LONG-TERM TRENDS IN FATALITY RATES OF BIRDS AND BATS IN THE ALTAMONT PASS WIND RESOURCE AREA, CALIFORNIA

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Abstract: Long-term fatality monitoring revealed multi-annual cycles of fatalities in the Altamont Pass Wind Resource Area (APWRA), California. Cycle periods were 4-5 years, with peaks recorded in 2000, 2006-2007 and 2010-2011 (a peak year might have been missed between 2003 and 2005, when no monitoring was performed). Nadir years were in 2002 and 2009. Fatality rates during the latest peak years were damped compared to previous peaks among most of the old-generation turbines. The damping of the most recent fatality peaks was likely due to the removals of wind turbines that the Alameda County Scientific Review Committee (SRC) rated 8.5-10 for collision hazard. An exception to this damping was at the 95 KW Vestas turbines in the Santa Clara project, where Alameda County exempted the project from hazardous turbine removals. At Santa Clara, the 2011 fatality peaks were higher than the previously recorded fatality peaks.

Wind turbines the SRC rated 8-10 for collision hazard yielded disproportionately high numbers of golden eagle, red-tailed hawk and American kestrel fatalities prior to 2009, but killed disproportionately fewer numbers of these species after most of the turbines rated 8.5-10 were removed. However, even though the turbine removals were highly effective, the removals happened towards the end of the declining portions of fatality cycles. Raptor fatalities at Diablo Winds declined 46% from 2006 through 2010, but this reduction had nothing to do with the Avian Protection Program because no fatality reduction measures were implemented at Diablo Winds. On the other hand, raptor fatalities at Diablo Winds were lower on average than they were during the years of the FloWind project prior to repowering. Given the complexity of the fatality patterns in the APWRA due to multi-annual cycles of fatalities, interpreting the effects of management actions can by prone to confounding. This complexity coupled with the large standard errors associated with the fatality rate estimates and changes in the extent of monitoring undermines the credibility of the recent conclusion that a 50% fatality reduction was achieved by the Avian Protection Program. Determining the level of change in fatality rates needs to be attempted within the context of a multi-annual cycle. An example would be comparing fatality rates between peaks of the cycle.

The SRC's recommended management actions were sound, as the hazardous turbine ratings were effective. In the near term, turbine removals should be expanded to those rated 8, consistent with the SRC's standing recommendation. The turbines rated 7 and 7.5 should be repaired or removed to lower their ratings to <7. Wind turbines hazardous to burrowing owls need to be identified and relocated or removed. More important than these management actions, the old-generation turbines should be repowered as soon as possible and the new turbines should be carefully sited to minimize collision risk. Repowering remains the quickest and most likely way to achieve the 50% reduction target set by the Settling Parties in January 2007.

INTRODUCTION

Estimates of bird and bat fatality rates are being compared among wind energy projects to assess project-specific and regional and national impacts (Smallwood 2013), but also to understand geographic, turbine design, and management factors that influence fatality rates. Such fatality rate estimates were compared without adjusting for differences in methodology and assumptions (Smallwood and Thelander 2005, Barclay et al. 2007, Ferrer et al. 2012, Erickson et al. 2001, Erickson et al. 2005, GAO 2005), but Smallwood (2013) compared estimates that were adjusted for most of the known, major sources of potential bias and based on a common estimator. However, even Smallwood's (2013) comparison failed to adequately account for inter-annual variation in fatality rates at wind energy projects, even in the Altamont Pass Wind Resource Area (APWRA), which has been monitored longer than any other wind energy project. The APWRA has been monitored for fatalities over 10 of the last 14 years, the last few of years following the implementation of two mitigation measures intended to reduce fatalities – winter curtailment of energy generation and hazardous turbine removals. A focused study of APWRA fatality rates is warranted.

Beginning in the winter of 2005-2006, most of the wind turbines in the APWRA were shut down over part of the winter. During the first two years, the wind turbines in either the north or south half of the APWRA were shut down 1 November through 31 December, and then turned on 1 January through February while the turbines in the other half of the APWRA were shut down. This winter shutdown was characterized as a cross-over design. However, the fatality search intervals during the first two years were too long for measuring the effect of the crossover design (the search intervals exceeded the duration of the shutdown at some turbines). Also, it was feared that the mid-winter restart of half the turbines was killing disproportionate numbers of wintering birds that had habituated to the shutdown turbines. Therefore, the Alameda County Scientific Review Committee (SRC) recommended a four-month winter shutdown (1 NOV – 28 FEB) without a crossover design element. Alameda County required a universal shutdown beginning 1 November 2007, but did not require four months of shutdown as the SRC had recommended. The duration of the shutdown was 2 months the first year, followed by increasingly longer duration until 3.5 months of shutdown in 2011-2012.

The SRC also recommended removal or relocation of wind turbines it had rated 8-10 on a 10-point scale. These turbines were believed to be disproportionately hazardous to golden eagle, red-tailed hawk and American kestrel due to landscape settings, such as location in ridge saddles, steep slopes, or on breaks in slope. These hazardous landscape situations were originally hypothesized in Smallwood and Thelander (2004, 2005), who performed a series of chi-square tests, which were then screened to minimize confounding and identify the strongest relationships between fatality rates and measured variables. The strongest relationships were addressed further in a series of unpublished CEC staff reports (Smallwood and Spiegel 2005a, b, c), which recommended relocations or removals of the most hazardous turbines, which were ranked in tiers of hazard levels. On 22 August 2005 the Alameda County Board of Supervisors resolved that the turbines in the most hazardous tiers be removed or relocated by certain dates, and these requirements were written into the new conditional use permits issued by Alameda County to the wind companies. Once the Alameda County SRC was established, it followed up on the Smallwood and Spiegel tiers of priority for removal by using newly collected fatality monitoring

data to validate Smallwood and Spiegel's tiers of priority, and then deciding to expand on the approach to the rest of the wind turbines in the APWRA. The SRC made field trips to all of the APWRA's wind turbines to rate the hazard levels on a 1 to 10 point scale. The SRC recommended repair of inter-turbine situations that lead to ratings of 7 and 7.5, and it recommended removal or relocation of turbines rated 8-10, which were based on landscape settings posing greater collision risk to golden eagle, red-tailed hawk, and American kestrel.

Confounding is one of the greatest challenges of interpreting trends in fatality rates in the APWRA. Management actions were implemented at most of the wind turbines in the APWRA, so changes in fatality rates before and after mitigation could have been due to the mitigation or to inter-annual changes in relative abundance, or both. A small group of 660 KW wind turbines – the Diablo Winds Energy Project – was exempted from management actions, so were not shut down over the winter months and were not subject to turbine removals or relocations. This group of wind turbines could serve as a reference group, although it was monitored for only 5 of the years the other wind turbines were monitored. Alameda County staff declared that another group of turbines was exempt from management actions. These were the 95 KW Vestas turbines in the Santa Clara project. Whereas these turbines were shut down during winter months in concert with the other old-generation wind turbines, those rated 8-10 for collision hazard were not removed or relocated.

One objective of my focused comparison of fatality rates was to explore the possibility of multi-annual cycles of fatality rates, which would presumably be driven by multi-annual cycles of relative abundance. Another objective was to assess the effectiveness of the SRC's recommendation for the removal/relocation of turbines rated 8-10.

STUDY AREA

I divided the APWRA into what I termed *turbine fields*. The following list describes the turbine fields, which were defined by geography, ownership, turbine model, and turbine size.

Tres Vaqueros included 85 330-KW Howden turbines located between Vasco Road and Los Vaqueros Reservoir. These turbines were in decline through November 2008, when wind power generation ceased. The turbines remained on site and were monitored for another two years. At the time of this report (July 2013), the turbines were still in place.

Northwind included 186 65-KW Nordtank turbines located west of Vasco Road in the northern extreme portion of the APWRA. Fatality monitoring at Northwind was performed every two weeks during most of one year during a special study in 2007 (Smallwood et al. 2010). Due to the brief monitoring in this turbine field, I did not include it in fatality rate estimates in this report. Many of the turbines were removed since early spring 2013, and the rest are out of service.

Vasco Winds included 726 KCS56-100 KW turbines and 20 KVS33 400-KW turbines. It was repowered in 2011. Some fatality monitoring continued at Vasco Winds into 2011, but I excluded the results of this monitoring for use in this report because too few turbines were

monitored. The last year of complete monitoring was 2010. Fatality monitoring resumed at the repowered project in May 2012.

Buena Vista included 5 5-KW turbines, 61 150-KW turbines, 12 160-KW turbines, 76 200-KW turbines, and 21 250-KW turbines before it was repowered in 2005/2006. There were only two searches for fatalities at these turbines prior to repowering, and these searches were in 2002-2003. Fatality monitoring began at the 38 1-MW Mitsubishi turbines in the repowered project in January 2007 and continued for three years. In this report I did not include the results of the earlier 2 fatality searches or the post-repowering monitoring.

Dyer North included 424 KCS56-100 KW turbines north of the Landfill property and east and north of Dyer Road.

Dyer West included 286 KCS56-100 KW turbines west of Dyer Road and north of Old Altamont Pass Road.

Landfill area included 77 KCS56-100 KW turbines on the Landfill property, north of the Altamont Landfill.

Gomes Ranch included 175 KCS56-100 KW turbines on north of the Bethany Pumping Station and Gate 13.

Elworthy Ranch included 16 KCS56-100 KW turbines, 189 Bonus 120 KW turbines, and 99 Bonus 150 KW turbines.

East Slope included 236 KCS56-100 KW turbines north of Gate 11 and between Gomes Ranch and the Micon and Enertech turbines in the Forebay project. The turbines in the East Slope area were owned by AWI, Inc.

The Diablo Winds turbines included 31 660-KW Vestas turbines, which were installed in 2004 as a repowering of the 111 150-KW and 21 250-KW FloWind turbines that had all been removed by 2002. The FloWind turbines were monitoring for fatalities for longer than one year in 1999-2000, but only one full year (1999) was included herein because the monitoring in the other year spanned only part of the year. Monitoring at Diablo Winds spanned 2006-2010, and the search radius was 75 m instead of the usual 50 m applied to most of the rest of the old-generation turbines in the APWRA. The Diablo Winds turbines were scattered in small groups across the Elworthy Ranch.

Mountain House included 131 65-KW Micon turbines east of Mountain House Road, west of the California Aqueduct, and north of Old Altamont Pass Road.

GB Midway included 52 65-KW Micon turbines on the east side of Midway Road, north of Patterson Pass Road and south of Highway 205.

The Viking and Taxvest projects included 38 65-KW Micon turbines located between the Altech project and the East Slope turbine field, east of Elworty Ranch.

The Altech project included 144 40-KW Enertech turbines north of Old Altamont Pass Road and east of Elworthy Ranch.

The Venture project included 20 40-KW Enertech turbines, 26 65-KW Windmatic turbines, and 12 108-KW Polenko turbines across Old Altamont Pass Road to the south of the Altech project. The Enertech turbines were removed from this project prior to the initiation of monitoring in 2006, and many of the other turbines were non-operational at various times since 2006. The Alameda County Monitor stopped monitoring at this project after 2010.

The Santa Clara project included 200 95-KW Vestas turbines located between Highway 580 and Old Altamont Pass Road.

Midway included 324 KCS56-100 KW turbines, 16 250-KW WEG turbines, and 1 400-KW KVS33 turbine. Midway was located south of Highway 580, north of the Patterson Pass turbine field, and between gate 1 on Patterson Pass Road and Gate 4 on North Flynn Road.

North Flynn included 540 KCS56-100 KW turbines, 4 250-KW WEG turbines, and 18 400-KW KVS33 turbines. It was located west of North Flynn Road and south of Highway 580.

Patterson Pass included 334 65-KW Nordtank turbines between the Midway turbine field and Patterson Pass Road, and between Gate 3 and North Flynn Road.

South of Patterson Pass Road included 476 KCS56-100 KW turbines owned.

METHODS

Field

Fatality searches were initially performed at all of the wind turbines that were available to the monitors . By 2000 some of the available turbines were searched for reasons unknown to me. Some of these turbines not searched in 2000 were searched in 2001 and 2002. The monitoring in 2006 was performed at wind turbines selected randomly from groups of turbines defined by owner and turbine model. Another 500 wind turbines were added to the monitoring effort in spring 2007. After 2010, the monitoring effort was reduced to <50% of the turbines that had been monitored until that time, and a rotating panel design was implemented at 40% of the turbines that remained in the monitoring effort.

Since 1998 fatality searchers walked parallel transects around rows of wind turbines, where the transects were usually separated by 6-8 m. Fatality searches extended to 50 m from most of the wind turbines, but to 60 m from the Howden turbines and to 75 m from the 660 KW Vestas turbines in the Diablo Winds project and the 1 MW Mitsubishi turbines in the Buena Vista project. Searches were conducted at intervals ranging from monthly to >50 days, depending on the year and the turbine locations.

Data

I downloaded the wildlife fatality data through September 2012 that were posted on ICF International's web site in March 2013. I processed the data in preparation for making independent estimates of fatality rates at monitored APWRA wind turbines. For the most part, I did not change any data that I obtained prior to 2010. The exception was burrowing owl fatalities in 2007, when burrowing owl fatalities had spiked. I carefully reviewed all of the burrowing owl fatality records, resulting in the following findings and changes to the data set.

Burrowing owl FatalID 20070122-07 was reported to have died after winter shutdown, but remains of FatalID 20061204-03 had been found before shutdown in almost exactly the same place. FatalID was assigned <30 days since death (ETD used in data base was 19) even though the Notes in the data base described it as "old remains." This record appeared to have been a double-count. FatalID 20070629-03 was given >30 day since death and ETD = 60, even though the notes read "very old bleached bones brittle feathers." FatalID 20070625-07 reported as old remains, but given ETD=19. FatalID 20070911-01 reported as old remains, but given ETD=60 days. In total, I found 22 cases of double counts of burrowing owl during the peak fatality year of 2007. Fatality records found during the KB study (48-hour search interval study) were included as valid fatality finds in the monitor's data set. Also included were fatality records found during a study in Vasco Caves Regional Preserve during the peak fatality year of 2007. I cleaned out all of these fatality records from the data set used herein.

Unaccounted for was an apparent shift in data recording methods that happened at the end of the 2007 bird year. In 2007, all burrowing owl fatalities were recorded, but afterwards there was confusion among monitors over whether they should record burrowing owl remains found near ground squirrel burrows or active burrowing owl burrows. A data field was created to record all burrowing owl fatalities associated with "burrows." This data field was populated with affirmative values when the Notes field in the data set included some mention of nearby burrows, but the frequency of associations dropped off after 2007. Predation as a cause of death was also frequently recorded in 2007, but dropped off afterwards. Based on my interviews of personnel and on review of the data, it appeared that some monitors stopped recording burrowing owl fatalities found at or near burrows, while others continued recording the remains as fatalities. At a minimum there was confusion over whether and how to record many of the burrowing owl fatalities after 2007, and at worst there was a bias introduced into the monitoring of burrowing owl fatalities.

Unlike the monitoring team, I included WRRS fatality records and incidentally found carcasses at monitored turbines, including fatalities that were not golden eagles. I estimated fatality rates at wind turbines that were monitored >70% of a given year. I also adjusted fatality rates for the proportion of carcasses not detected due to insufficient search radius (Smallwood 2013). This adjustment was intended to account for variation in combinations of tower height and maximum search radius, based on distances of found carcasses reported at many wind projects across North America.

The MW-basis in the fatality metric was the installed number of rated megawatts at the beginning of monitoring at any given set of wind turbines. For example, if the total rated

capacity of a row of 10 100-KW turbines was 1 MW in April 1998, and if monitoring at that row began in April 1998, then 1 MW was the capacity used in all of the fatality rate calculations at that turbine row since monitoring started there, even if turbines had since been removed. This approach avoided the considerable uncertainty in representing the installed MW of the turbine string through time. Not only are wind turbine operations intermittent due to the intermittency of suitable wind, but wind turbine operations vary due to mechanical problems and circuit failures. Attempting to be responsive to the maintenance records of thousands of wind turbines would be unrealistic. Furthermore, not all of the collision risk is in the moving parts of a wind turbine; risk of collision is also in the stationary parts and in the slowly moving (feathering) blades when there is insufficient wind for energy production. Using rated capacity captures all of these sources of uncertainty, whereas installed capacity must account for each of these sources of uncertainty. The fatality metric I used was more reliable, but a bias was possible if wind turbine removals were more or less common among non-monitored wind turbines as compared to monitored wind turbines. Assuming there was no bias, the fatality rate estimates could be compared as if they were APWRA-wide estimates, so long as the underlying sampling can justify an APWRA-wide expansion of the estimates.

Estimator

I used national averages for carcass persistence rates (*R*) and searcher detection rates (*p*) based on trials in which investigators placed carcasses in fatality search areas around wind turbines at many wind projects where ground cover was grassland and ground visibility was classified as high or very high (Smallwood 2013). These adjustment terms were used in the following fatality estimation equations derived from Horvitz and Thompson (1952):

$$\mathrm{F}_A = \frac{\mathrm{F}_U}{p \times R_c \times d}, \qquad \text{eqn 1}$$

where F_A and F_U were adjusted and unadjusted fatality rate estimates, respectively, d was the proportion of carcasses predicted to be found within the maximum search radius, given the combination of the search radius and the tower height, and based on patterns of fatalities found with increasing distance from the turbines (Smallwood 2013). R_c was derived from the following equation (Smallwood 2007):

$$R_c = \frac{\sum_{i=1}^{I} R_i}{I},$$

where R_i was the predicted proportion of carcasses remaining at the ith day into the trial, based on nonlinear regression used to fit a predictive model to the data, and I was the day into the trial which corresponded with the average search interval of the fatality monitoring. I doubled R_c values applied to birds weighing >1 kg, because monitors at wind projects across North America often placed rock pigeons, ducks, and other birds that were much smaller than 1 kg to represent "large birds." Also, an ongoing, integrated trial intended to estimate an overall detection rate in the avian safety test of a new wind turbine design in the APWRA found high persistence rates of

bird carcasses of species >1 kg in size (Smallwood et al., unpublished data). National average R_c values >0.5 were converted to 1.0 for bird species >1 kg. The doubling yielded persistence rates of large birds that were consistent with the values obtained by Smallwood et al. (unpublished data). I used the root mean square error (RMSE) of the nonlinear regression models to serve as standard error.

Search Radius and Carcass Distance from the Turbine.--Fatality rates are not comparable between wind projects unless one accounts for variation in combinations of tower heights and maximum fatality search radius (Smallwood 2009, 2013). This comparability problem is emerging in the APWRA, as well, because turbine size and maximum search radii vary considerably, even now. These combinations of tower height and search radius partly determine the proportion of fatalities that are found, because turbines on taller towers can throw some birds and bats outside the search area, and search areas that have been implemented at projects have been decided somewhat arbitrarily. The adjustment factor, *d*, represents the proportion of carcasses likely to be found from within the maximum search radius around wind turbines on given tower heights. To obtain *d* in fatality rate equation 1, I reviewed tables and appendices in available reports to obtain distances of fatalities from wind turbines (Smallwood 2013). I summed fatality finds within 1-m intervals of distance from the turbines for each group of tower heights and each group of maximum search radii, and I used least-squares regression analysis to fit logistic functions to the cumulative sum fatalities with increasing distance from the turbine. I restricted these regressions to the distance of the maximum search radius plus 5 m to account for the area likely searched as the searcher reached the search boundary. In all cases, I fit a logistic function to the data, iteratively changing the upper bound value of the dependent variable in the model until I obtained a minimum root mean square error (RMSE):

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

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

I used the regression models to predict cumulative sum fatalities as functions of distance from the turbine, which I then extended to distances beyond the maximum search radii that were reported at wind-energy projects (Smallwood 2013). I extended these model predictions to greater distances to identify asymptotic values, which I then divided into predicted values at each 1-m interval to represent the predicted value as a proportion of the asymptotic value. The result was a predicted cumulative proportion of fatalities relative to the predicted maximum (1.0) that would have been found had the searches extended well beyond the search boundary.

