in utilization rates. Over the past year, my colleagues and I have been processing the utilization data collected by the monitoring team from 2005 through January 2010. These data are still being processed, but I now have enough of the processing completed to explore the data for inter-annual trends. Herein I report on specific hypothesis tests, including whether inter-annual fatality rates related to utilization rates, and whether fatality rates related to SRC hazard ratings. One goal is to use utilization rates to help interpret the meaning of changes in fatality rates. Another is to assess the effectiveness of the SRC at identifying disproportionately hazardous wind turbine locations or situations. The latter goal bears on the mitigation directed toward the ongoing operations of old-generation wind turbines as well as the siting of new turbines to be installed as part of repowering.

METHODS

Field methods directed to fatality searches were summarized in Smallwood and Karas (2009). Fatality rates were first calculated as the number of fatalities found divided by the rated MW capacity of each wind turbine and by the proportion of the year the searches were performed. Most values for the year were 1.0, but the last search for which fatality data were available to me were sometimes in August or early September 2009, so short of a full year. Also, the baseline surveys did not always match the SRC's bird year, so some turbines were searched for two thirds of a year, and some for nearly a year. The fatality rate metric accounted for searches lasting less than one year, but of course certain seasons of the year were not equally represented in the resulting fatality rates at all turbines during the baseline monitoring period, during 2005 for Diablo Winds, and during 2007 and 2009 for some of the old-generation turbines searched in the current study period (e.g., some turbines were added to the monitoring effort in April 2007).

Fatality rate adjustments

I used different adjustment factors than I did in earlier reports (Smallwood 2007). This time I had processed data from hundreds of searcher detection trials and from hundreds of scavenger removal trials. My sample sizes were much larger and included trials from a wider range of environmental conditions, field methods, and species placed. The methods I used to process the data from these trials need to be reported in a stand-alone report to the California Energy Commission's Public Interest Energy Research program, so I will not describe them here. My intent here is to point out that removal rates and searcher detection rates were different from

those I used earlier, and now I have adjustment factors for bats, as well. Most of the differences were slight.

The only new scavenger removal trial that included raptors was Smallwood et al. (2010). However, I chose not to rely on this trial alone. Furthermore, patterns in the newly acquired data from across North America alerted me to a potential bias in removal rates due to using carcasses of animals that were killed one, two, or more days before the carcass was either frozen or placed in a trial. Using older carcasses can change the shape and location of the removal curve. I therefore adjusted the results of removal trials using older carcasses by adding in the proportions of carcasses that would have been removed over the first several days had the trials involved freshly killed birds. I obtained these proportions from the trials that reportedly did use fresh carcasses. The existing raptor removal trials were thus adjusted, but the small sample sizes left me reluctant to rely solely on the results of these trials. Therefore, I combined large raptor trial results with the results of other large bird trials, and I also combined small raptor removal rates with the rates of other small birds. I should also note that I did not see any obvious differences in removal rates between raptors and other birds of the same size classes.

I also characterized a third adjustment factor, which I termed the search radius adjustment. For this adjustment, I plotted cumulative counts of carcass with increasing 1-m distance intervals from turbines in wind projects across North America (Figure 1). My plots were limited to turbines for which reports were available to the public, but I obtained 9,174 suitable reports of bird and bat fatalities from 20 combinations of tower height and maximum search radius from amongst 31 project sites. My plots also excluded mobile, wounded birds and birds or bats found beyond the reported maximum search radius plus 5 m to account for the area likely searched as the searcher reached the search boundary. I violated the assumption of linear regression analysis that observations were independent, but my objective was only to fit a curve to the distribution of the data. For the purpose of model fitting, I sought to minimize the root mean square error (RMSE). In all cases, I used a logistic function to fit the data, iteratively changing the upper bound value of the dependant variable in the model until the minimum RMSE was obtained:

$$Y = \frac{1}{\left(\frac{1}{u} + a \times b^x\right)},$$

where u was the upper bound value of the dependant variable Y , X was meters from wind turbine where nearest fatality remains were located, and a and b were fitted coefficients.

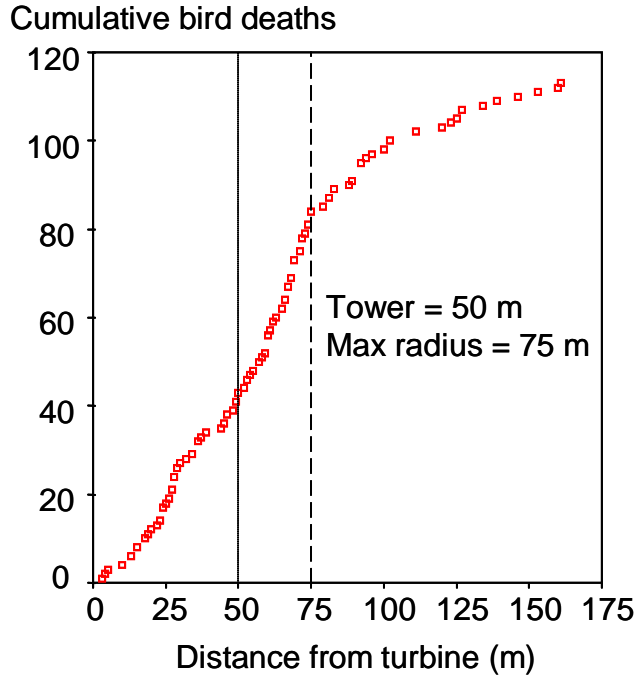


Figure 1. Cumulative counts of bird deaths increased logarithmically with increasing distance from the wind turbine at wind turbines mounted on 50-m towers and searched to 75 m from the tower base.

I used the regression models to predict cumulative sum fatalities as functions of distance from the turbine, and I extended the predictions to distances far beyond the maximum search radii that were reported at wind energy projects. My reason for extending predictions to greater distances was to identify asymptotic values, which I then divided into predicted values at each 1-m interval. The result was a predicted cumulative sum of fatalities represented as the proportion of the maximum number to have been found had the searches extended well beyond the search boundary. I then estimated the proportion of missed carcasses to be $1.0 - p_{sr}$, where p_{sr} was the proportion of carcasses predicted by the model fit to have been found within the search radius.