Carrying Error Terms through Calculations

I carried the error through the equations using the Delta Method (Goodman 1960), shown here applied to the adjustment factors, *p*, R_c, and *d*:

$$SE[F_A] = \sqrt{\left(\frac{1}{p \times R_C \times d} \times SE[F_U]\right)^2 \times \left(\frac{F_U}{p \times d} \times \frac{-1}{R_C^2} \times SE[R_C]\right)^2 \times \left(\frac{F_U}{R_C \times d} \times \frac{-1}{p^2} \times SE[p]\right)^2 \times \left(\frac{F_U}{R_C \times p} \times \frac{-1}{d^2} \times SE[d]\right)^2}.$$

RESULTS

Monitoring effort

Fatality monitoring in the APWRA was conducted by two different teams, one during 1999-2002, and the other 2006-2012. The latest team also changed composition and leadership since 2006. Along with differences in who was performing the monitoring, the overall effort and the sampling design changed, and there were additional changes due to budget constraints. Therefore, the MW of capacity being monitored changed considerably since 1999 (Figure 1A-F). These changes could have influenced the fatality rates that were compared in this report.

The monitoring effort also needs to be examined with respect to a potential bias that could result from the expansion of fatality rate estimates at monitored turbines to those turbines that are not monitored. Bias could result from unparallel trajectories in capacity between the monitored turbines and the non-monitored turbines through the years. Figures 1A-F show where such biases were unlikely and where they might have occurred. For example, bias was indicated at the turbine field identified as Dyer West (Figure 1D). Overall, and considering the total capacity in each turbine field, this potential source of bias did not appear to be strong.

Fatality rates

When examining only the 61 MW of turbines monitored from 1999 through 2012, and considering the gap in monitoring from 2003 through 2005, each raptor species appeared to exhibit a four-year cycle in fatality rates in the APWRA (Figure 2). These cycle periods also corresponded with each other, so the peaks and nadirs of the cycles occurred at nearly the same years. When examining these graphs, however, it bears considering that the last cycle peak may have been dampened by the removals of many hazardous wind turbines.

Using linear least-squares regression to determine multi-annual trends in fatality rates at the 61 MW of turbines monitored from 1999 through 2012, the span of years selected for the regression affected the estimated slope of the regression (Figure 3). Selecting the years 2006 through 2012 resulted in steeper regression slopes than did selecting the years 1999 through 2012.

The inter-annual trend in raptor fatalities at the Diablo Winds Energy Project can serve as a reference for comparison against fatality rates among turbines where management actions were taken to reduce raptor fatalities (Figure 4). At Diablo Winds -- the turbines of which were interspersed with old-generation turbines across a large, central portion of the APWRA -- no turbines were removed and none were shut down over the winter months. Raptor fatalities

declined from 2006 through 2010 at a rate of 11.44% per year. When comparing the reduction of raptor fatalities over the same time period at any group of wind turbines that were subjected to management actions, it would be prudent to consider this rate of fatality reduction as the portion that had nothing to do with the management actions.

A few wind projects and groups of wind turbines could not be included in APWRA-wide estimates because they were not monitored or monitored over too brief of a time period. A small portion of the Northwind project was monitored only for part of a year during a special study in the Vasco Caves Regional Preserve (Smallwood et al. 2010), and many of the Howden turbines were also monitored for 1.5 years in the Vasco Caves study (Smallwood et al. 2010). The Buena Vista project was monitored for only three years, and beginning and end dates of those years did not correspond with the beginning and end dates of the monitoring across most of the rest of the APWRA. Comparable monitoring representative of 495.7 MW, or of a majority of the APWRA, was conducted 2006 through 2010 (Figures 5-7). Fatality rates over that time revealed part of the multi-annual cycles (Figures 5 and 6) that were more clearly evident in Figure 2, and were as close to AWPRA-wide as could be estimated without including fatality monitoring at Buena Vista. After 2010, the monitoring effort was reduced substantially, partly due to budget constraints and partly due to repowering of the Vasco Winds project.

At the 495.7 MW of the APWRA that were monitored from 2006 through 2010, estimates of all birds as a group appeared to increase in 2007 and 2008, and then decreased (Figure 7). Estimates of all bats as a group increased during this time period (Figure 7).

After losing >140 MW of turbines in the turbine fields monitored only through 2010, 356.5 MW of turbines remained comparable through 2012. Estimates of fatality rates from 2006 through 2012 (Figure 8) revealed more of the next increase in fatalities as part of the multi-annual cycle evidenced in Figure 2. However, the latest peaks in the cycles appeared to have been damped for red-tailed hawk and golden eagle, and perhaps damped to lesser degrees for American kestrel and burrowing owl (Figure 8). A notable exception was at the Santa Clara project with its 200 95-KW Vestas turbines, where Alameda County exempted the project from hazardous turbine removals. At Santa Clara, the 2011 fatality peaks were higher than the previously recorded fatality peaks (Appendix A: Figs. A5 and A6).

To isolate the effect of removing turbines the SRC rated 8-10 for collision hazard, I compared the fatalities at these turbines as the proportions of the fatalities at all of the turbines monitored. For example, golden eagle fatalities at hazardous turbines comprised about 58.75% of the eagle fatalities among all of the monitored turbines in 2008 (top left graph of Figure 9). These turbines comprised 12.44% of the monitored turbines, so golden eagle fatalities at the hazardous turbines were 4.6 times other than expected in 2008. By 2010, golden eagle fatalities declined to between 0 and 1 times other than expected (Figure 9), indicating that the hazardous turbine removals were highly effective at reducing golden eagle fatalities. This management action was also effective for red-tailed hawks, which in 2008 were killed at the hazardous 100 KW turbines about 3.7 times other than expected (top left graph of Figure 9). The hazardous turbine removals were also effective for American kestrels (Figure 9). The hazardous turbine removals had no effect on burrowing owl fatalities, but this result was expected because wind turbines were not rated by the SRC for their hazard level to burrowing owls.

The impact of the turbines the SRC rated 8-10 for collision hazard can be seen in graphs comparing fatalities/MW/year and total fatalities/year (Appendices A-C). For example, the number of American kestrel fatalities/MW/yr was >30 times greater at the hazardous 40 KW turbines compared to the total number of 40 KW turbines in 2008 (Fig. A1). Because the hazardous turbines were so few, however, the total number of American kestrel fatalities at hazardous turbines equaled the total number of American kestrel fatalities at all of the 40 KW turbines. In other words, all of the American kestrels killed by Enertech turbines in 2008 were at turbines the SRC rated 8-10. Burrowing owl fatalities/MW/yr were >9 times greater at the hazardous 40 KW in 2006 than at all of the 40 KW turbines, but the total number of burrowing owl fatalities at hazardous turbines was about a third of the total amongst all the 40 KW turbines (Fig. A1).

All American kestrel fatalities occurred at hazardous 65 KW turbines in 2011, and the resulting fatality rate exceeded any previously recorded fatality rate at 65 KW turbines (Fig. A3). Only turbines rated 8.5-10 had been removed, leaving turbines rated 8. These turbines proved lethal in 2011. On the other hand, the hazardous 65 KW turbines that were removed appear to have been highly effective at reducing red-tailed hawk fatalities (Fig. A4).

The wind turbines on the Elworthy Ranch were monitored most of the years since 1999, and revealed a multi-annual cycle of raptor fatalities (Fig. B1). In the case of the 120 KW turbines, the first two peaks were higher than the last peak, especially at the hazardous turbines (Fig. B1). Relative to the fatality rates at all the 100 KW turbines, raptor fatality rates at the hazardous 100 KW turbines dropped sharply during the last two years of monitoring at Vasco Winds, indicating high effectiveness of the turbine removals (Fig. B2). The effect was visible sooner on the Landfill property, where EDF (EnXco at the time) took quick action to remove the turbines the SRC had rated 8-10 (Fig. B3). Fatalities at the hazardous turbines were reduced to 0 in 2008, the year when EDF removed the hazardous turbines on site.

Turbine size

Adjusted fatality rates of most bird birds generally declined with increasing turbine size (Figures 10-13). Fatality rates declined with increasing turbine size for American kestrel (about 90% from smallest to largest turbines), burrowing owl, and red-tailed hawk (about 65% from smallest to largest turbine) (Figure 10), as well as for barn owl, great-horned owl, mourning dove, and western meadowlark (Figure 12), and for rock pigeon and European starling (Figure 13). Fatality rates declined for all raptors as a group and all birds as a group (about 84% from smallest to largest turbine) (Figure 12). However, fatality rates did not decline for golden eagle (Figure 10) or for all bats as a group (Figure 11).

DISCUSSION

Carefully examining fatality rates over the long term revealed cyclic patterns of fatalities among raptor species. The differences in fatalities between peaks and troughs are large enough to warrant multi-year monitoring at wind energy projects. A single year of monitoring, or two years, and even three years, can be misleading when assessing a wind project's impacts, unless an experimental design is used (e.g., Before-After, Control-Impact design). The cyclic trends

can also confound determinations of fatality reductions resulting from management actions. The effectiveness of management actions needs to be assessed in the context of adequate experimental designs or over long periods of monitoring.

As an example of confounding, the yearly 11.44% decrease in the Diablo Winds raptor fatality rates from 2006 to 2010 represented the downswing of a multi-annual cycle of raptor fatalities that had nothing to do with management actions in the APWRA (Figure 4). Applying this decrease to the same time period at most of the rest of the wind turbines in the APWRA could account for a 46% decrease in fatalities, which readily explains the decreases in fatalities exhibited in Figure 6, and which readily explains the decreases reported by ICF International for the four target species monitored through 2010 in the APWRA. Since 2010, raptor fatalities have been increasing, consistent with the multi-annual cycle, but the increase appears to be slower than observed prior to past peaks in fatalities. This dampening of the cycle peak was likely due to hazardous turbine removals.

This study also revealed the effectiveness of selective turbine removals to reduce fatality rates of target species. The SRC's ratings of collision hazard levels were highly effective, especially for golden eagle. The fatalities that were not prevented by these hazard ratings occurred at turbines that were not removed by the wind companies. Alameda County required that the wind companies remove or relocate turbines the SRC rated 8.5 to 10, which allowed the wind companies to leave in place turbines that had been rated 8. Had the companies fully complied with the SRC's recommendation, not only would the effectiveness of the removals been extended to turbines rated 8, but the reductions would have happened three years earlier (as seen in the case of the wind turbines on the Landfill property).

The effectiveness of the hazardous turbine removals also indicates the likely effectiveness of careful wind turbine siting as part of repowering. The factors that contributed to the SRC's ratings of 8-10 are the same factors that Smallwood and Neher have been using to carefully site new wind turbines as part of repowering, although the siting has also been informed by burrowing owl nesting locations and golden eagle, red-tailed hawk, and American kestrel flight data. In the case of golden eagle, the need for careful siting as part of repowering was evidenced by the lack of a relationship between golden eagle fatality rates and wind turbine size. Careful siting is also going to be needed for bats, as repowering will usually involve much larger turbine sizes.

The fatality reductions that can be achieved through repowering are obvious (Figures 10-13). For most species affected by the wind turbines, the increase of turbine size alone will substantially reduce fatalities, and for others the opportunity to carefully site new turbines as part of repowering will greatly reduce fatalities. None of the management actions that are planned or currently implemented can match the fatality reductions through repowering. At the same time, the wind turbines are much more efficient and can generate much more renewable energy with the same APWRA-wide rated capacity.

Bat fatalities might emerge as an issue with repowering, but I suspect that bat fatalities have not necessarily increased with turbine size because bat fatalities are usually found on the turbine pads, which increase in extent with increasing turbine size. Anecdotally, I found half of the bats

in the fatality monitoring that took place during 1999-2002, even though I was not doing fatality searches, but these bats were on the pads. To get a better understanding of how many bats are killed at small turbines, and whether bat fatalities would truly increase with repowering, trained dogs and dog handlers should be deployed immediately as part of the monitoring in the APWRA.

Repowering can also involve alternative wind turbine designs, such as the mixer-ejector wind turbine to be deployed in an experiment at the Forebay sites. Such alternative designs need not include increases in turbine size.

In lieu of repowering, the fatality patterns reported herein support the SRC's standing recommendations that (1) all turbines rated 8-10 for collision hazard should be removed or relocated, and that (2) the conditions related to all turbines rated 7 and 7.5 should be rectified through vacant tower removals or turbine repairs. At this time I cannot make any recommendation on the winter shutdown, because the fatality data would need to be rearranged for a focused test of the effectiveness of the winter shutdown. A focused test is warranted, however, because even non-operating wind turbines pose some degree of collision risk. Wind turbines located in hazardous locations may still pose considerable collision risk during the winter shutdown.

Some of the fatality rate estimates herein were likely biased high or low due to the adjustment factors, which remain poorly founded. Searcher detection error and carcass persistence rates applied to two size categories continue to misrepresent very small birds and very large birds, and probably bats. The small bird size range can include birds weighing 4 g to 200 g, yet the small bird trials often involve birds weighing 34 g (house sparrows), 78 g (European starlings), or 90 g (quail) on average. The large bird size range can include birds weighing 240 g to 4,560 g (or larger), yet the large bird trials often involve birds weighing 322 g (rock pigeon) or 1150 g (mallard). Using rock pigeon persistence rates to represent golden eagle can result in substantial over-estimation of golden eagle fatalities.

Another source of bias was the too-common practice of placing carcasses that had been found during routine fatality searches or along roadsides. These carcasses may appear fresh, but my ongoing study of carcass aging in the APWRA indicates that such aging can be highly inaccurate. Error in aging these carcasses is critical because most of the removals of fresh carcass in trials happen within the first 48 hours of placement, while the carcass is still attractive to vertebrate scavengers. Some of the trial data available to me likely made use of found carcasses, but did not report the practice, so my adjustment rates for carcass persistence were likely biased.

Searchers are tested for detection rates on the same day fresh carcasses were placed, even though during routine fatality searches, the searchers encounter bird carcasses that were on the ground for much longer time periods, and often have repeat encounters instead of just the single encounter allowed in typical detection trials. Trial birds placed on the pads might yield very different searcher detection and carcass persistence rates than collision victims deposited far from the pads. Furthermore, my adjustment for the proportion of carcasses deposited within the maximum search radius could have been biased by a number of factors because I relied on found carcasses to characterize the distribution of fatalities with increasing distance from the turbine.

If searcher detection is biased by distance from the turbine, then my adjustment for search radius bias was itself biased.

In preparation for repowering the APWRA, directed research is needed on these adjustment factors. An integrated trial is being implemented at two projects I am involved with in the APWRA. These trials involve periodic placements of fresh frozen carcasses at random locations within the fatality search areas. The carcasses are left in place for the fatality searchers to find or not find after any number of searches following the placements. The result is an overall detection rate that is a function of body mass. This approach overcomes most of the biases discussed in the preceding paragraphs, but there are still several important needs. First, trials involving trained dogs should be used to obtain more accurate estimates of bat fatalities at old-generation turbines, while the opportunity remains. Second, the integrated trial approach I have been using needs to be implemented at the search intervals that have been typically used at the old-generation turbines, i.e., search intervals averaging 30 to 50 days. Third, detection rates and fatalities need to be estimated at various distances from turbines, including within extended maximum search radii around old-generation turbines.

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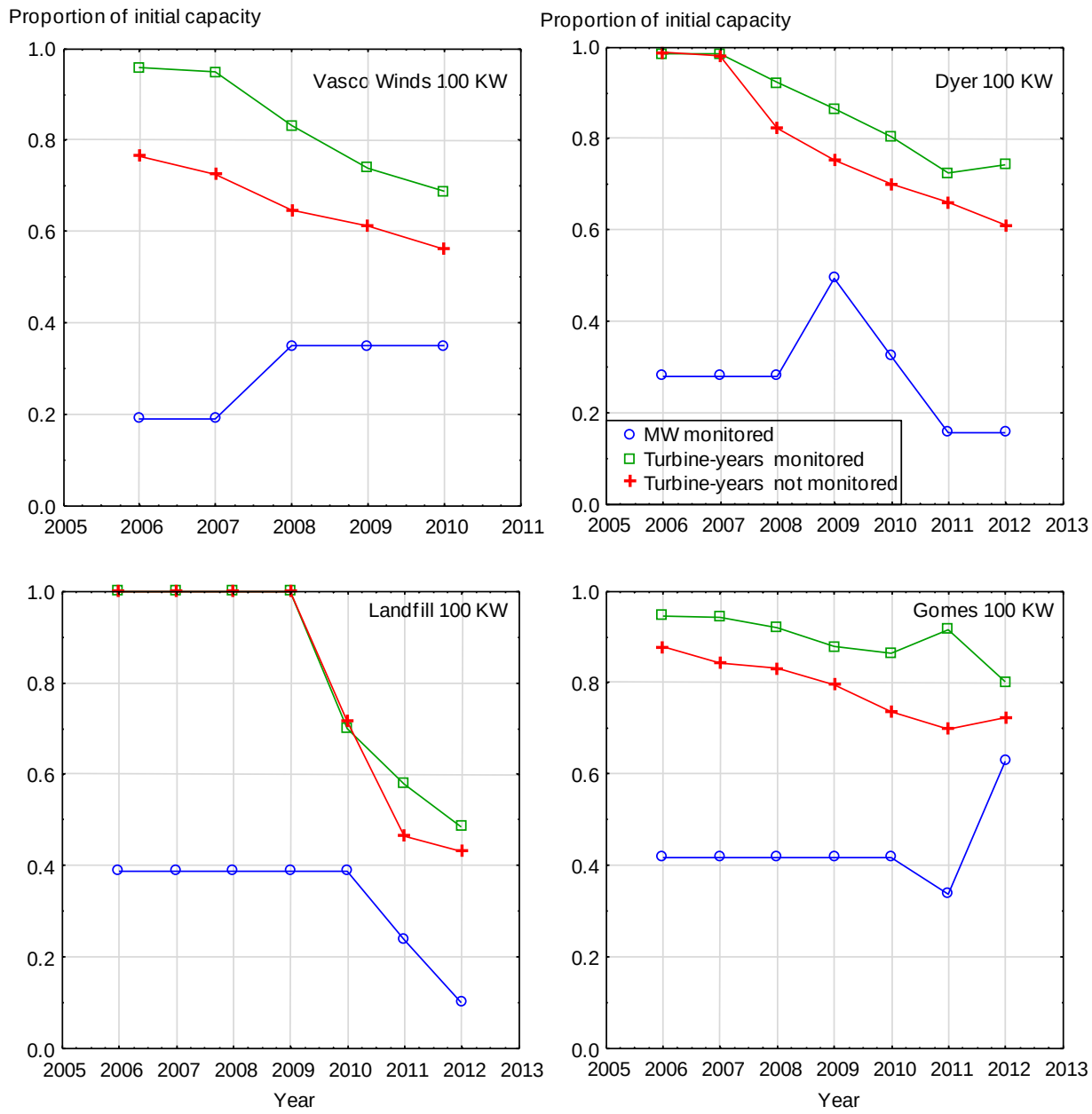

Figure 1A. The proportion of the initial capacity (MW) and the initially installed wind turbines (and towers) monitored for fatalities over at least 70% of each year in the Altamont Pass Wind Resource Area, where the initial conditions were those at the start of the monitoring period compared.