I adjusted fatality rates, F_A , for carcasses not found due to searcher detection error, scavenger removals, and insufficient maximum search radius as:

$$F_A = \frac{F_U}{D \times R_C \times p_{sr}},$$

where D was the proportion of fatalities found by searchers, R_C was the estimated cumulative proportion of carcasses remaining since the last fatality search, assuming wind turbines will deposit carcasses at a steady rate through the search interval, and p_{sr} was the proportion of carcasses to have been found within a predicted distance asymptote of deposited carcasses. For the purpose of hypothesis-testing herein, I did not carry error terms from the adjustment factors.

Utilization surveys

Utilization surveys consisted of visual scans from observation points (OPs) located throughout the Altamont Pass Wind Resource Area (APWRA), and which varied in duration and maximum survey distance (Table 1). Data were not always collected, so there were gaps (Table 2). Observers recorded on maps the locations of birds on the minute every minute into each session. They also recorded attributes of the observation, such as the number of birds comprising the observation, whether the bird(s) was flying or perching, direction of flight, and species. An earlier monitoring team entered the first several years of the attribute data into two electronic spreadsheets that were supposed to be linked, but the link was corrupted for thousands of records and the electronic data appeared to include many errors. Therefore, a team led by Lee Neher and myself entered the data to spreadsheets again, this time making sure that the linking variables were sound. Neher's team is also digitizing the map data so that the data can be adjusted for both distance from the observer, for the proportion of visible airspace, and for levels of overlap of the airspace from multiple neighboring OPs. The digitized data will be ready later, and will be used for other hypothesis tests.

Most, but not yet all, of the attribute data have been entered to new spreadsheets. I estimate that about 90% of the data were available for my use at this time. I identified the first record of each bird during each session through September 2009. I then tallied these first observations across sessions per bird year, where the bird year was defined by the SRC as October 1 through September 30. To derive utilization rates, I divided tallies of first bird observations by the number of hours composing all of the sessions performed during the bird year. Utilization rates were thus measured as the number of birds seen per hour.

I used the distance functions in Table 1 of Smallwood and Neher (2010) to adjust all of the utilization rates to a common maximum survey radius of 800 m. This adjustment was suitable for making inter-annual comparisons, but not for making inter-OP comparisons because the latter would require additional adjustments for variation in the visible airspace due to each OPs position on the terrain.

Table 1. History of utilization surveys during the current monitoring program in the APWRA.

Data range	Area	Session duration (minutes)	Maximum survey radius (m)	Behavior recorded?
Dec 2005 to Jan 2007	Altamont-wide	30	800	Yes
Mar 2007 to Jun 2007	Altamont-wide	10	800	No
Sep 2007 to present	Altamont-wide	10	500	No
Feb 2006 to Jul 2007	Diablo Winds	30	800	Yes
Aug 2007 to present	Diablo Winds	10	600	No

Table 2. Monthly availability of utilization survey data during the current monitoring program in the APWRA (X = data were collected).

Site	Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Diablo	2005				X	X	X	X	X	X	X	X	X
Diablo	2006	X	X			X	X	X	X	X	X	X	
Diablo	2007	X					X	X	X	X	X	X	X
Diablo	2008	X	X	X	X	X	X	X	X	X	X	X	X
Diablo	2009	X	X	X	X	X	X	X	X	X	X	X	X
Diablo	2010	X	X	X									
APWRA	2005												X
APWRA	2006	X	X				X	X	X		X	X	
APWRA	2007	X		X	X	X	X	X	X	X	X	X	X
APWRA	2008	X	X	X	X	X	X	X	X	X	X	X	X
APWRA	2009	X	X	X	X	X	X	X	X	X	X	X	X
APWRA	2010	X	X	X									

RESULTS

New fatality rate estimates based on new adjustment factors indicated little if any differences in means values and in levels of variation among the NREL core turbines between baseline and current study periods for the four target raptor species (Figure 2). Among the Santa Clara turbines, where mitigation measures were not implemented, fatality rates tended to increase for red-tailed hawks and American kestrels (Figure 3). After a 2007 spike in burrowing owl fatality rate, burrowing owl fatalities declined to zero.

Removals of 100-KW wind turbines in 2009 resulted in decreased fatality rates at those turbines (Figure 4). The only exception was for American kestrels at vacant towers or broken turbines.

Relationships between fatality rates and utilization rates differed between the Diablo Winds turbines and the old-generation turbines (Figure 5). Around the Diablo Winds turbines, fatality rates generally increased with increasing utilization rates of golden eagle, red-tailed hawk, and American kestrel, but decreased for burrowing owls. Around the old-generation turbines, fatality rates generally decreased for golden eagle, red-tailed hawk, and American kestrel, but increased for burrowing owl.

Combining fatality rates and utilization rates in a new metric led to a metric dominated by whichever rate varied the most in terms of inter-annual means. Therefore, I normalized fatality rates and utilization rates by dividing each inter-annual mean by the maximum mean among the bird years. I divided normalized fatality rates by normalized utilization rates. The resulting metric of mortality peaked in 2007 and declined since that time (Figure 6).

I compared normalized mortality estimates between old-generation and Diablo Winds wind turbines (Figure 7). Only red-tailed hawk mortality indicated parallel trends between old-generation and Diablo Winds turbines. American kestrel and golden eagle mortality appeared to trend in opposite directions between old-generation and Diablo Winds turbines. Burrowing owls

experienced a very large spike in mortality among the Diablo Winds turbines during the 2007 bird year.

Mitigation measures

In 2007 and 2010, the SRC rated wind turbines for collision hazard to golden eagle, red-tailed hawk, and American kestrel. These ratings corresponded with fatality rates, most especially for 2006 and 2007. The correspondence lessened in 2008 and nearly vanished by 2009, perhaps due to hazardous turbine relocations and removals (Figure 8).

Because the SRC ratings were not directed toward burrowing owls, and because burrowing owl fatality rates did not relate significantly with SRC ratings, I compared fatality rates among June 2005 Tier classifications (Smallwood and Spiegel 2005). Few Tier 1 turbines were monitored during the current study, so the small sample size did not produce reliable mean values. Burrowing owl fatality rates were generally higher among Tier 2 turbines, compared to higher Tiers (Figure 9). For the other target raptor species, the Tier classification did not perform as well as the SRC ratings.

I found no convincing evidence that painting one blade black reduced fatality rates of any of the target raptor species (Figure 10). Fatality rates at treated turbines were lower than non-treated turbines prior to treatment, but much higher in the two years following treatment.

DISCUSSION

Incorporating utilization rates into a mortality metric proved to be feasible, but interpreting the results may be more complicated than previously thought. Fatality rates related to utilization rates in unexpected ways, in my assessment. Possibly, the relationship needs to be further broken down by project and location, but this breakdown of the variation will need to await further data processing.

Comparing the inter-annual trends in the normalized mortality metric in Figure 6 to the fatality rate trends in Figure 2, one can see that the patterns of change between years are similar. Incorporating utilization rates into a mortality metric did not substantially change the inter-annual trends observed in fatality rates. However, inter-annual trends in mortality appeared to differ greatly between the old-generation turbines and Diablo Winds turbines (Figure 7). As mentioned earlier, much may be learned from breaking down inter-annual trends in mortality by wind energy project or by location.

Fatality rates declined when Santa Clara turbines were shut down for 9 months in 2006 and when turbines elsewhere were removed or relocated in 2007-2009. The effects of turbine shutdowns could be further revealed if I had access to more details about which turbines were shutdown and when. Another question that remains is whether turbines adjacent to those removed or relocated subsequently caused higher fatality rates (a compensatory effect). I explored this question, but did not feel that the available data were suitable for testing it yet.

The 2007 spikes in burrowing owl fatality rates at Diablo Winds and Santa Clara were intriguing because the spike was not evident among the remaining suite of monitored wind turbines. It appears that the spikes in burrowing owl fatalities were local. Resolving burrowing owl fatality rates spatially should shed additional light on the 2007 spikes and what they mean. The spike at Diablo Winds was especially intriguing because it was so deviant from other years. Understanding what happened that year would contribute greatly to understanding burrowing owl mortality in the APWRA.

As for the SRC's hazard ratings, fatality rate estimates confirmed that the SRC was on the right track with its ratings. In 2007, the golden eagle fatality rate was about 30 times higher among turbines the SRC rated 10 as compared to those rated <7. In 2006, the red-tailed hawk fatality rate was about 80 times higher among turbines rated 10. In 2007, the American kestrel fatality rate was about 4 times higher among turbines rated 8.5 and 9.5 compared to those rated <7. There was certainly some variation in fatality rates amongst the ratings, but overall the trend definitely increased with increasing rating value. Burrowing owl fatality rates demonstrated no relationship with SRC ratings, but that was to be expected because the SRC did not rate hazard levels for burrowing owls. At least for three raptor species, the SRC's hazard ratings indicated that the SRC has identified factors that relate to fatality rates. These factors and similar ratings can now be directed toward careful repowering of the APWRA by guiding new turbine siting.

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NREL core turbines, searched 6-8 years

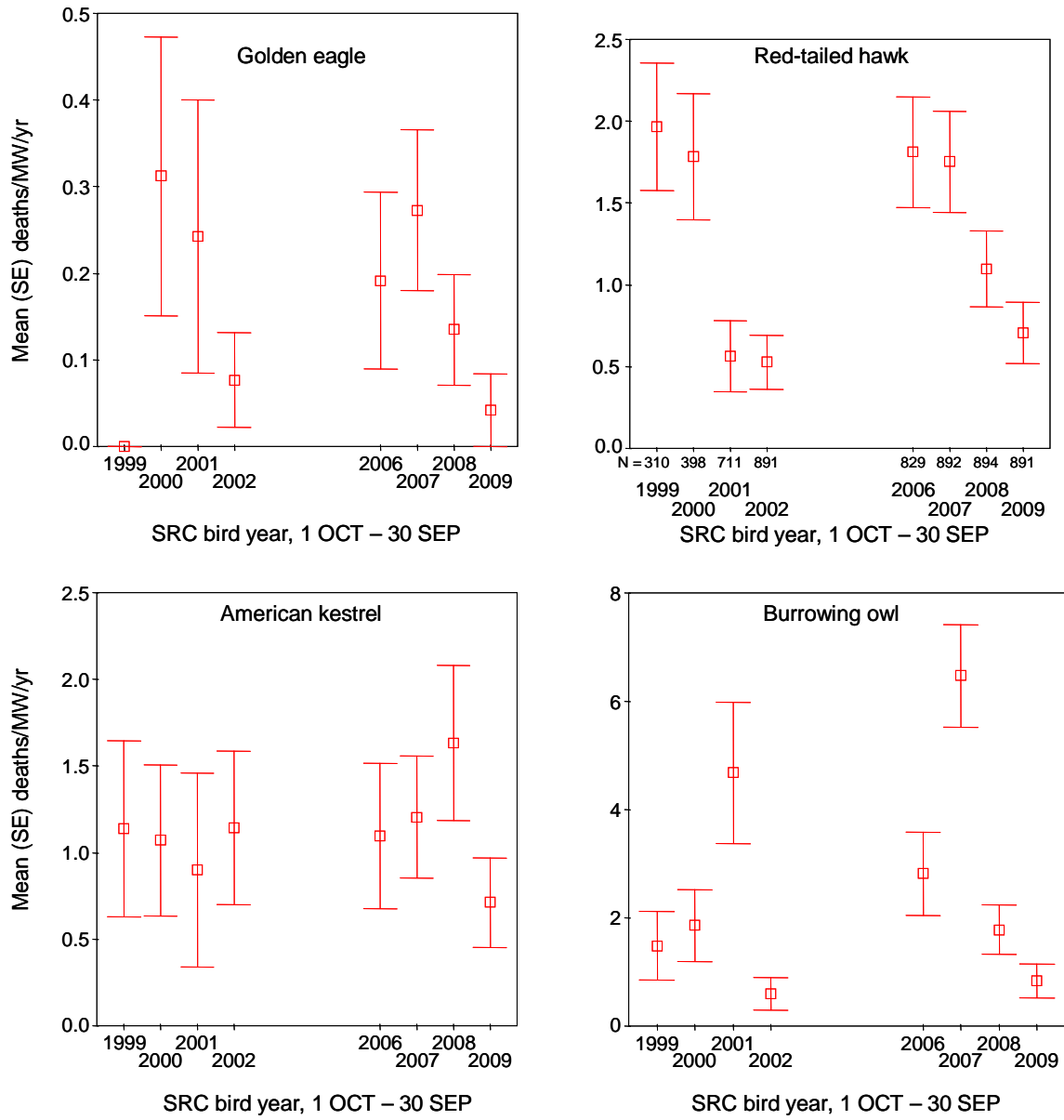


Figure 2. Inter-annual estimates of fatality rates of target raptor species among NREL core turbines monitored in the APWRA.