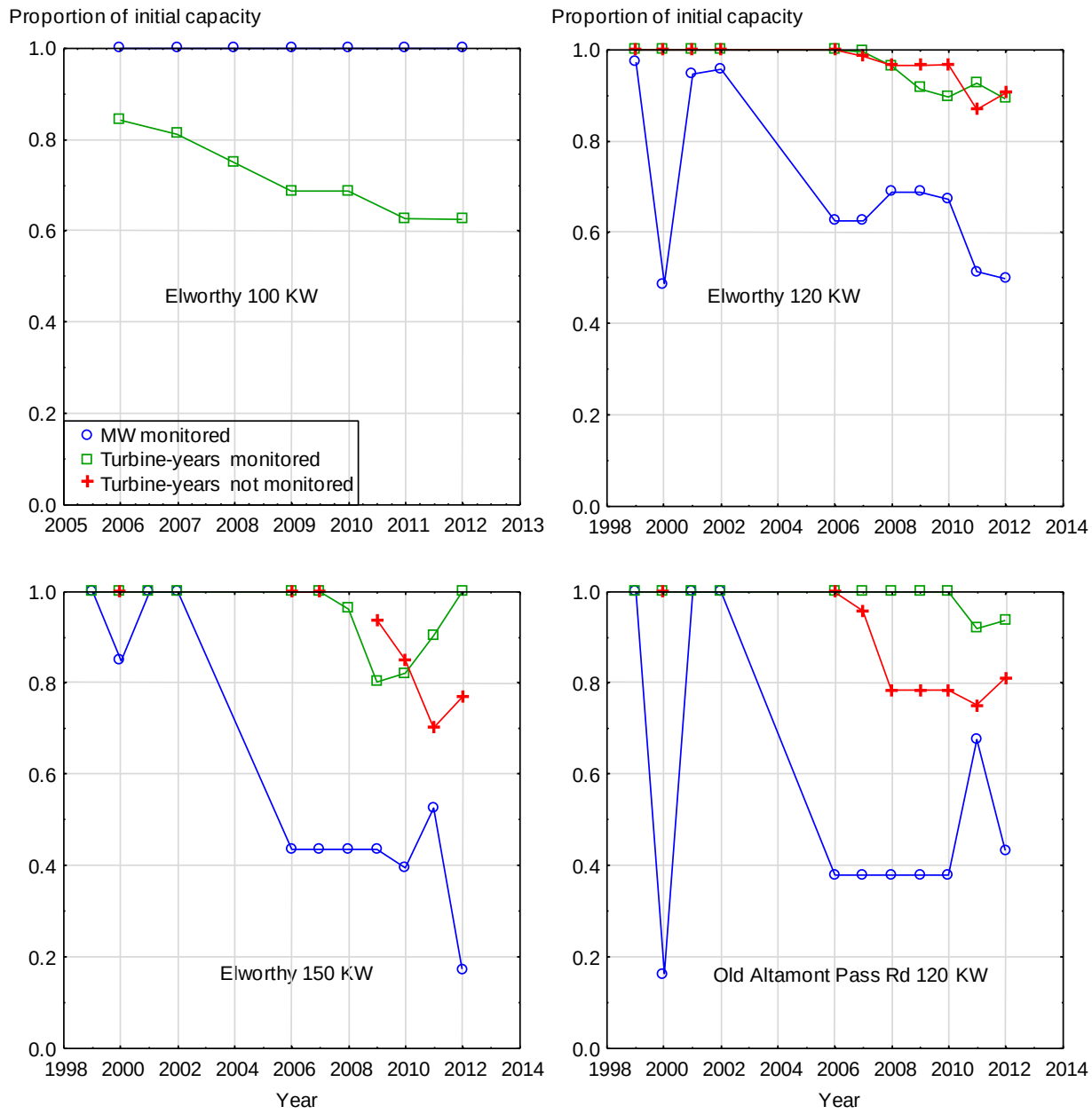

Figure 1B. The proportion of the initial capacity (MW) and the initially installed wind turbines (and towers) monitored for fatalities over at least 70% of each year in the Altamont Pass Wind Resource Area, where the initial conditions were those at the start of the monitoring period compared.

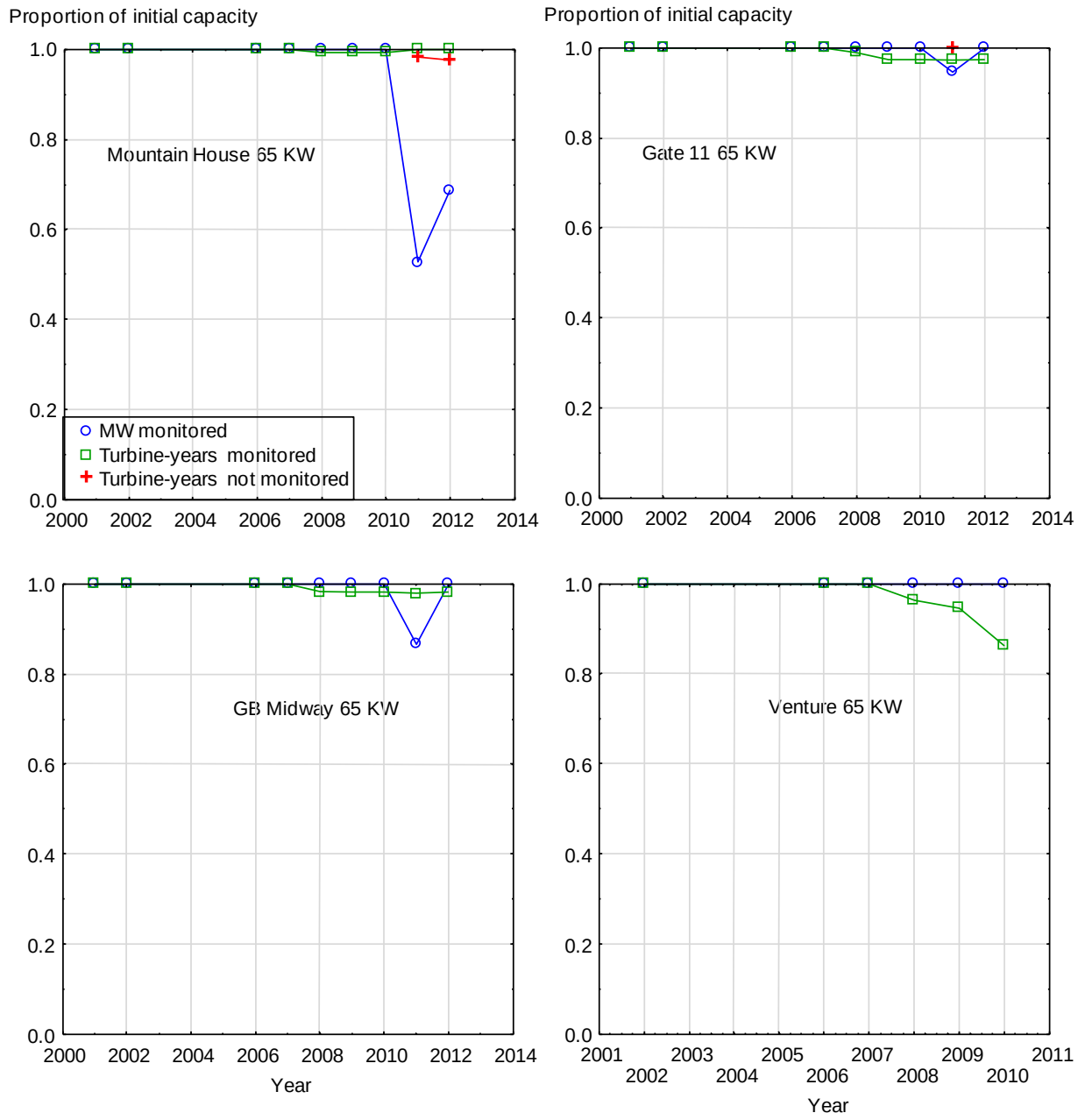

Figure 1C. The proportion of the initial capacity (MW) and the initially installed wind turbines (and towers) monitored for fatalities over at least 70% of each year in the Altamont Pass Wind Resource Area, where the initial conditions were those at the start of the monitoring period compared.

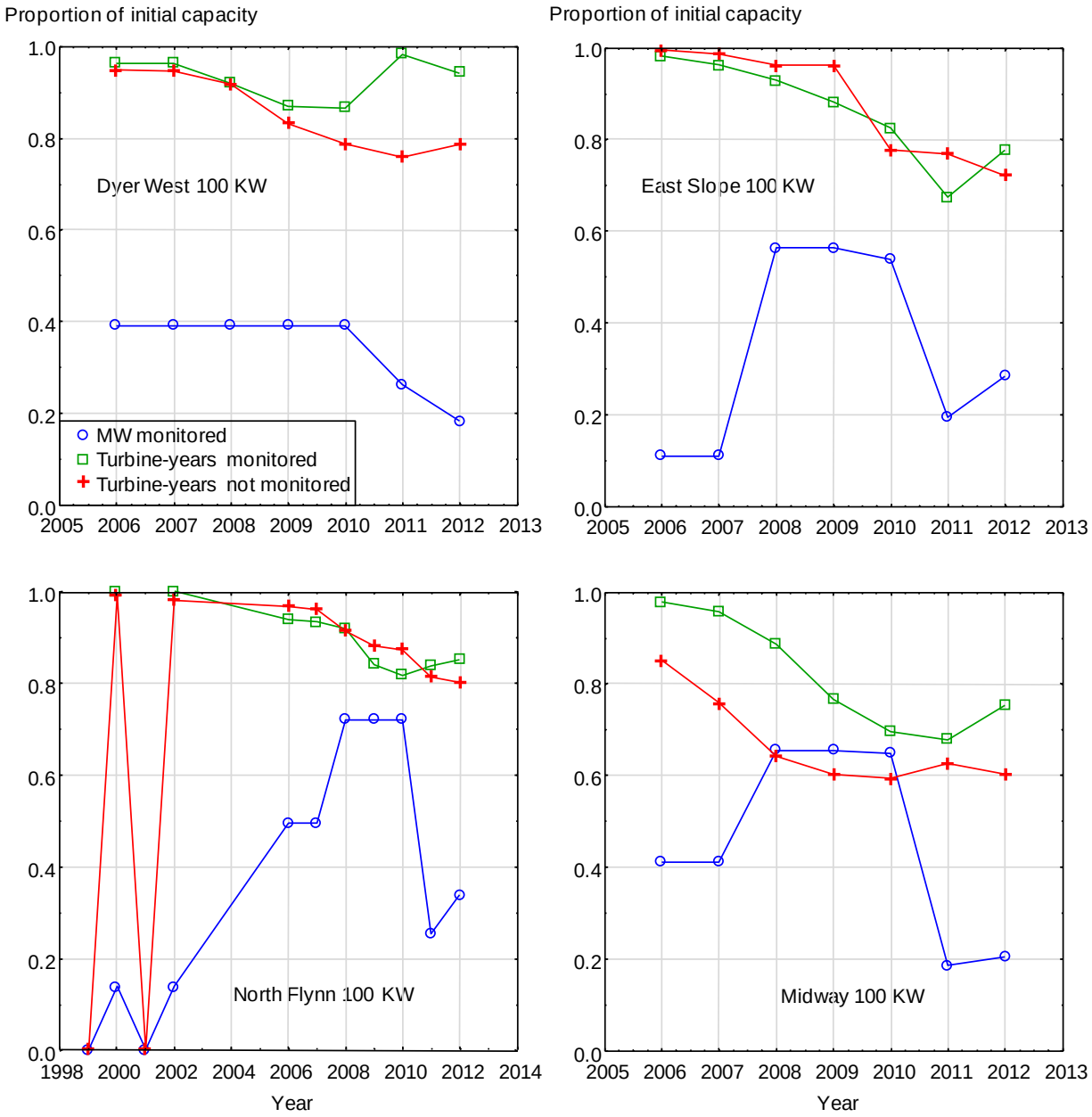

Figure 1D. The proportion of the initial capacity (MW) and the initially installed wind turbines (and towers) monitored for fatalities over at least 70% of each year in the Altamont Pass Wind Resource Area, where the initial conditions were those at the start of the monitoring period compared.

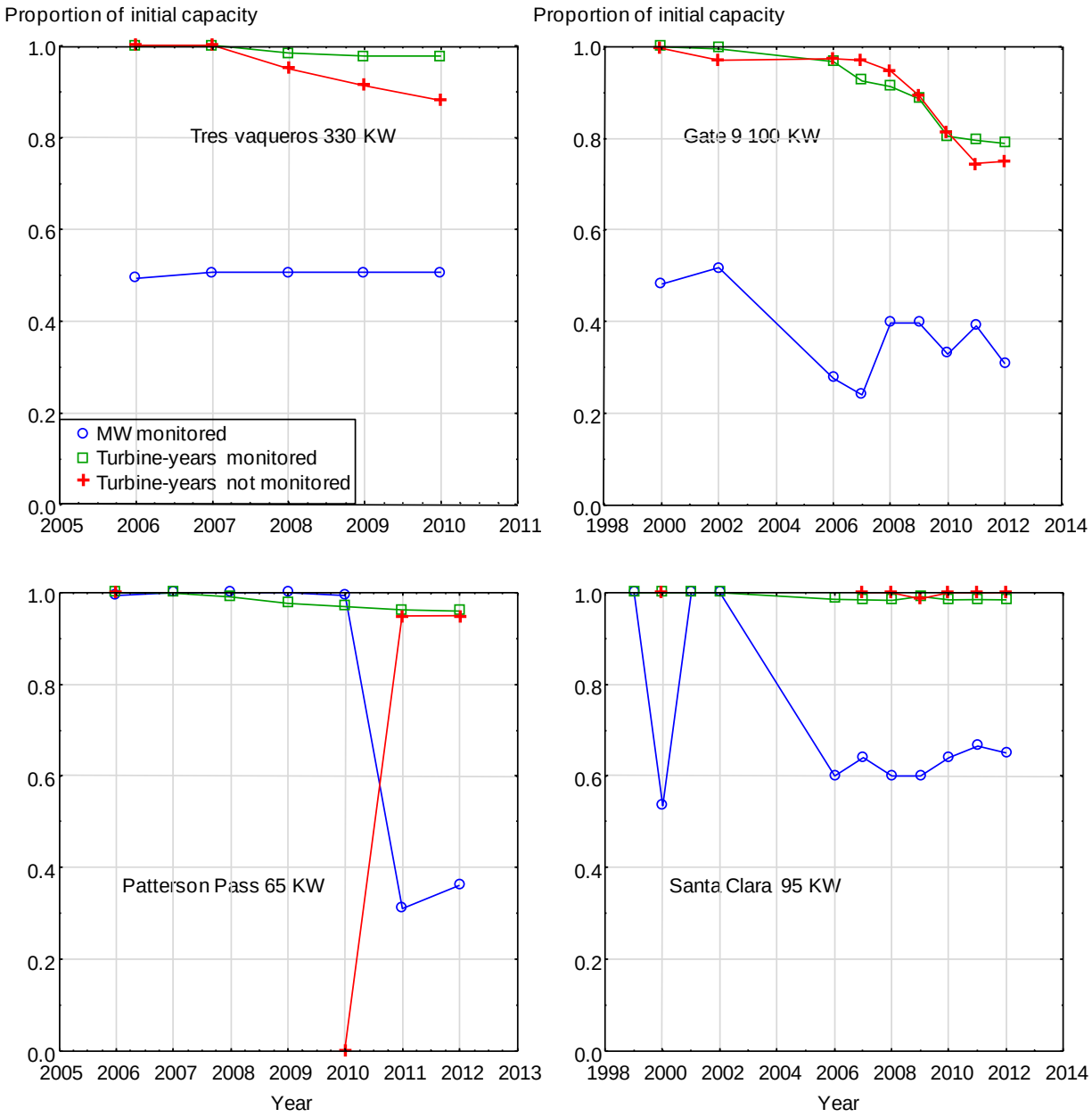

Figure 1E. The proportion of the initial capacity (MW) and the initially installed wind turbines (and towers) monitored for fatalities over at least 70% of each year in the Altamont Pass Wind Resource Area, where the initial conditions were those at the start of the monitoring period compared.

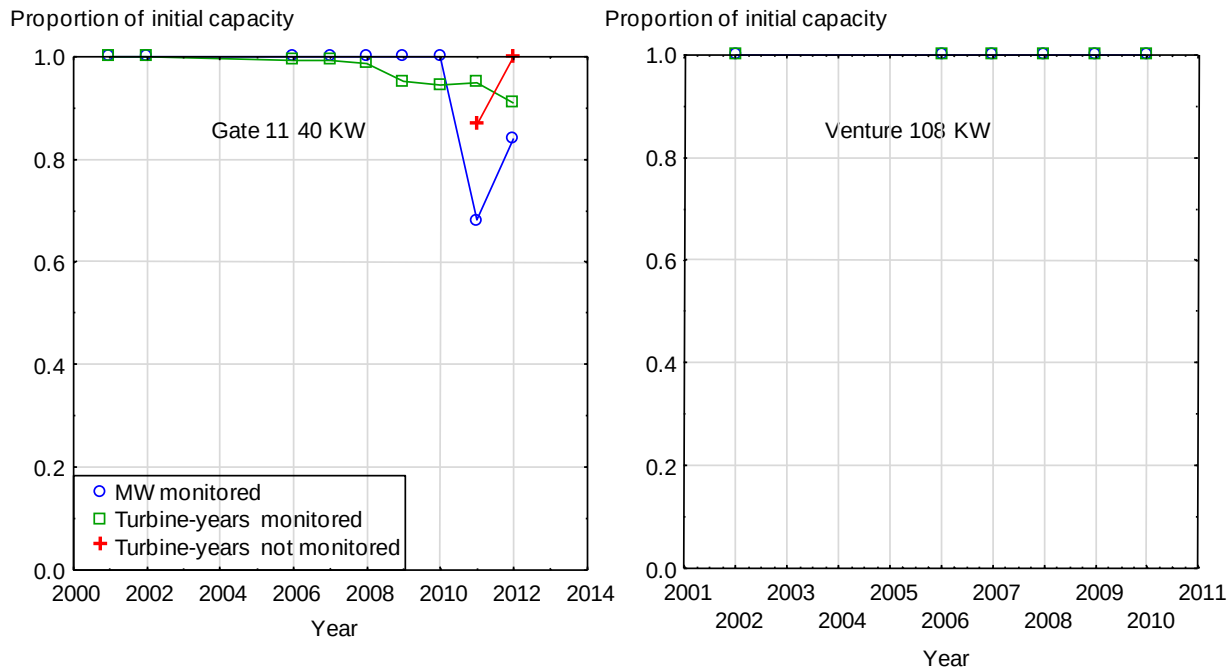

Figure 1F. The proportion of the initial capacity (MW) and the initially installed wind turbines (and towers) monitored for fatalities over at least 70% of each year in the Altamont Pass Wind Resource Area, where the initial conditions were those at the start of the monitoring period compared.

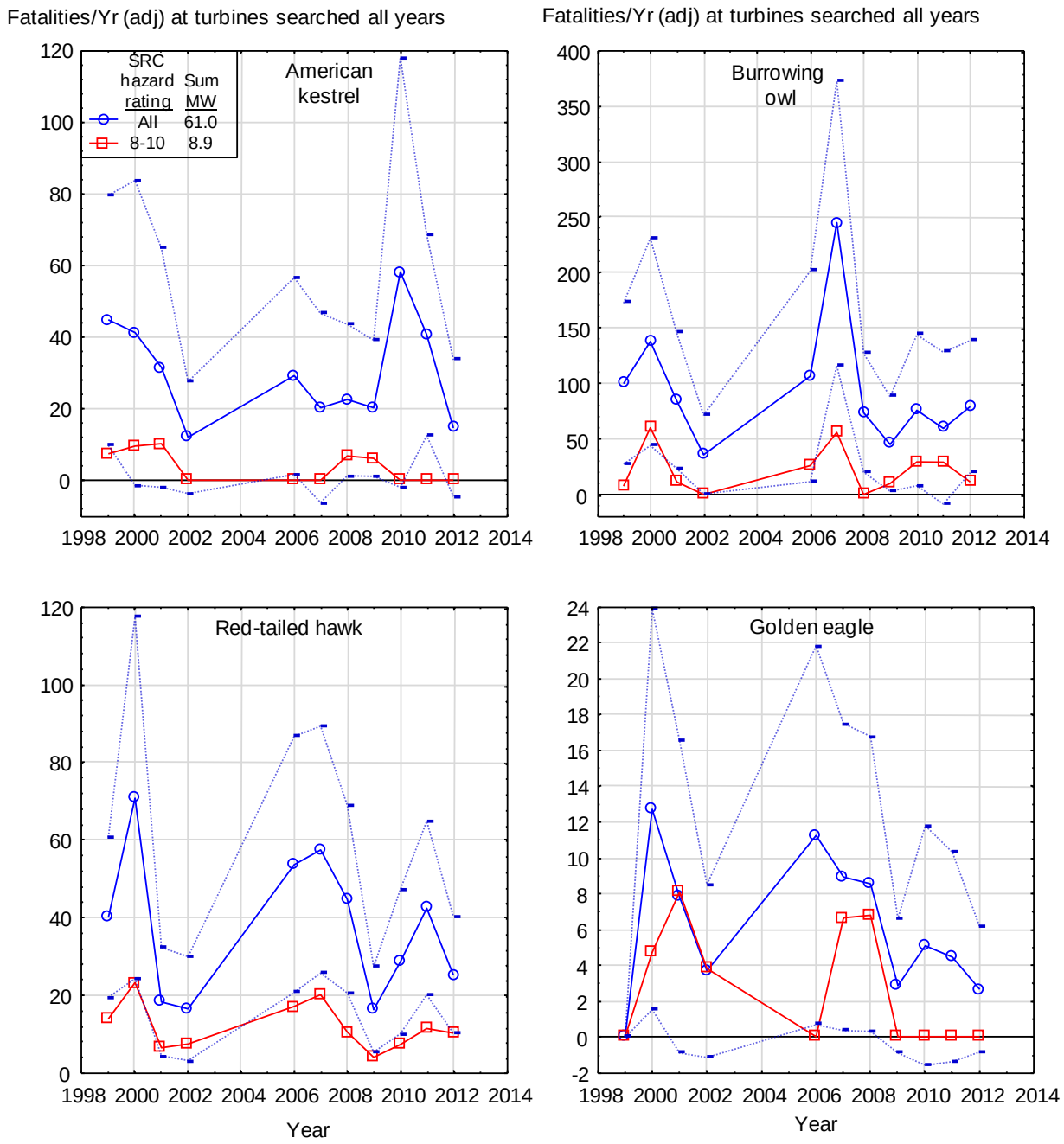

Figure 2. Annual fatality rates (solid blue lines) of four raptor species at 61 MW of turbines monitored from 1999 through 2012, including 80% confidence intervals (dotted blue lines). The red lines indicate the fatality rate contributions of wind turbines the SRC rated 8-10 for collision hazard.

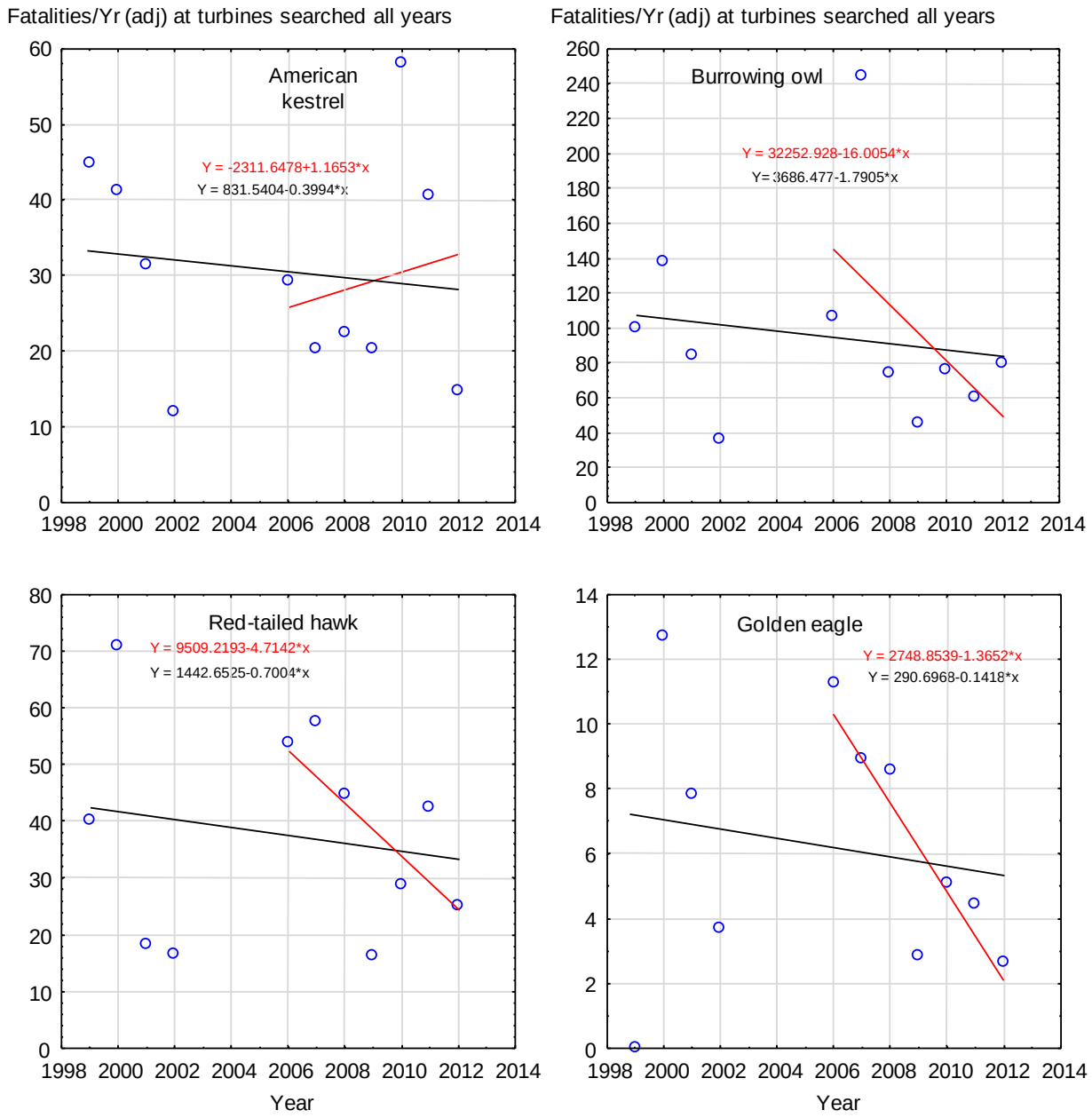

Figure 3. Trend lines fitted to annual fatality rates from 1999 through 2012 (black line) and from 2006 through 2012 (red line) using least-squares regression. The span of years selected determines the slope of the regression.

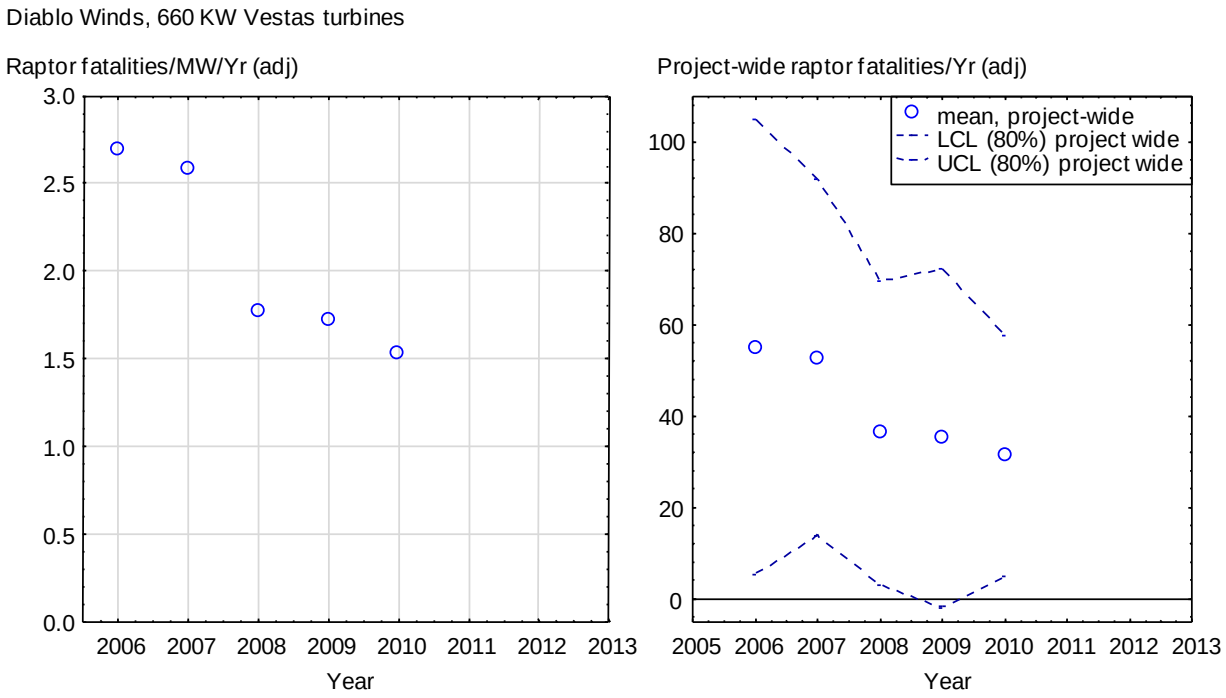

Figure 4. Inter-annual trend in raptor fatalities at the Diablo Winds Energy Project, where no turbines were removed and none were shut down over the winter months. This Project can serve as a useful reference for comparison against turbines where management actions were taken to reduce raptor fatalities.

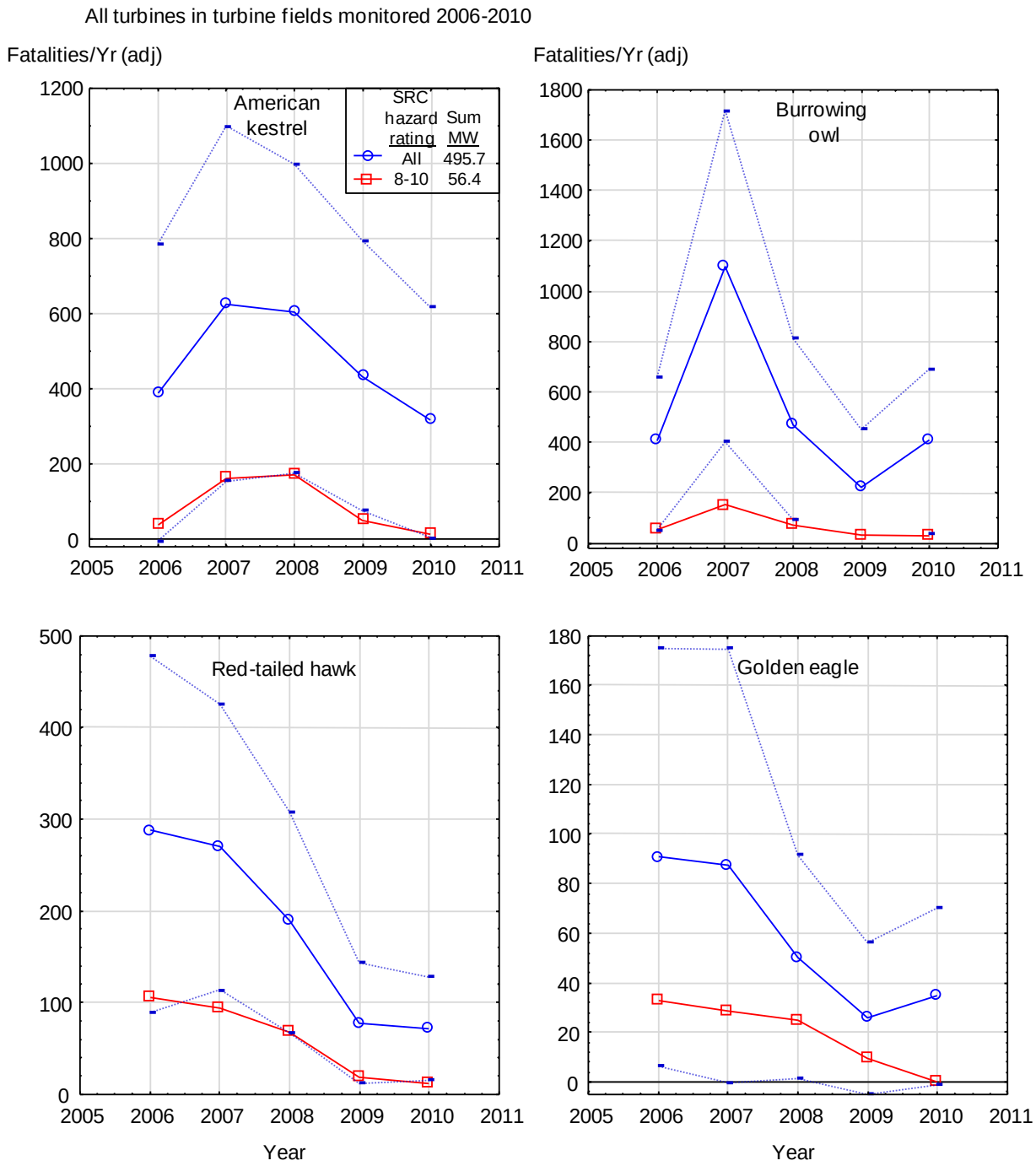

Figure 5. Estimated annual fatalities (solid blue lines) of four raptor species at 495.7 MW of turbines monitored from 2006 through 2010, including 80% confidence intervals (dotted blue lines). The red lines indicate the fatality rate contributions of wind turbines the SRC rated 8-10 for collision hazard.

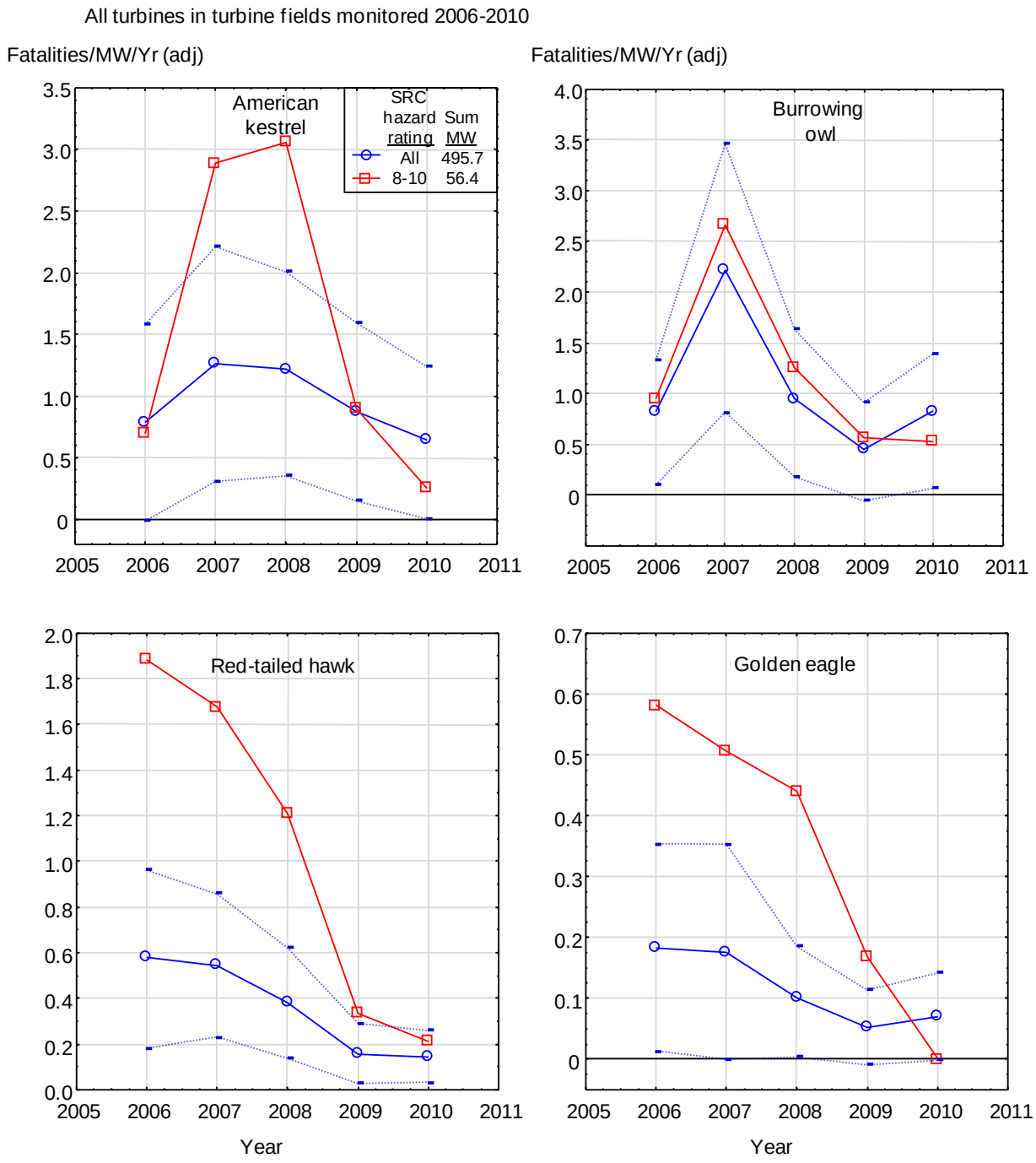

Figure 6. Estimated annual fatalities/MW (solid blue lines) of four raptor species at 495.7 MW of turbines monitored from 2006 through 2010, including 80% confidence intervals (dotted blue lines). The red lines indicate the fatality rate contributions of wind turbines the SRC rated 8-10 for collision hazard.

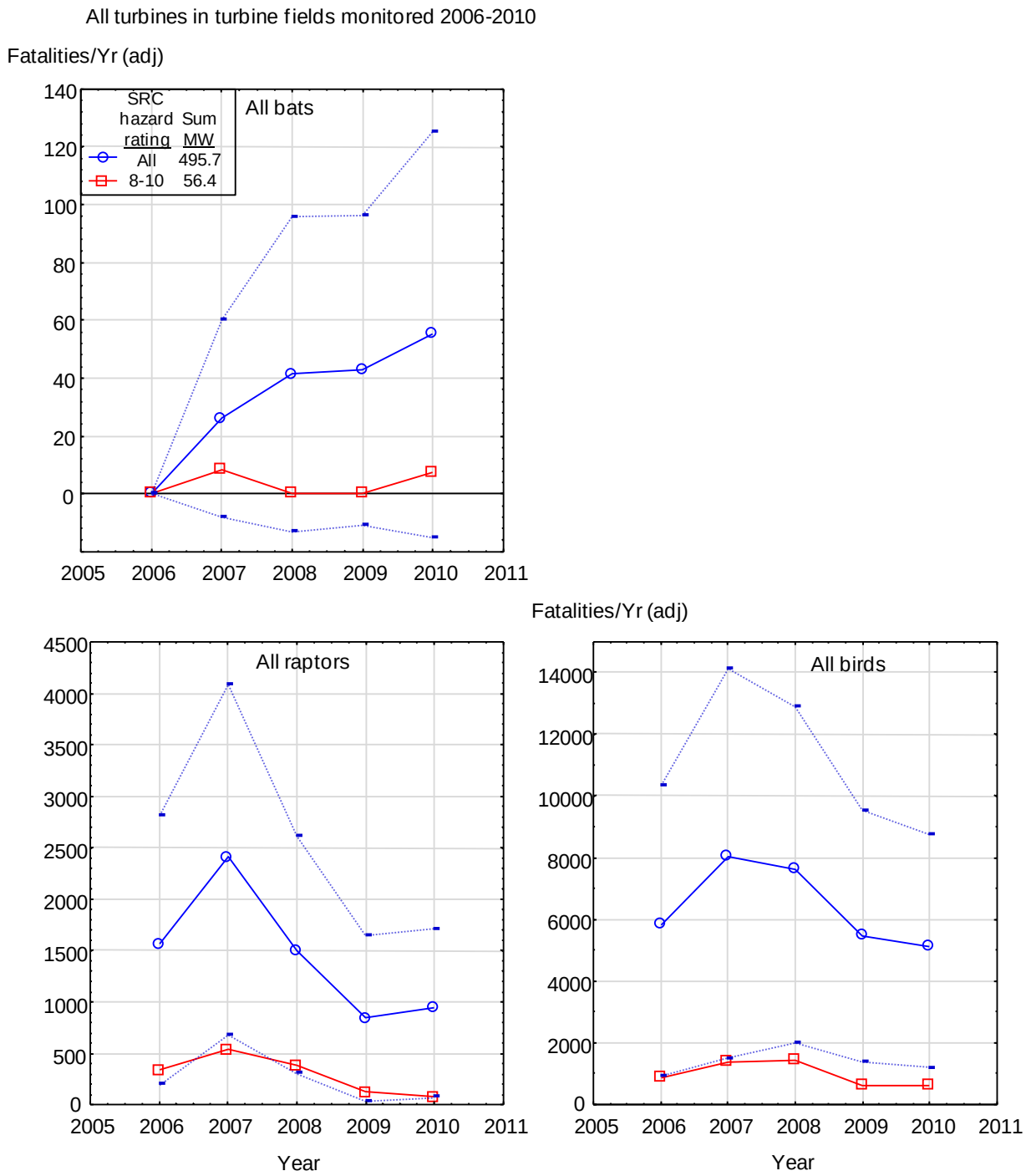

Figure 7. Estimated annual fatalities/MW (solid blue lines) of all bats (top left graph), all raptors (bottom left), and all birds (bottom right) at 495.7 MW of turbines monitored from 2006 through 2010, including 80% confidence intervals (dotted blue lines). The red lines indicate the fatality rate contributions of wind turbines the SRC rated 8-10 for collision hazard.