Santa Clara project, 0.95 KW turbines

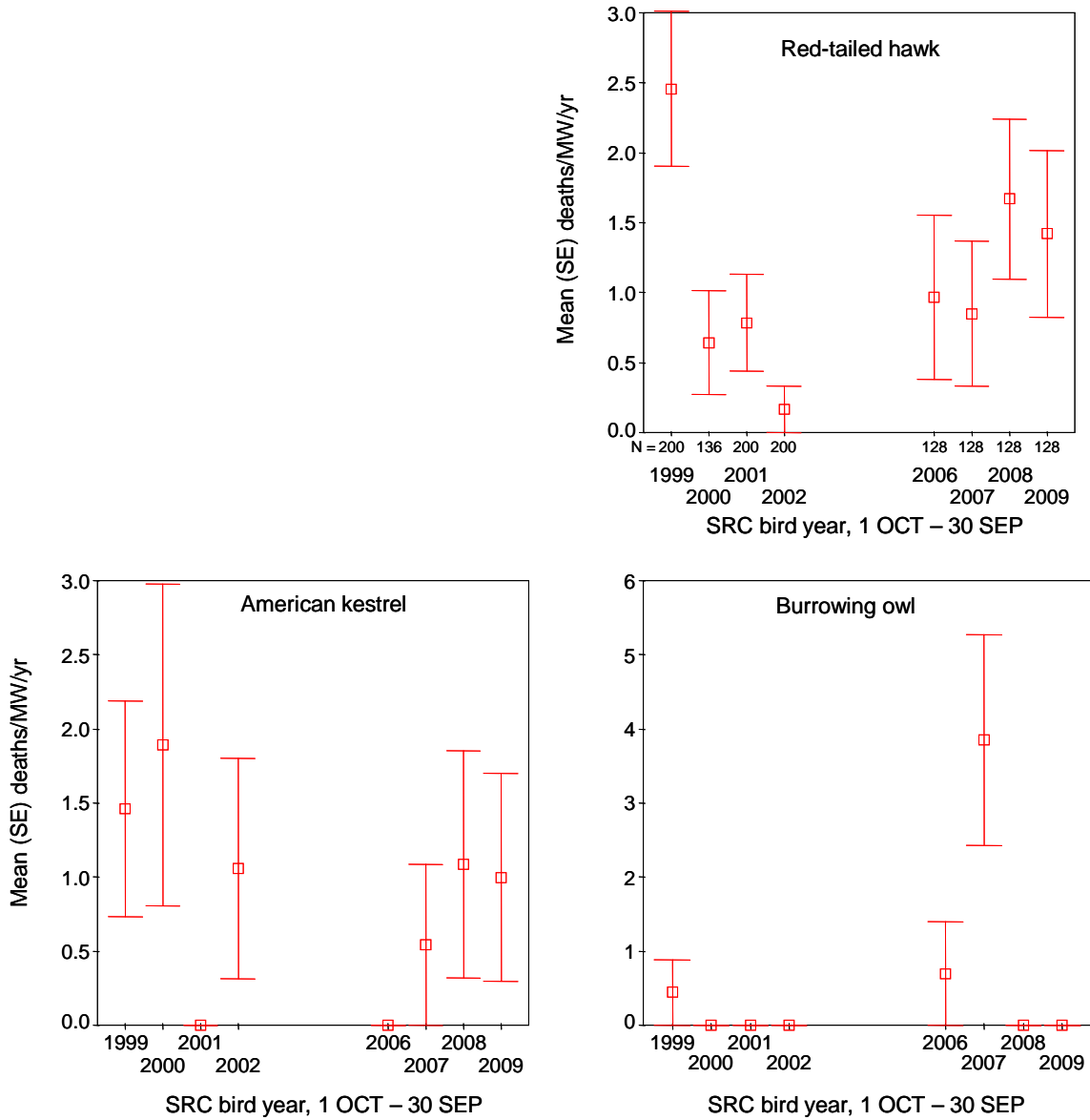


Figure 3. Inter-annual estimates of fatality rates of target raptor species among 0.95 KW Santa Clara turbines, which did not participate with the APWRA mitigation measures during the current monitoring program, and which experienced a year-long shutdown in 2006. Golden eagles are not depicted in a graph because no golden eagle fatalities were documented at Santa Clara from 2006 to 2009.