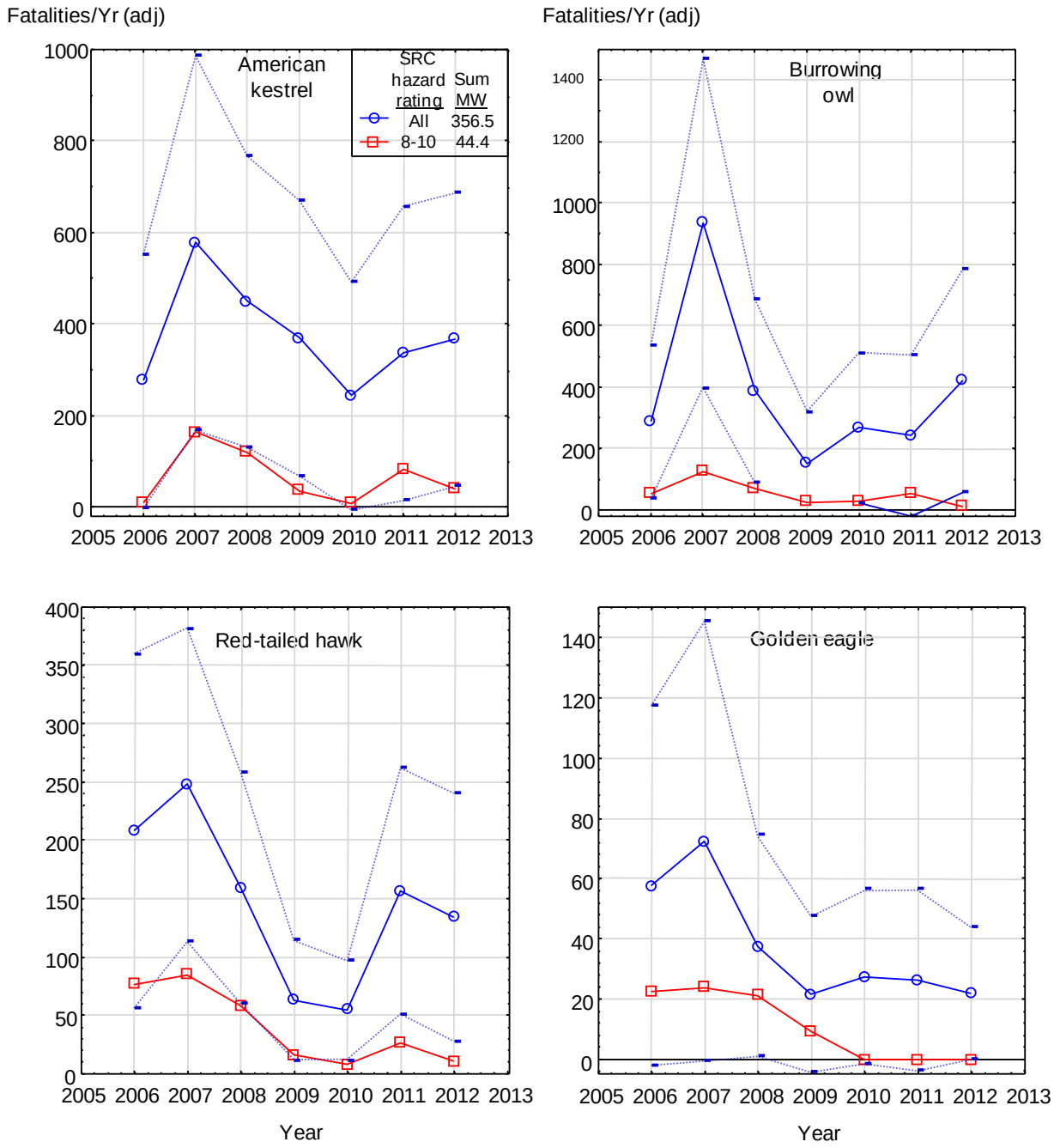

Figure 8. Estimated annual fatalities/MW (solid blue lines) of four raptor species at 356.5 MW of turbines monitored from 2006 through 2012, including 80% confidence intervals (dotted blue lines). The red lines indicate the fatality rate contributions of wind turbines the SRC rated 8-10 for collision hazard.

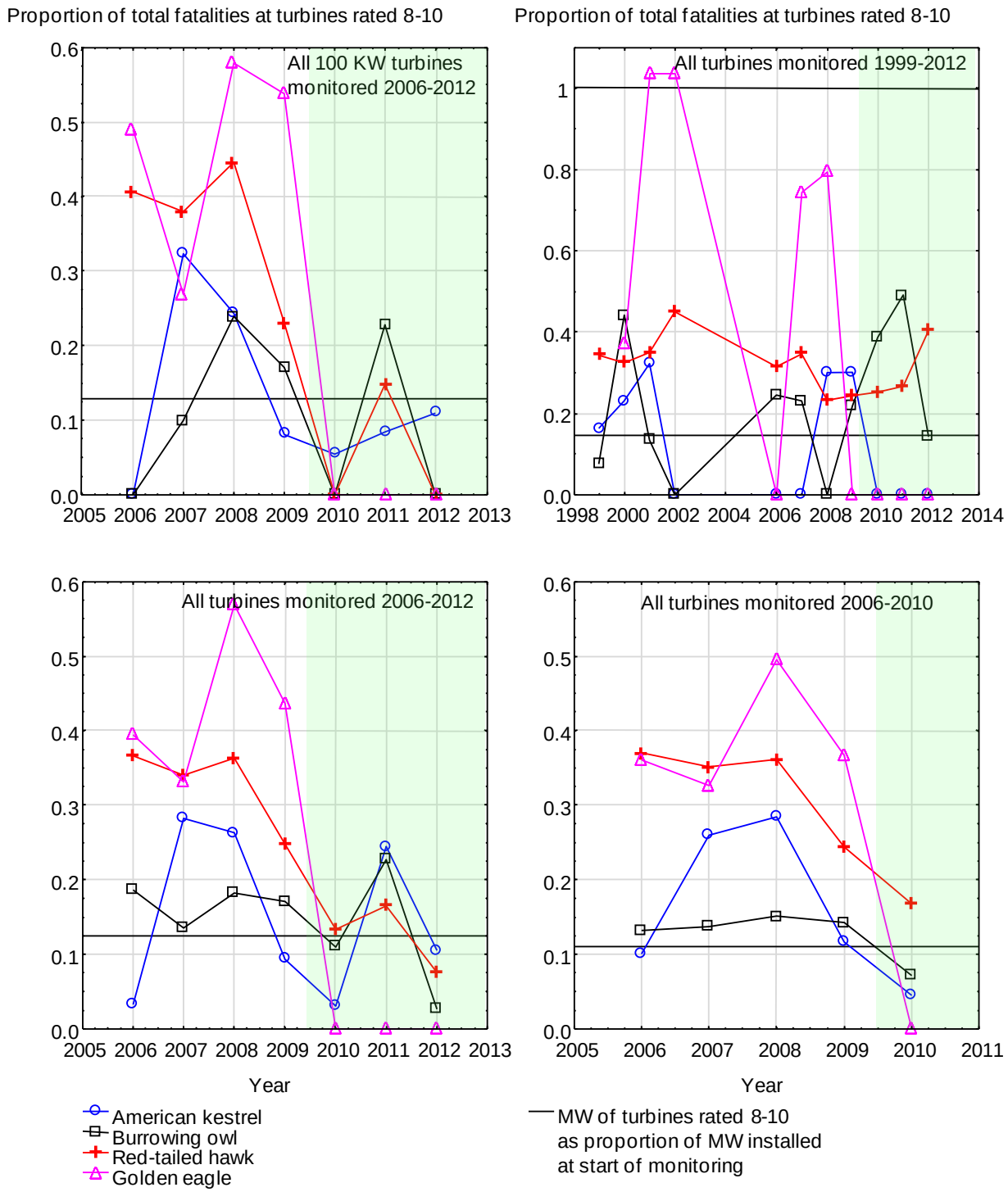

Figure 9. Proportion of total fatalities at wind turbines the SRC rated 8-10 for collision hazard. The horizontal black line indicates the proportion of the initially monitored wind turbines that consisted of turbines rated 8-10, and the shaded area depicts the time period following the removals of most of the turbines the SRC rated 8-10.

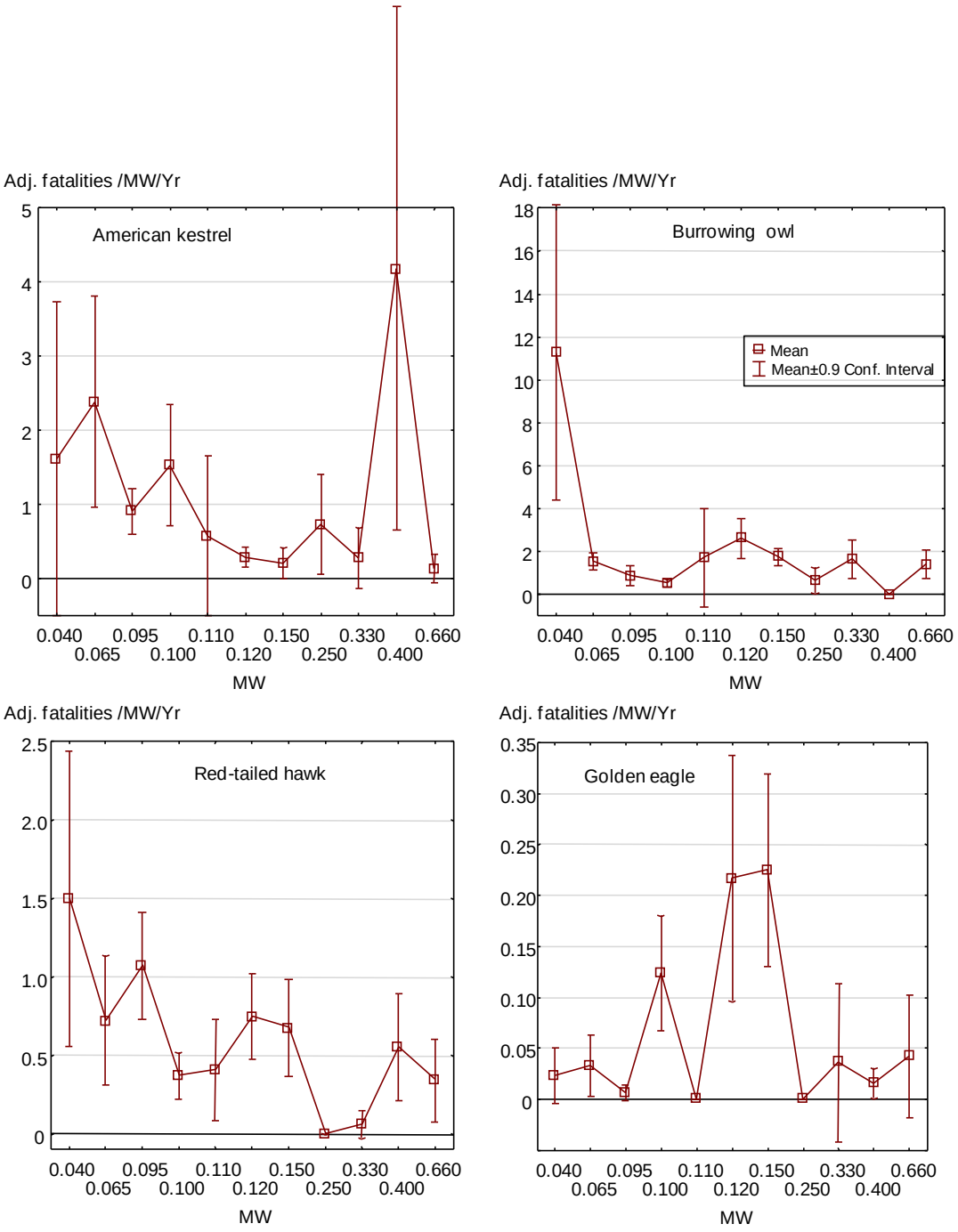

Figure 10. Mean adjusted estimates of fatalities/MW/Year declined with increasing wind turbine size for American kestrel (top left), burrowing owl (top right), and red-tailed hawk (bottom left), but not for golden eagle (bottom right) across all years of monitoring 1999-2012 in the Altamont Pass Wind Resource Area, California. The high burrowing owl fatality rate at 40 KW turbines might have been due to location, as the 40 KW turbines all occur in the Altech project where burrowing owl nesting densities are high. The high golden eagle fatality rate at 120 and 150 KW turbines were in the Difwind projects on Elworthy Ranch.

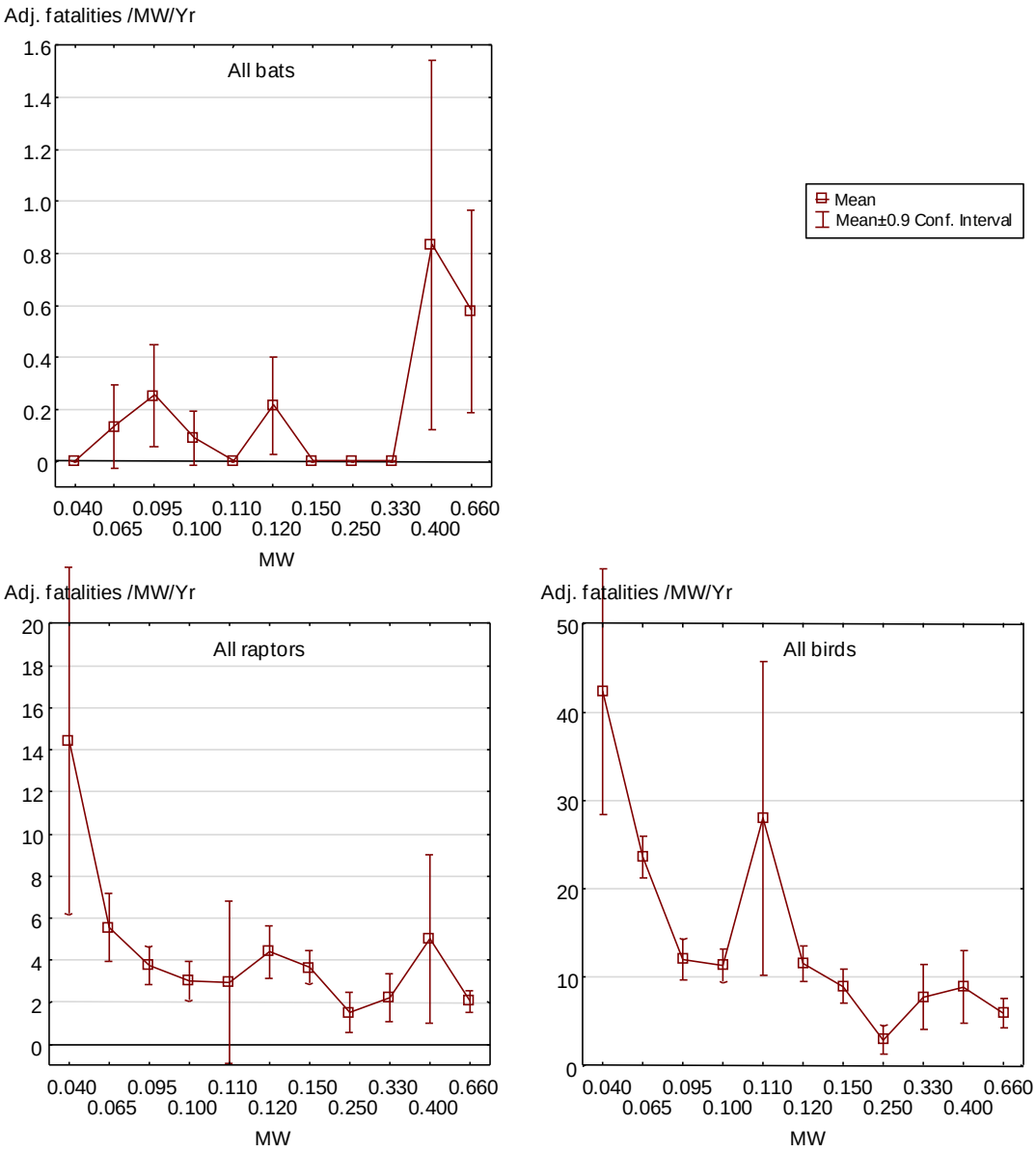

Figure 11. Mean adjusted estimates of fatalities/MW/Year were highest at the two largest wind turbine sizes compared for all bats as a group (top left), but declined with increasing wind turbine size for all raptors as a group (bottom left) and all birds as a group (bottom right) across all years of monitoring 1999-2012 in the Altamont Pass Wind Resource Area, California.

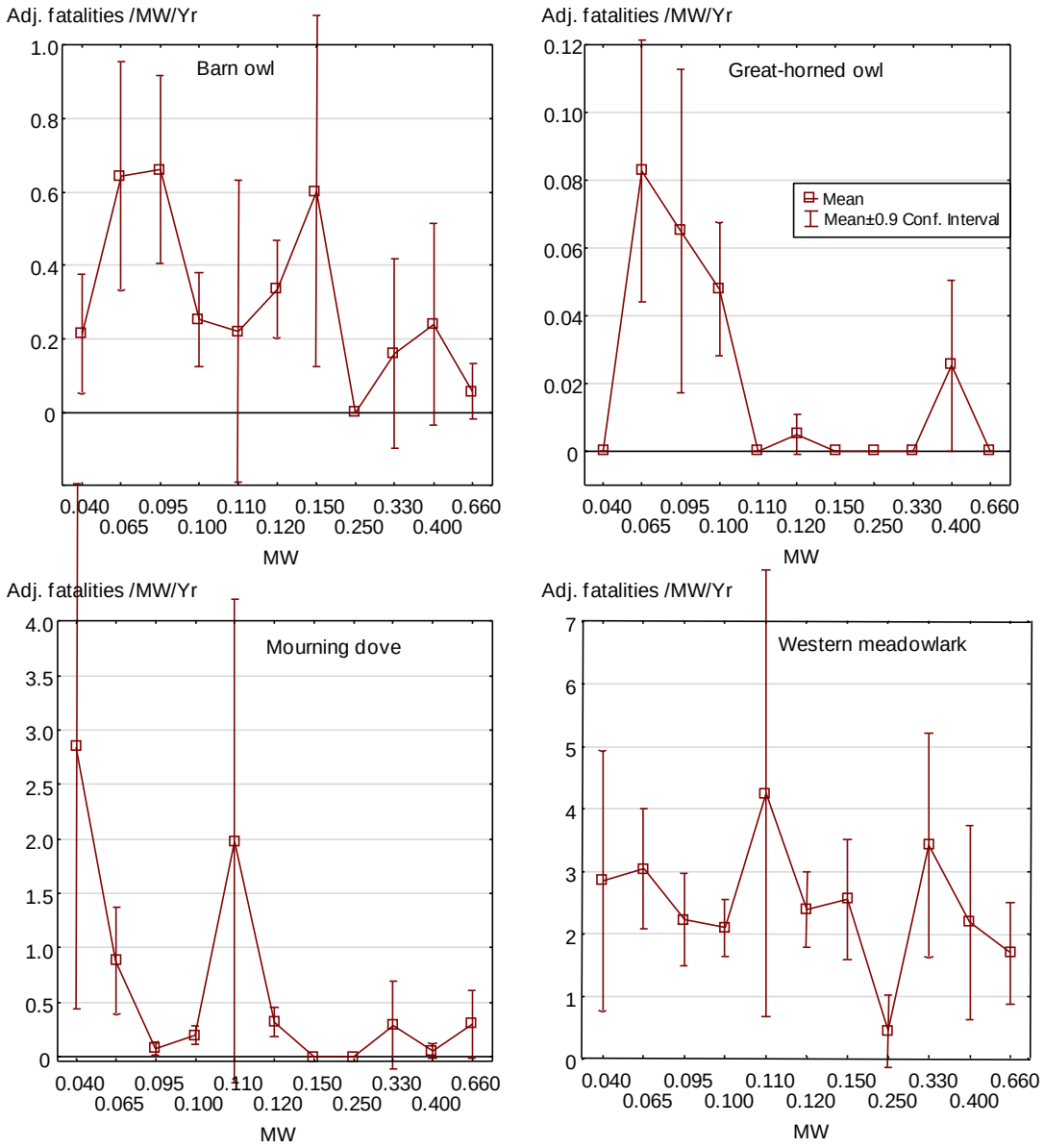

Figure 12. Mean adjusted estimates of fatalities/MW/Year declined with increasing wind turbine size for barn owl (top left), great-horned owl (top right), mourning dove (bottom left), and less so for western meadowlark (bottom right) across all years of monitoring 1999-2012 in the Altamont Pass Wind Resource Area, California. The high mourning dove fatality rate at 108 KW turbines was at the small group of Polenko turbines in the Venture project.

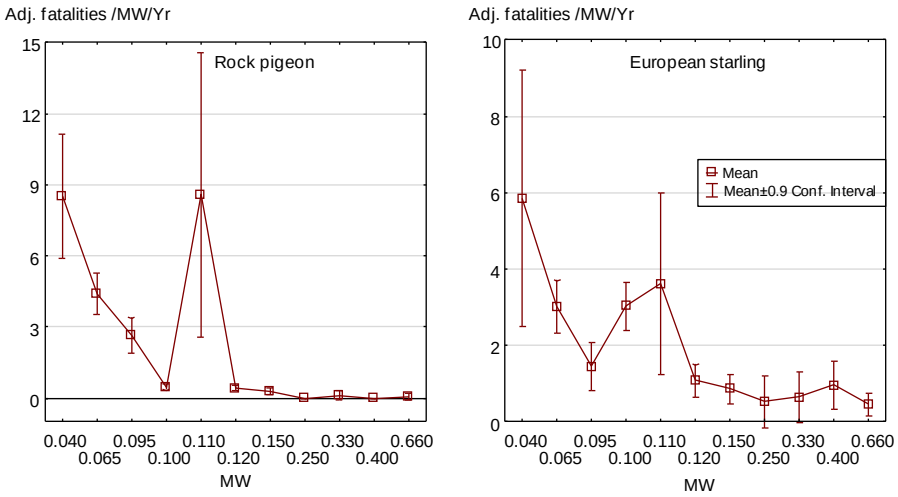

Figure 13. Mean adjusted estimates of fatalities/MW/Year declined with increasing wind turbine size for rock pigeon (left) and European starling (right) across all years of monitoring 1999-2012 in the Altamont Pass Wind Resource Area, California. The high American kestrel fatality rate at 400 KW turbines was at the KVS33 turbines in the North Flynn project. The high fatality rates at 108 KW turbines were at the small group of Polenko turbines in the Venture project.

APPENDIX A: Fatality rates by wind turbine size

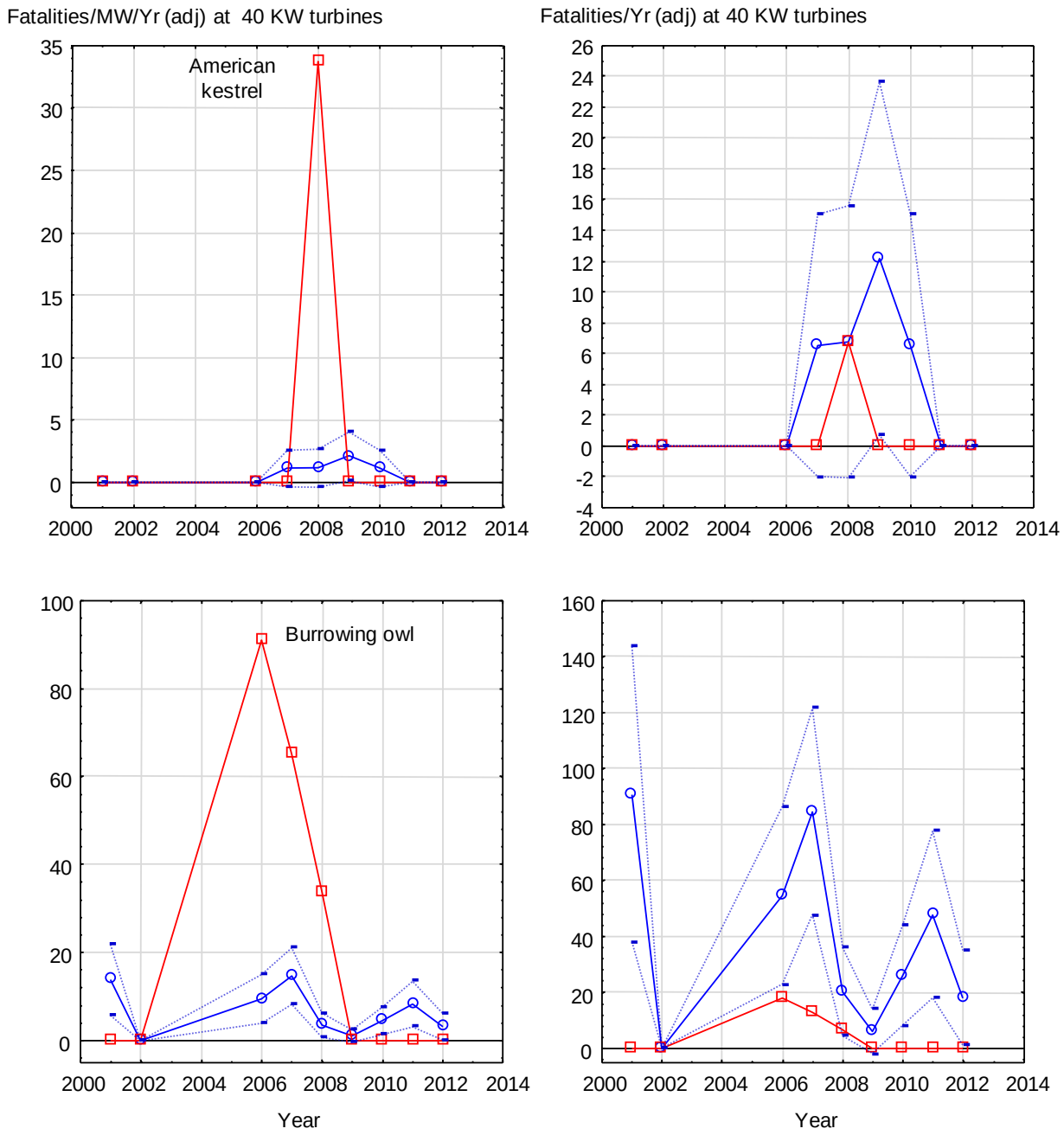

Figure A1. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 40 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

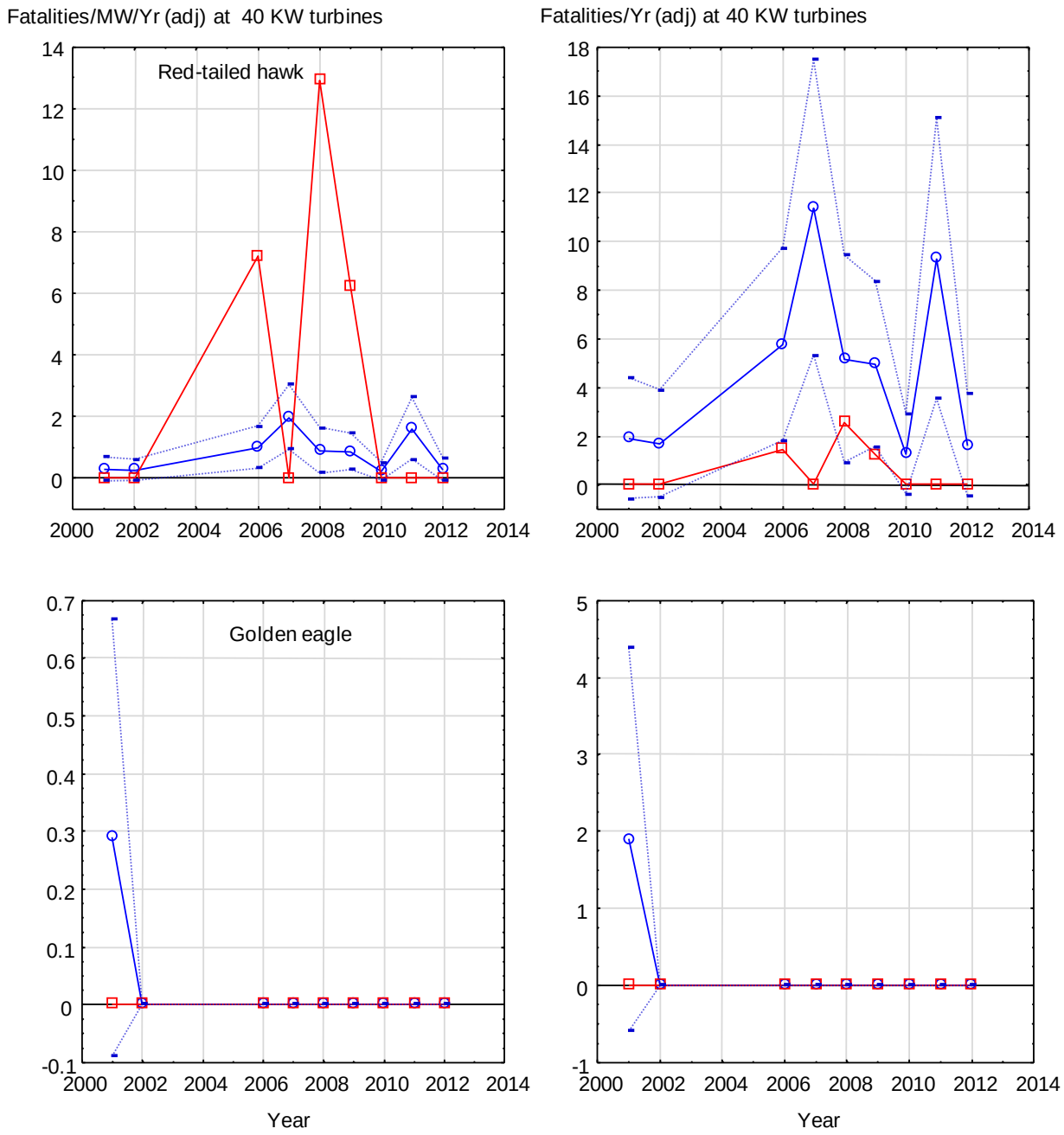

Figure A2. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 40 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

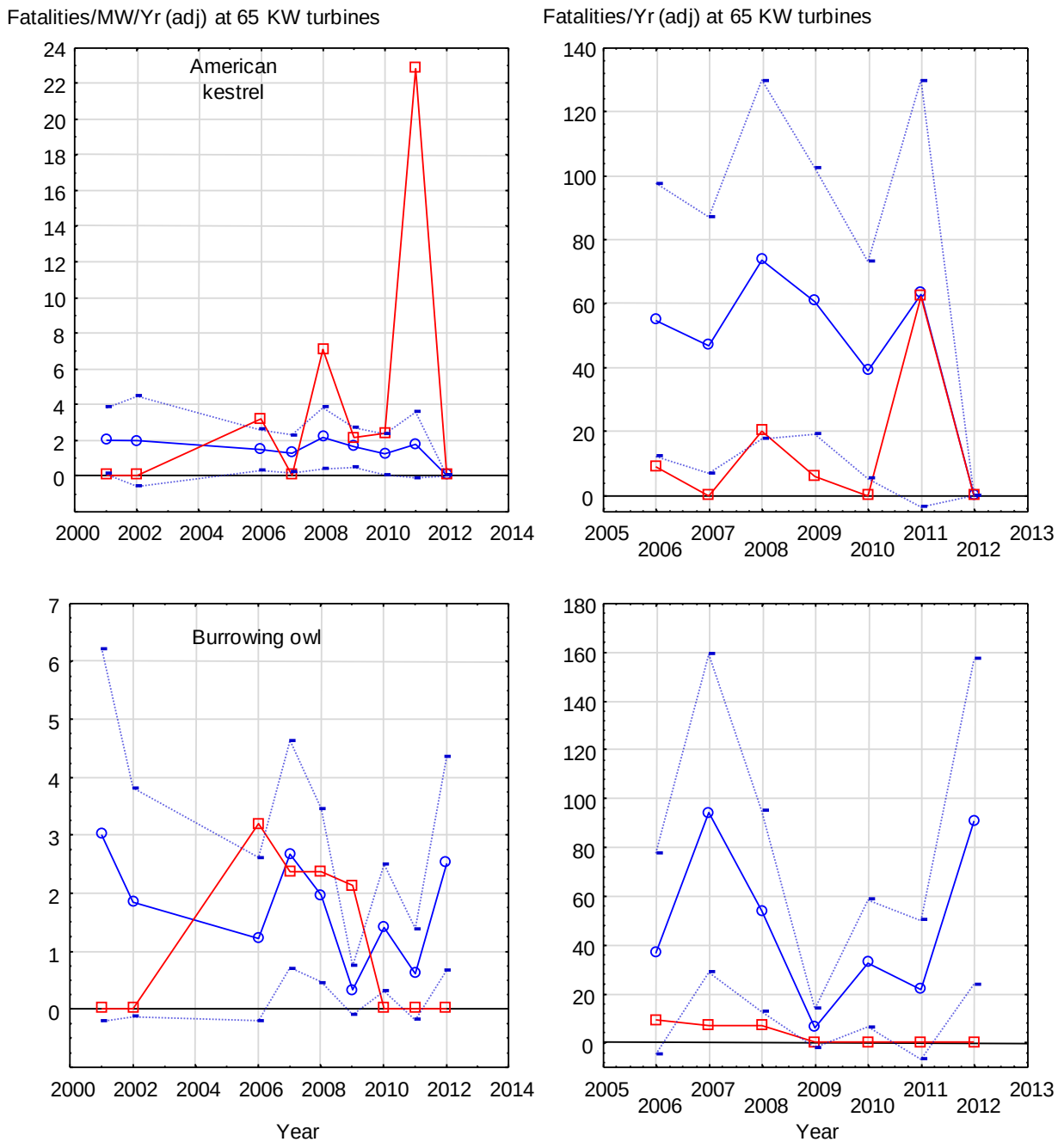

Figure A3. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 65 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

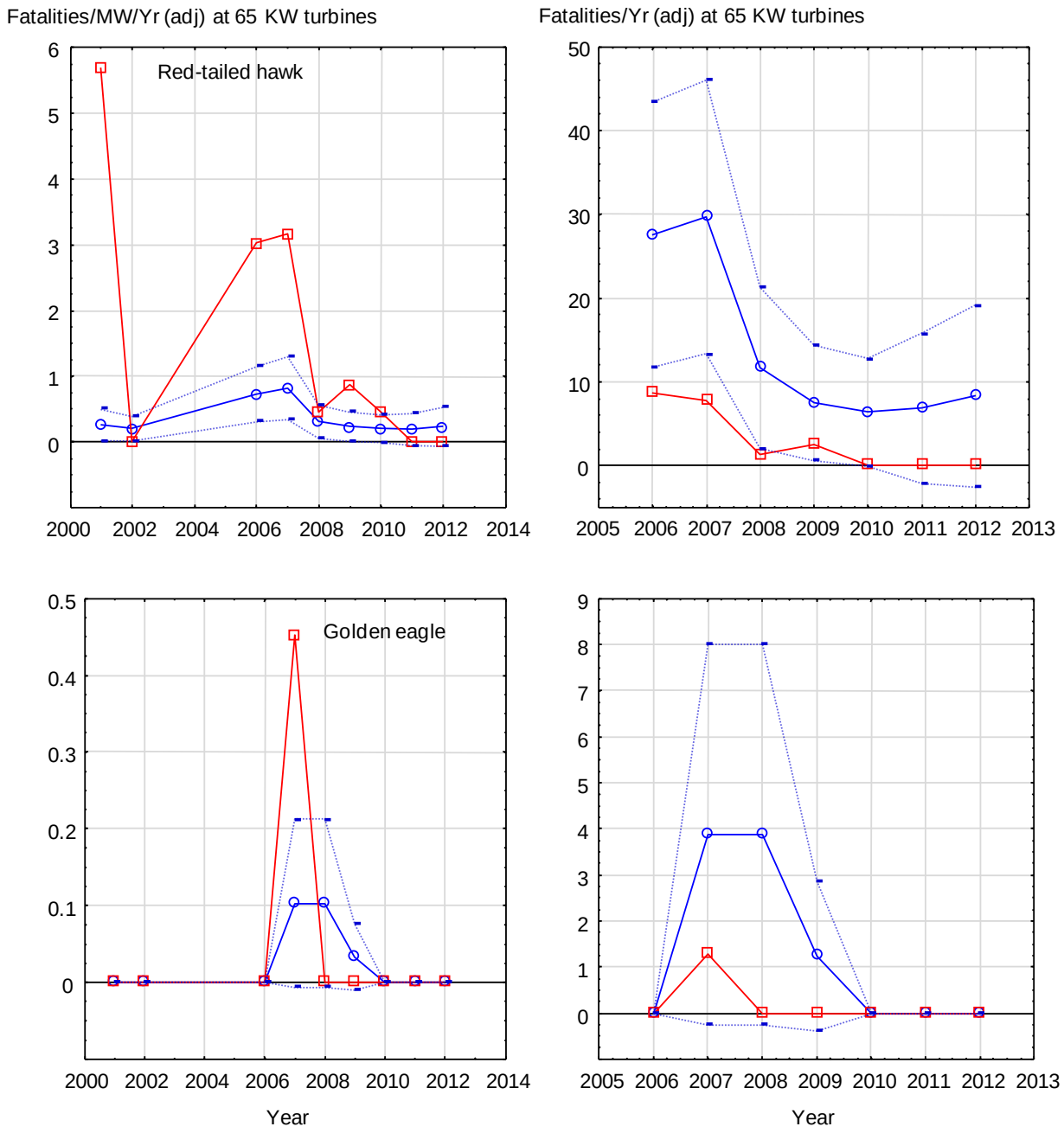

Figure A4. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 65 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