100 KW turbines

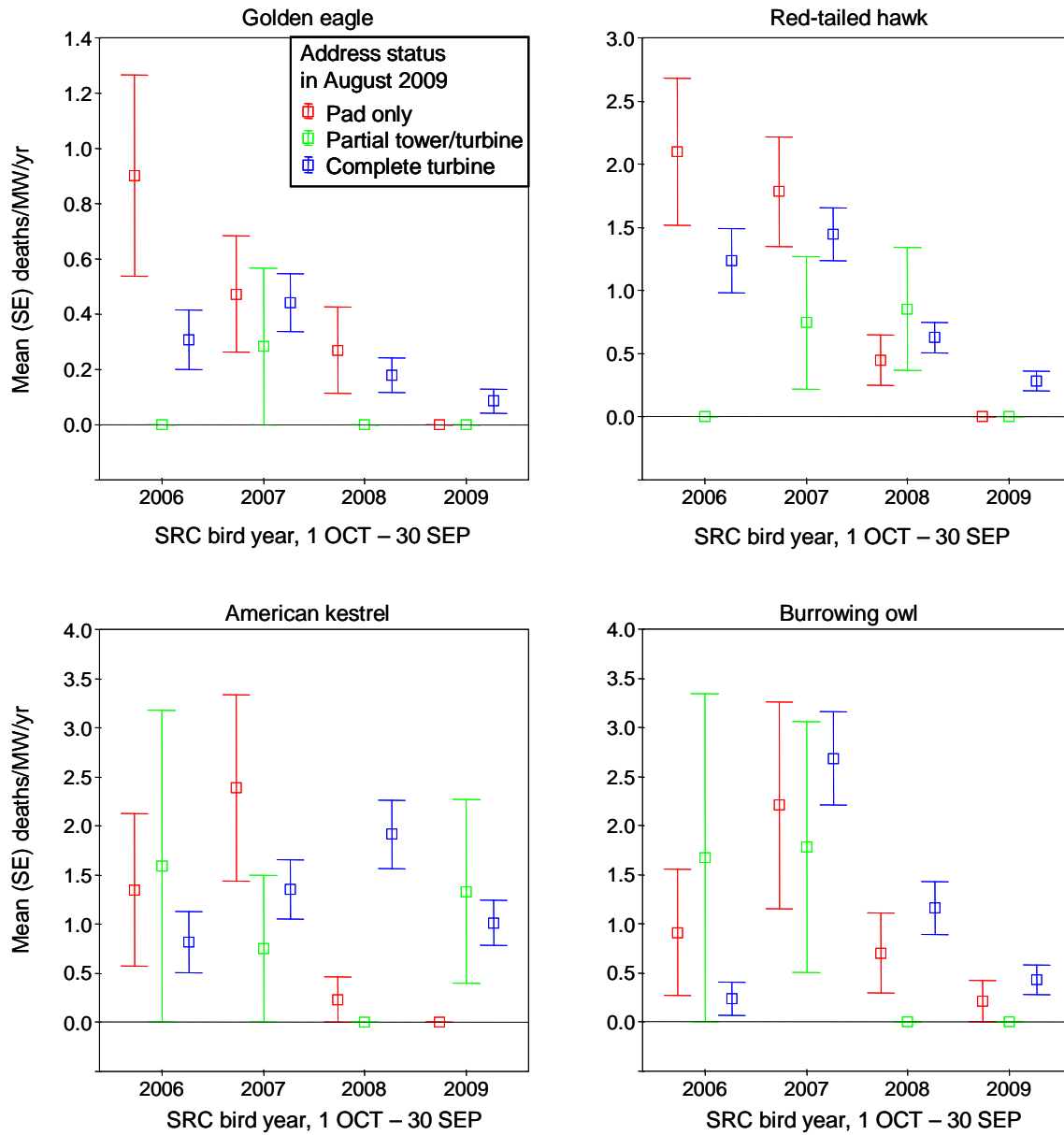


Figure 4. Inter-annual trends in fatality rates among wind turbines identified as empty addresses (red), vacant towers or broken (green), or intact (blue).

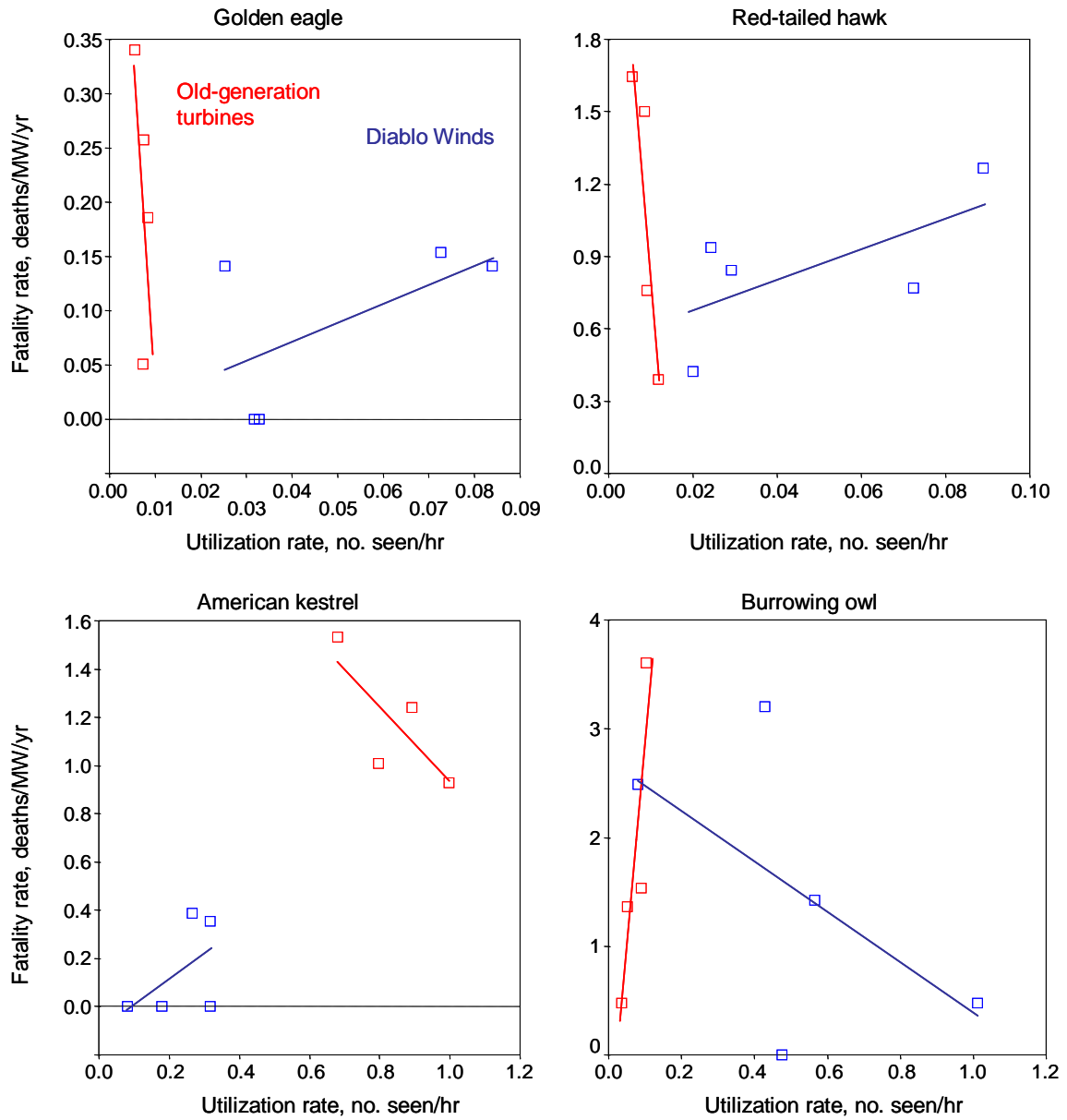


Figure 5. Estimated fatality rates related to estimated utilization rates between old-generation (red) and Diablo Winds (blue) wind turbines in the APWRA, 2005-2010.

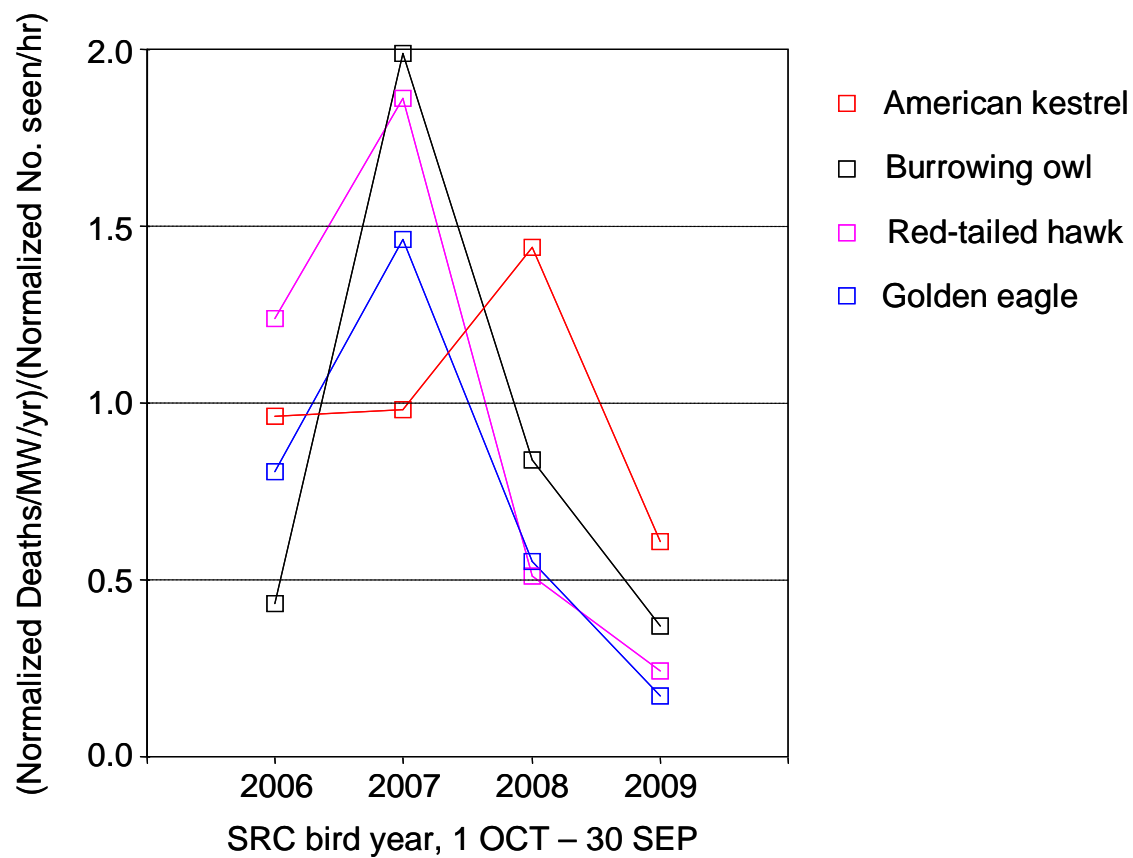


Figure 6. Inter-annual mortality of target raptor species among all wind turbines that were monitored in the APWRA (excluding the turbines at Buena Vista).

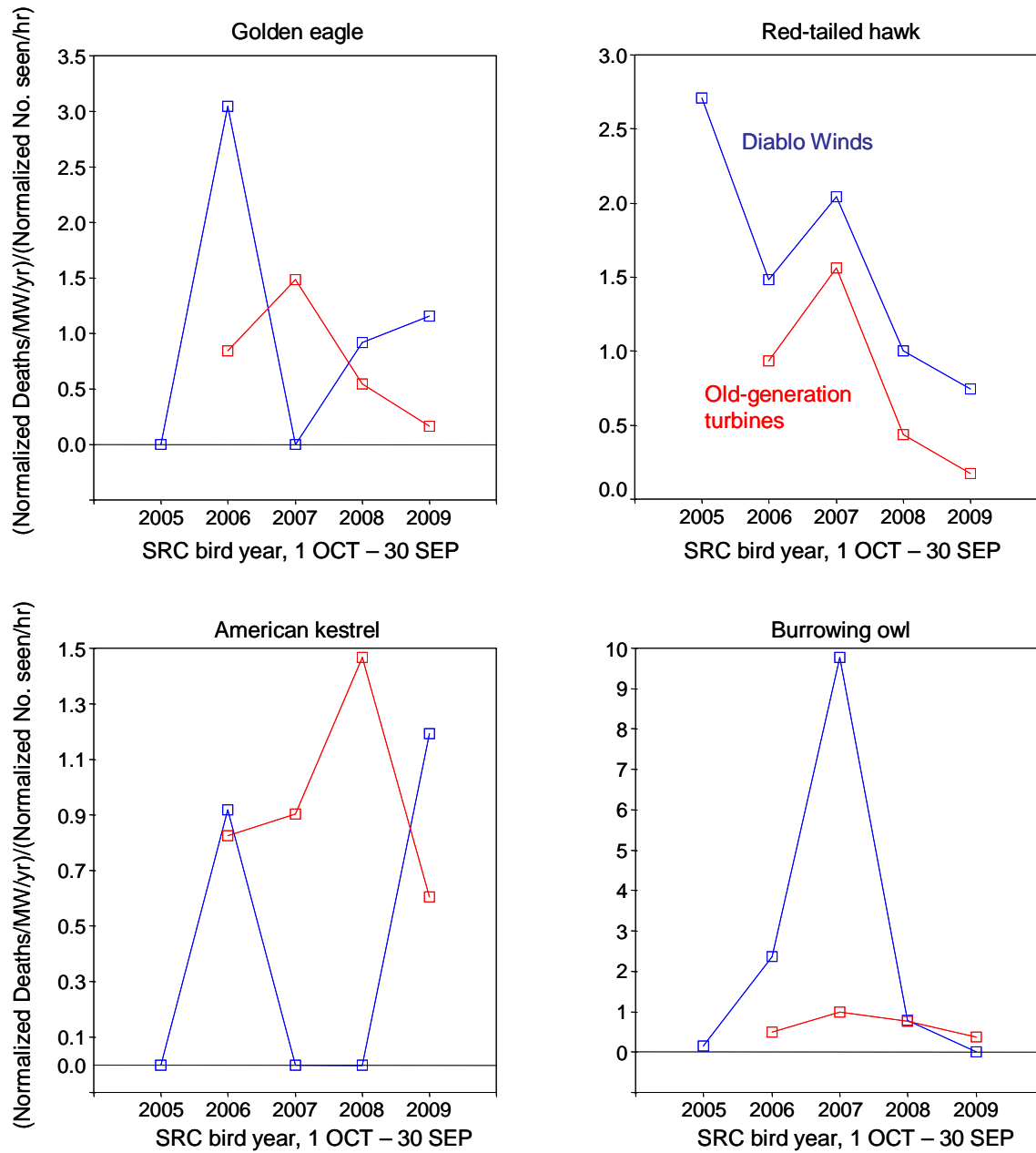


Figure 7. Inter-annual estimates of mortality between old-generation (red) and Diablo Winds (blue) wind turbines in the APWRA.