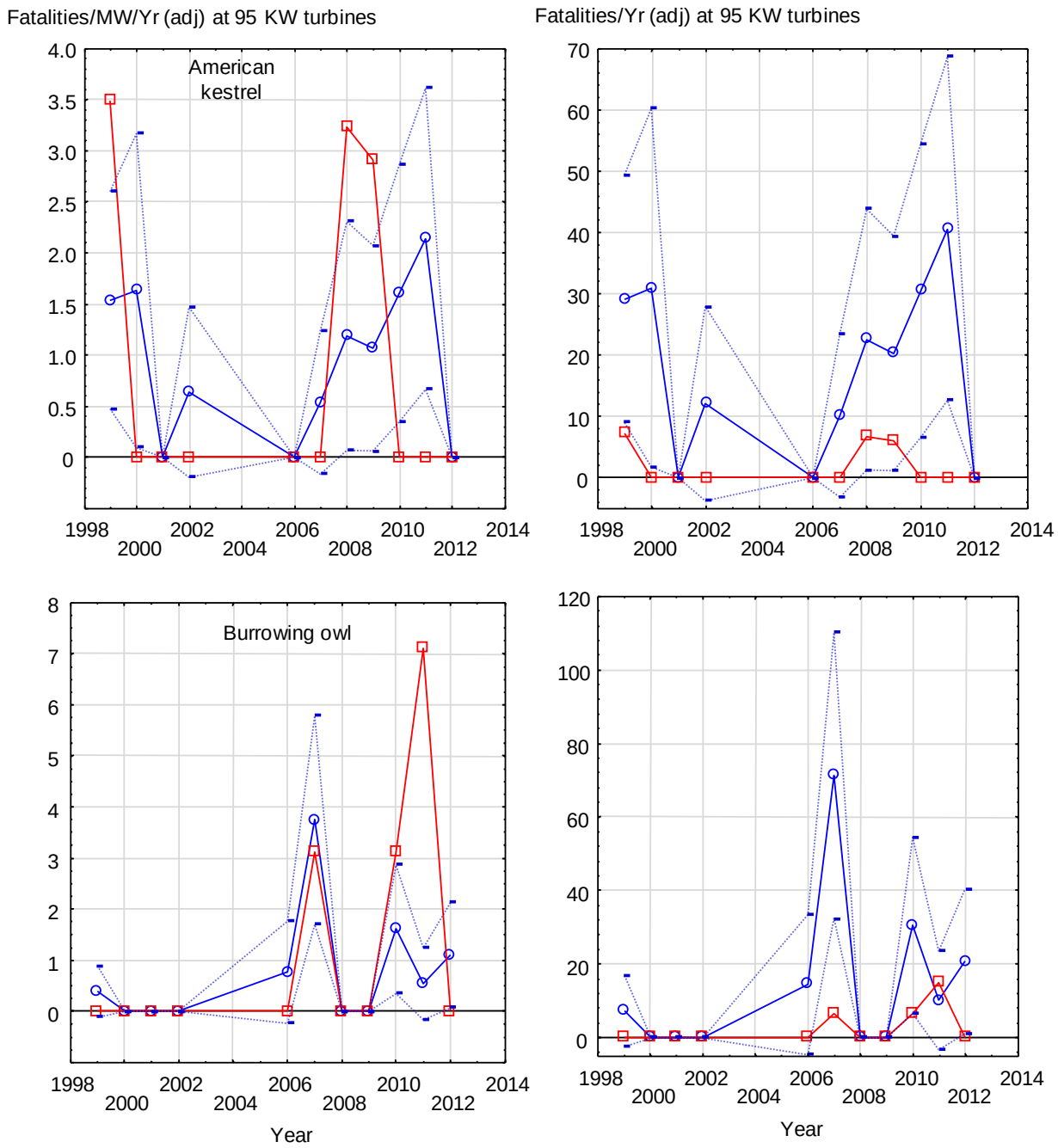

Figure A5. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 95 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

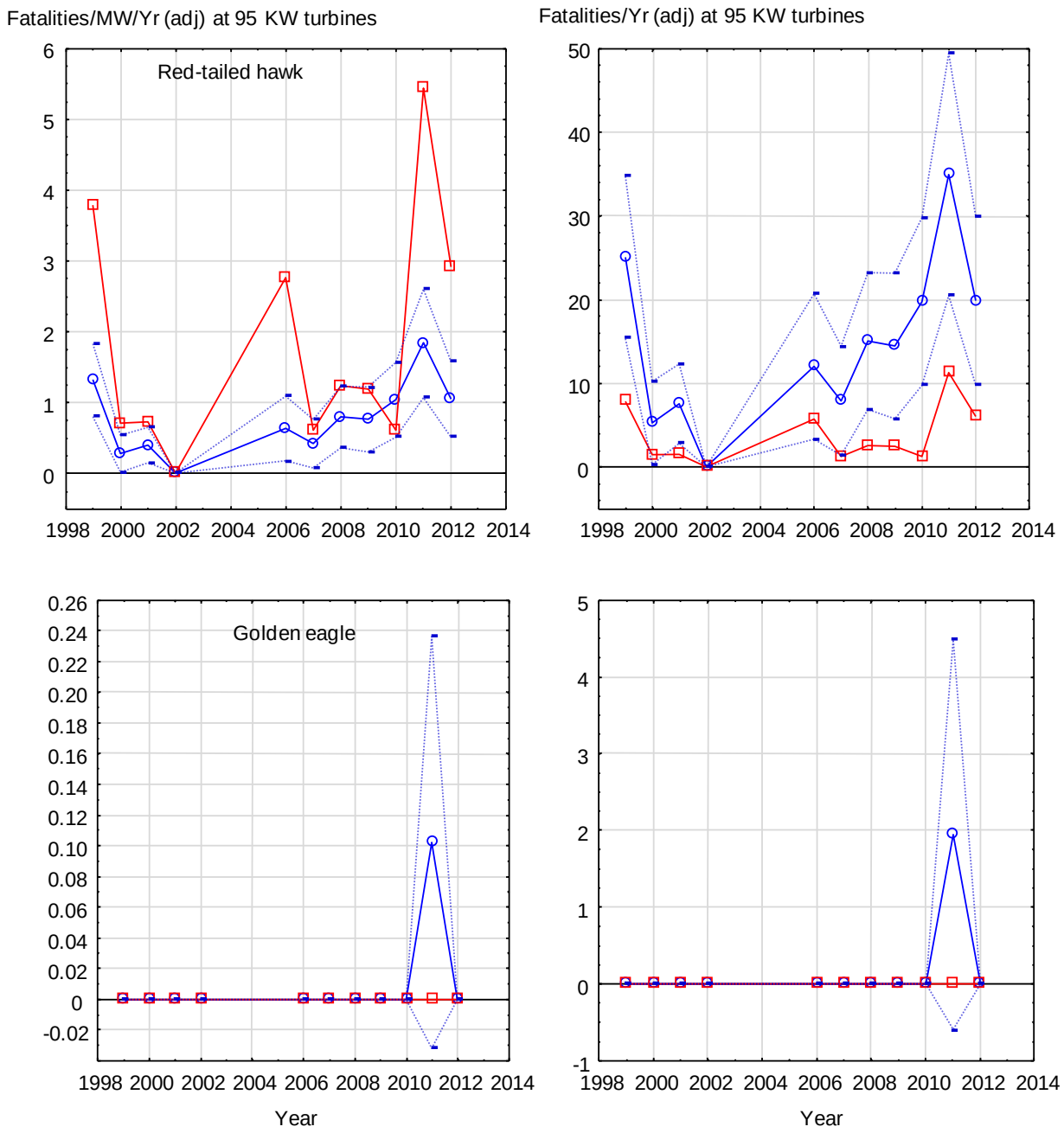

Figure A6. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 95 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

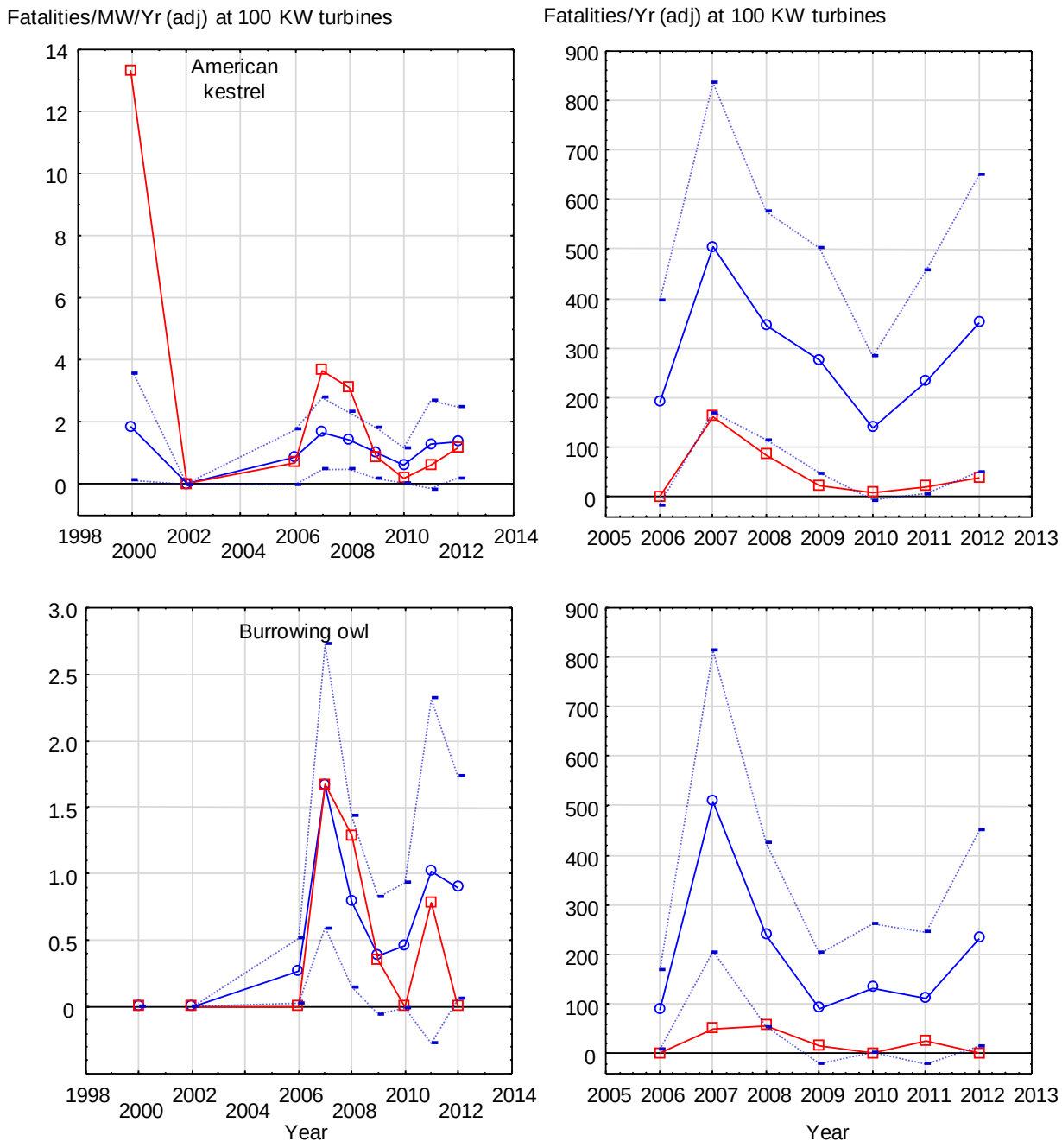

Figure A7. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 100 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

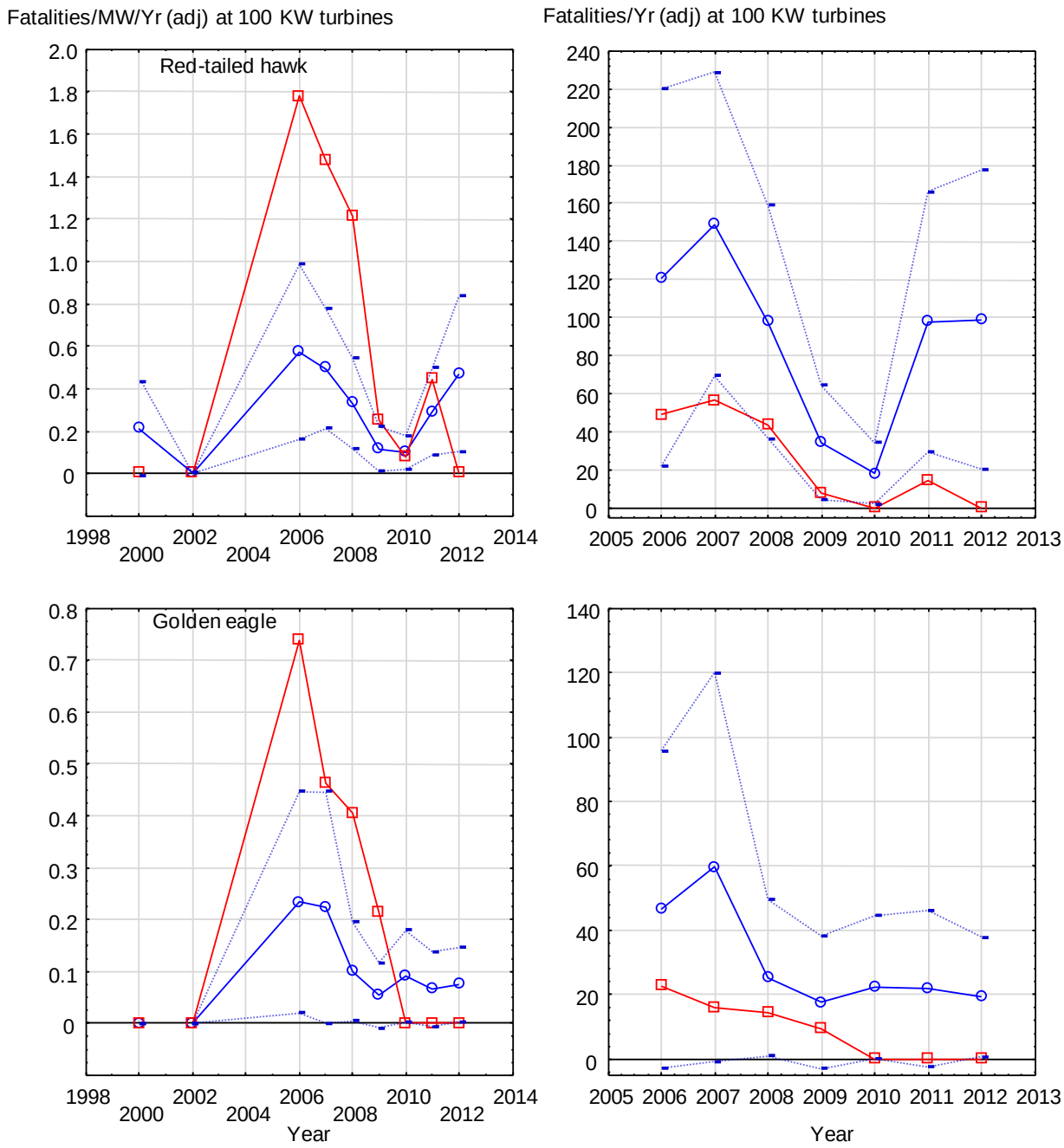

Figure A8. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 100 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

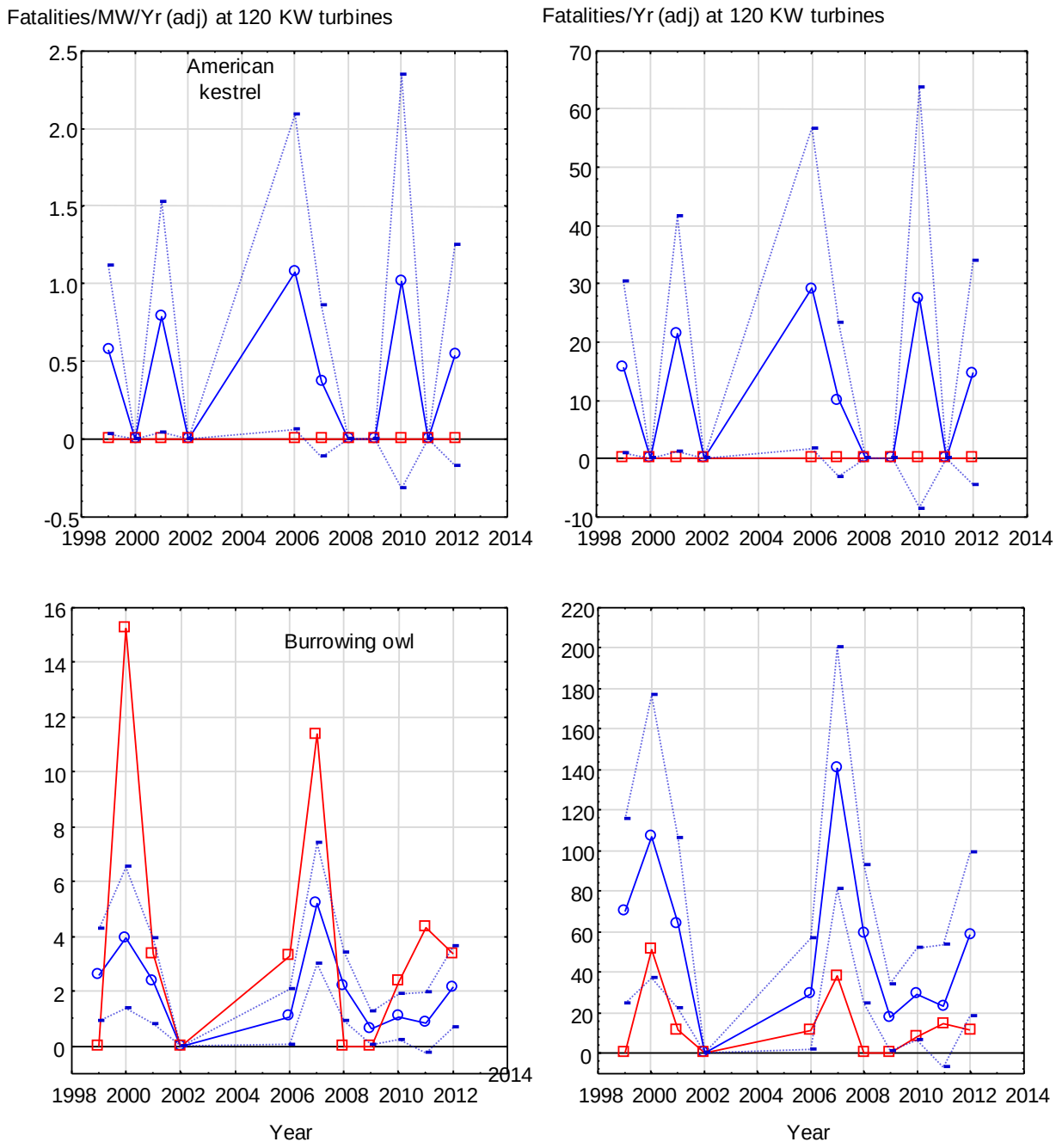

Figure A9. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 120 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