Adjusted fatality rates, deaths/MW/year

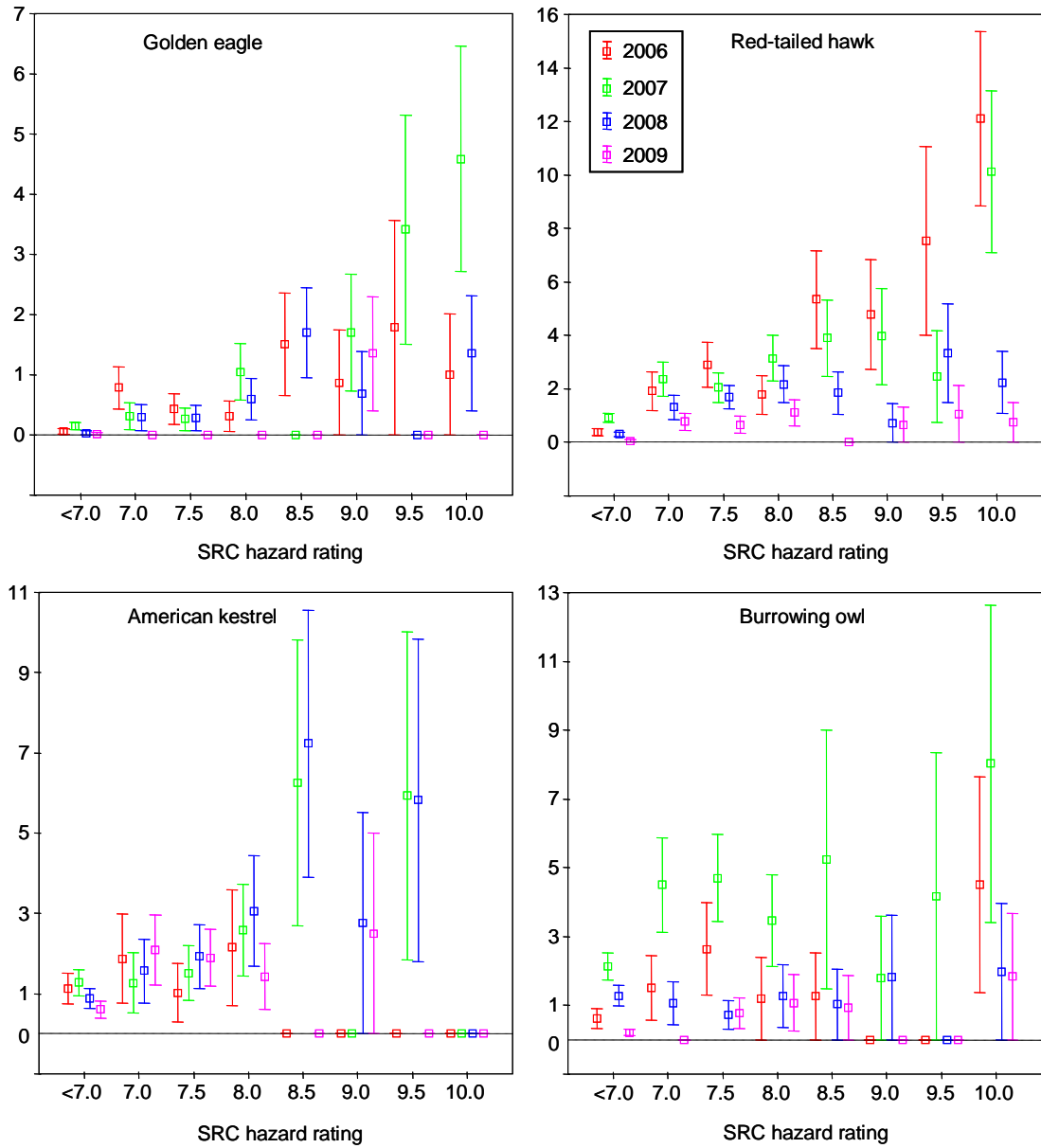


Figure 8. Estimated annual fatality rates among SRC hazard ratings of wind turbines in the APWRA.

Adjusted fatality rates, deaths/MW/year

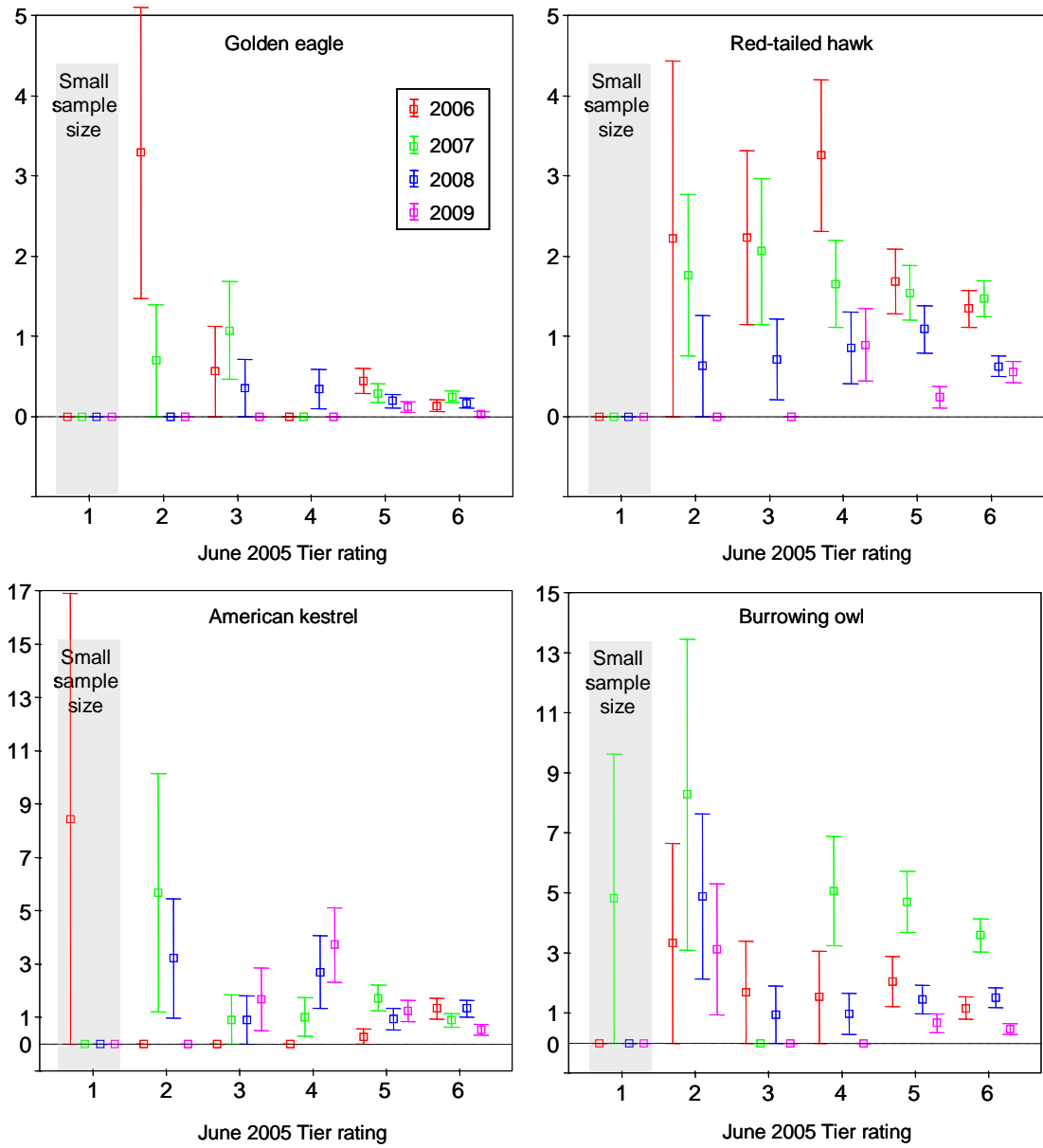


Figure 9. Estimated annual fatality rates among June 2005 Tier classes assigned to wind turbines in the APWRA.

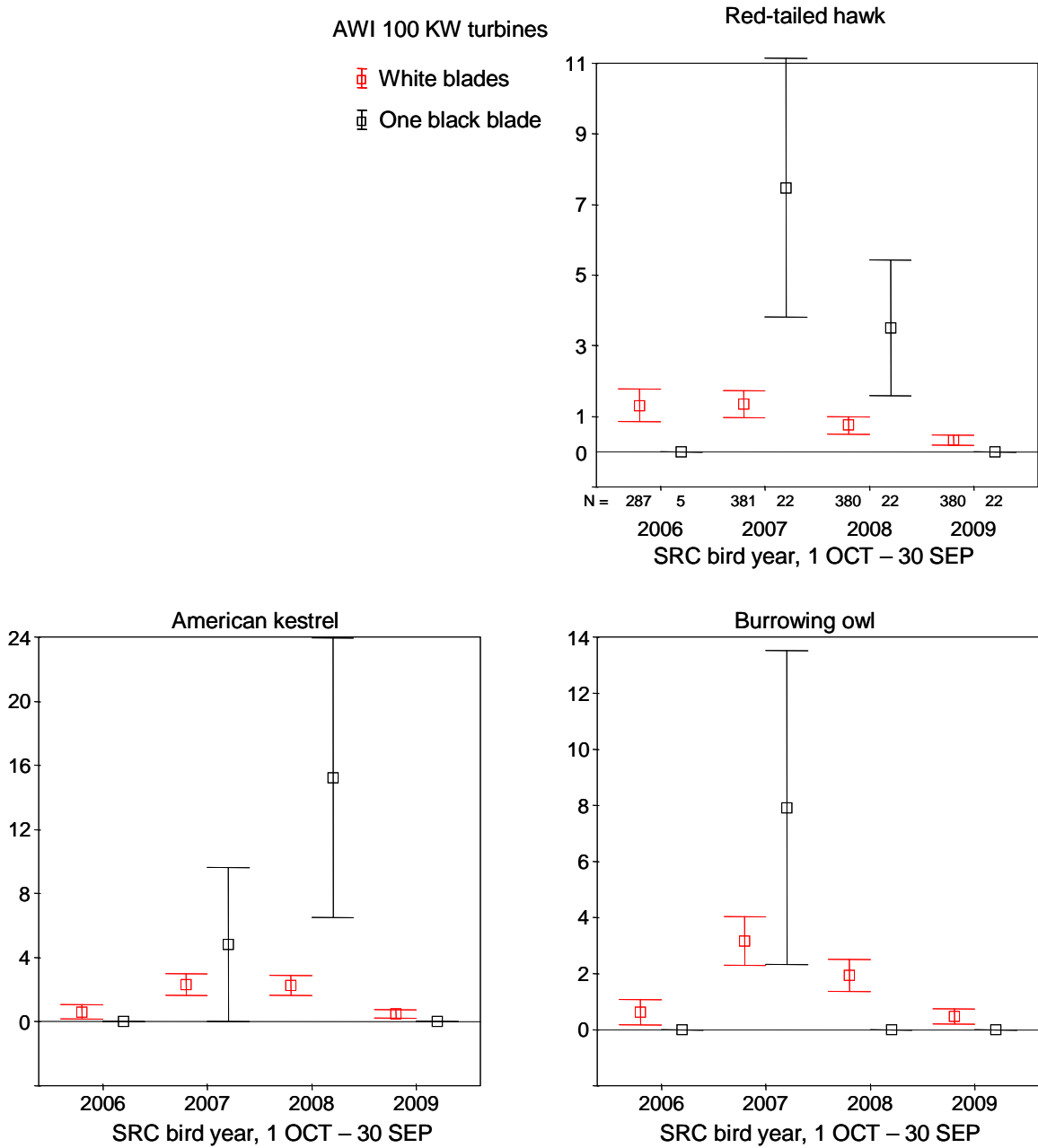


Figure 10. Inter-annual fatality rates by blade-painting scheme among AWI 100 KW turbines. No golden eagle fatalities are graphed because none were reported at turbines with black blades before or after treatment.