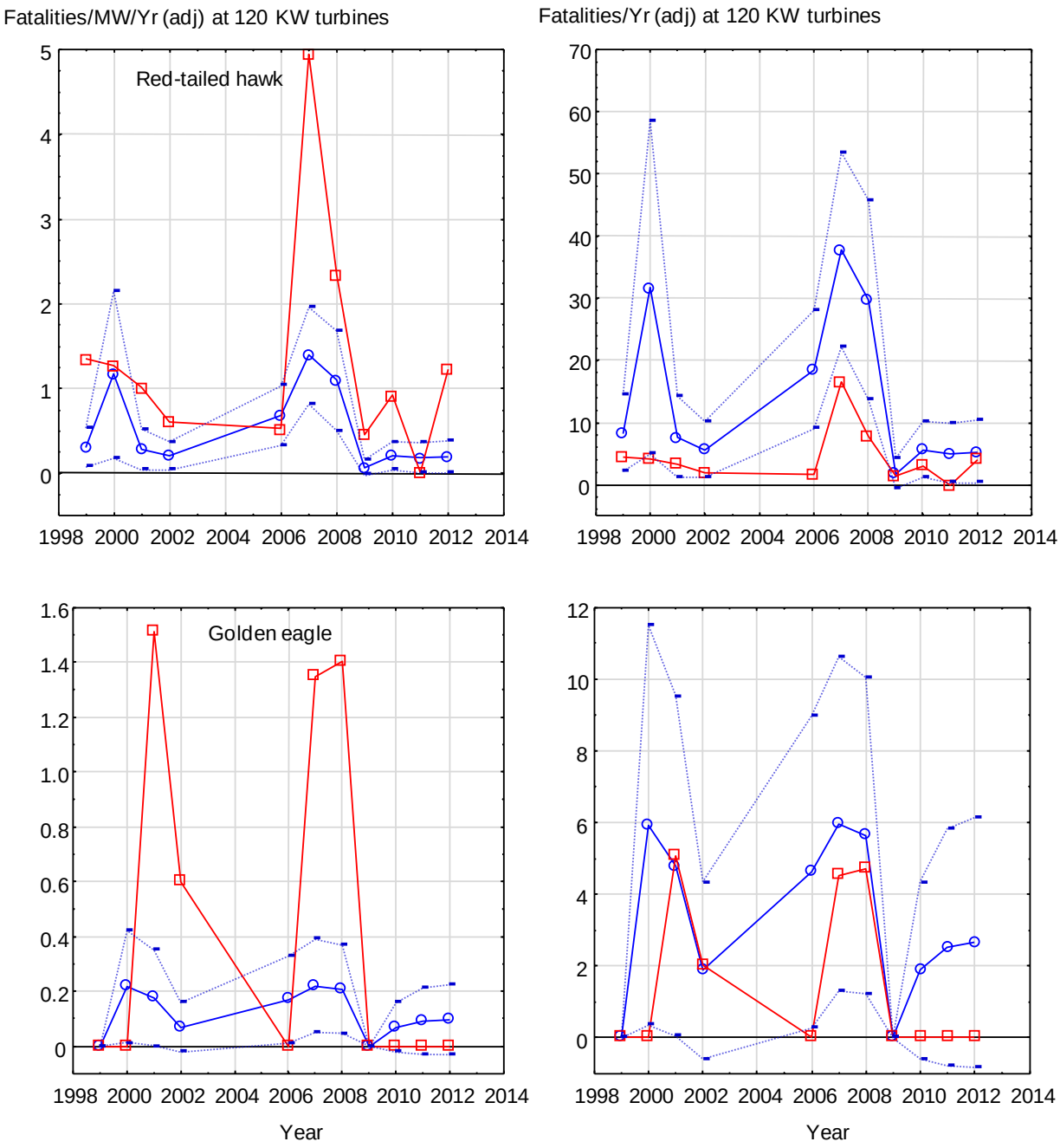

Figure A10. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 120 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

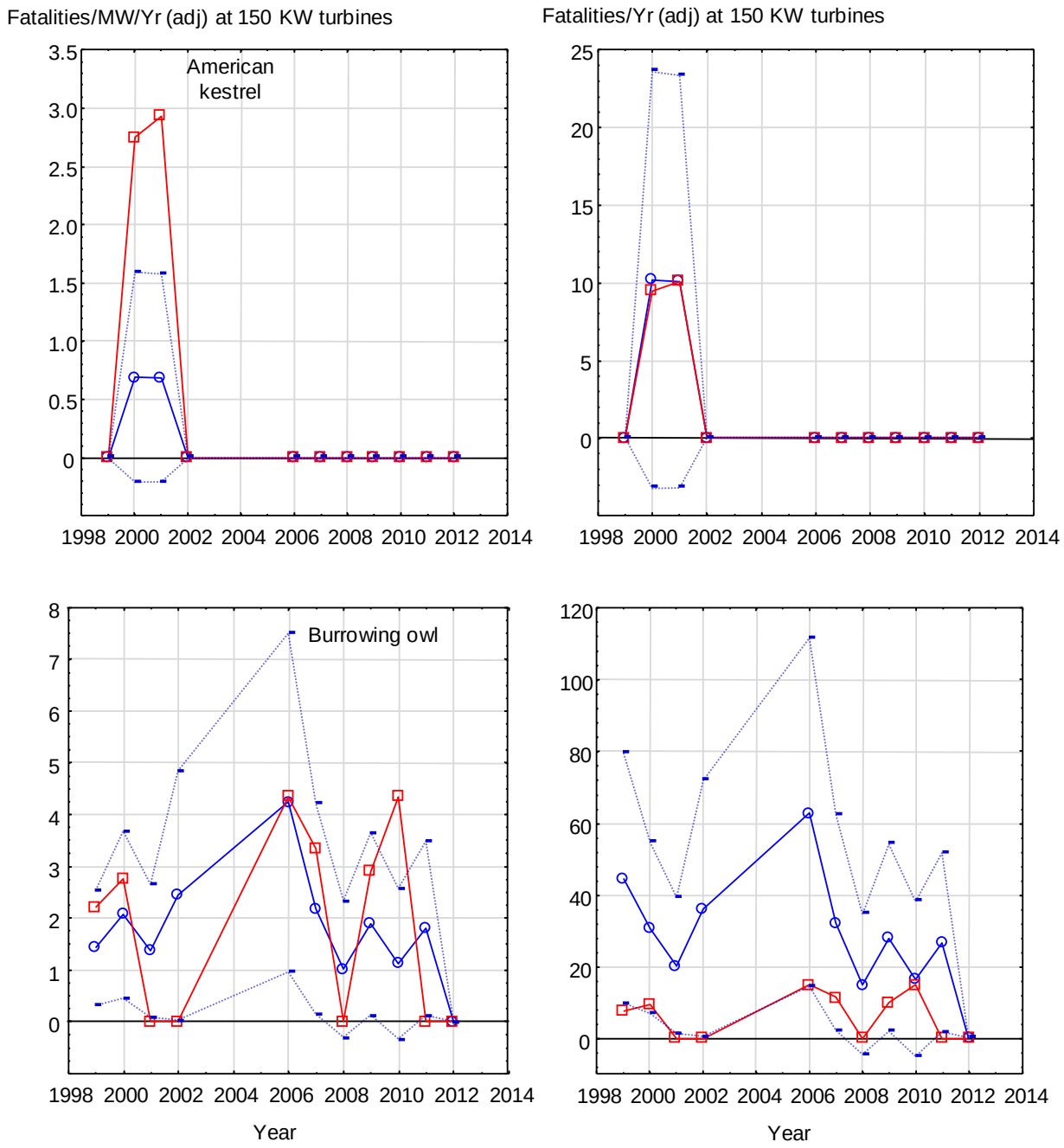

Figure A11. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 150 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

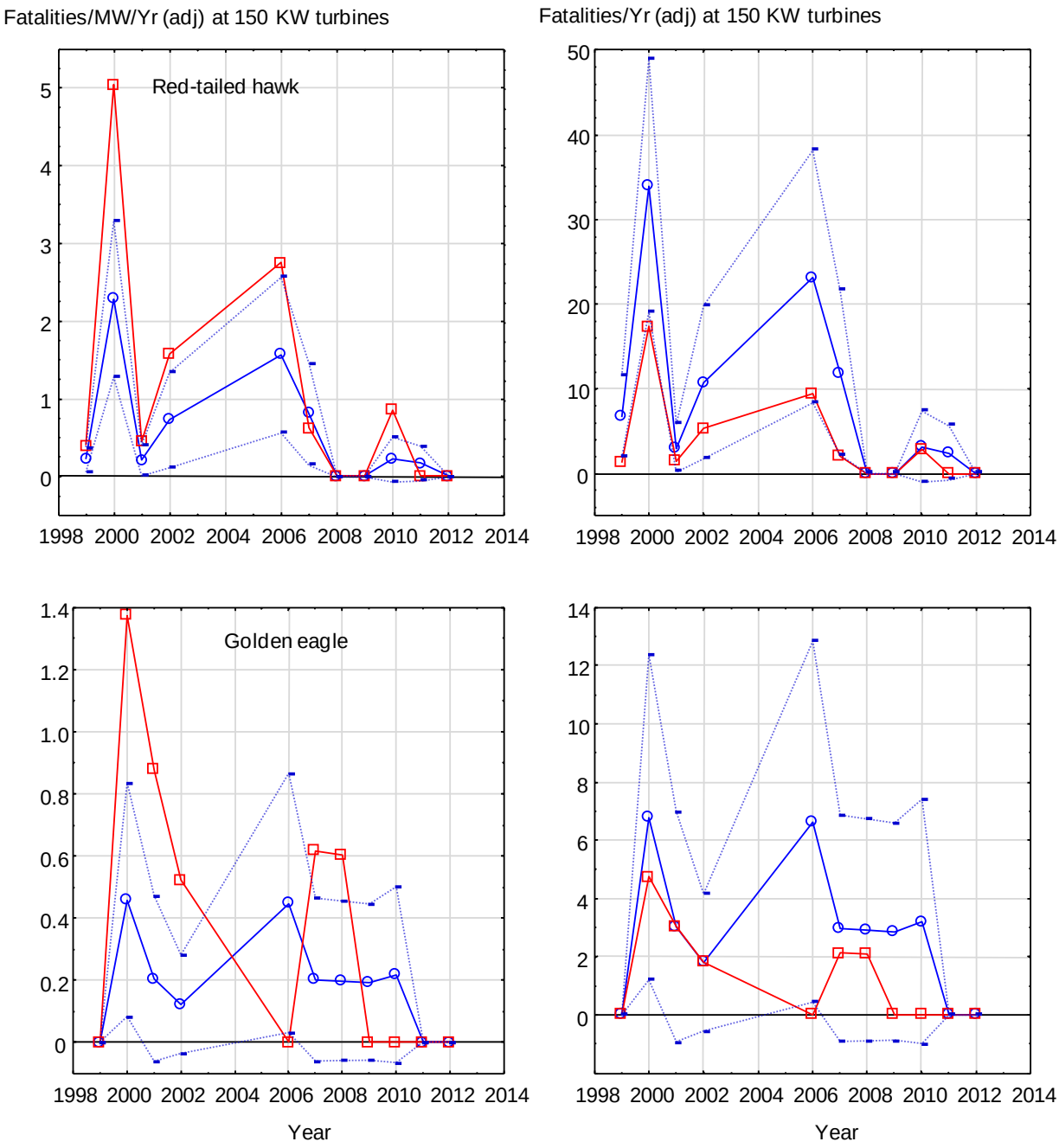

Figure A12. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 150 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

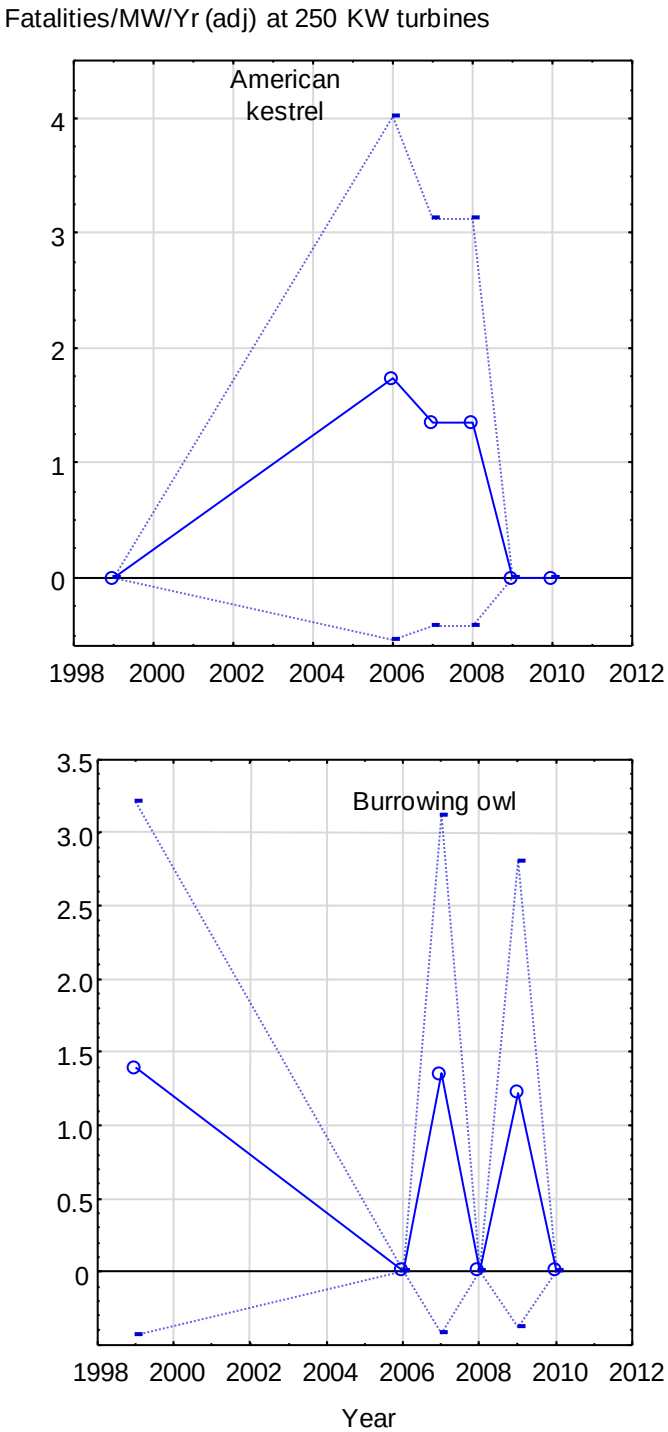

Figure A13. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 250 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

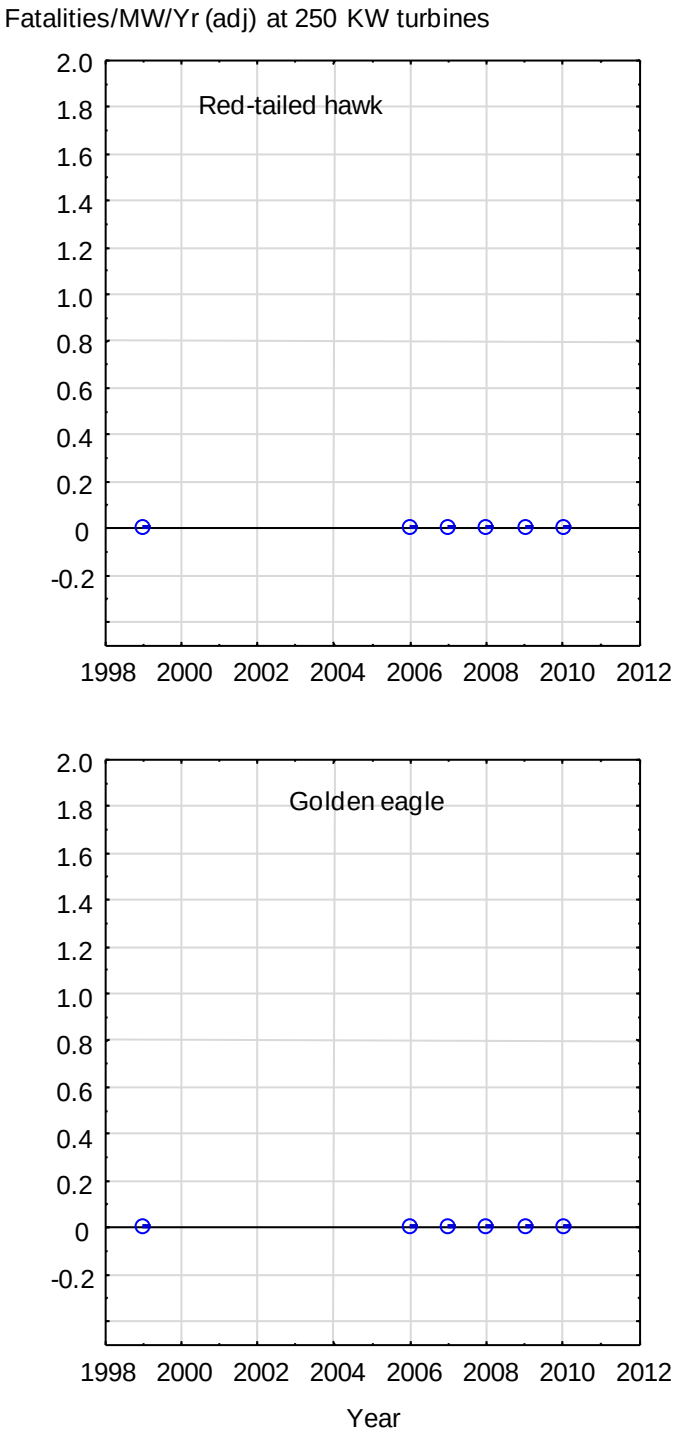

Figure A14. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 250 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

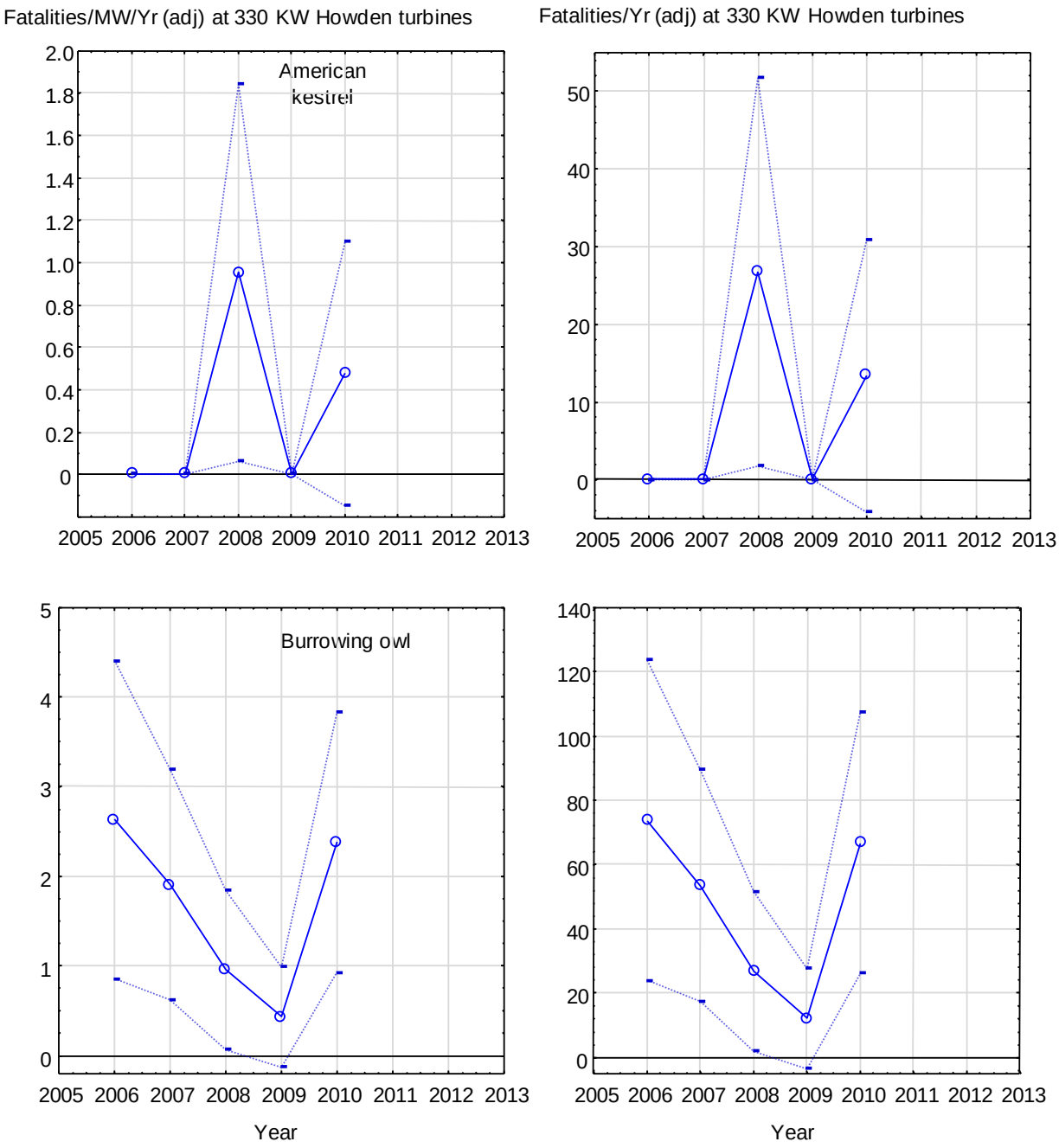

Figure A15. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 330 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

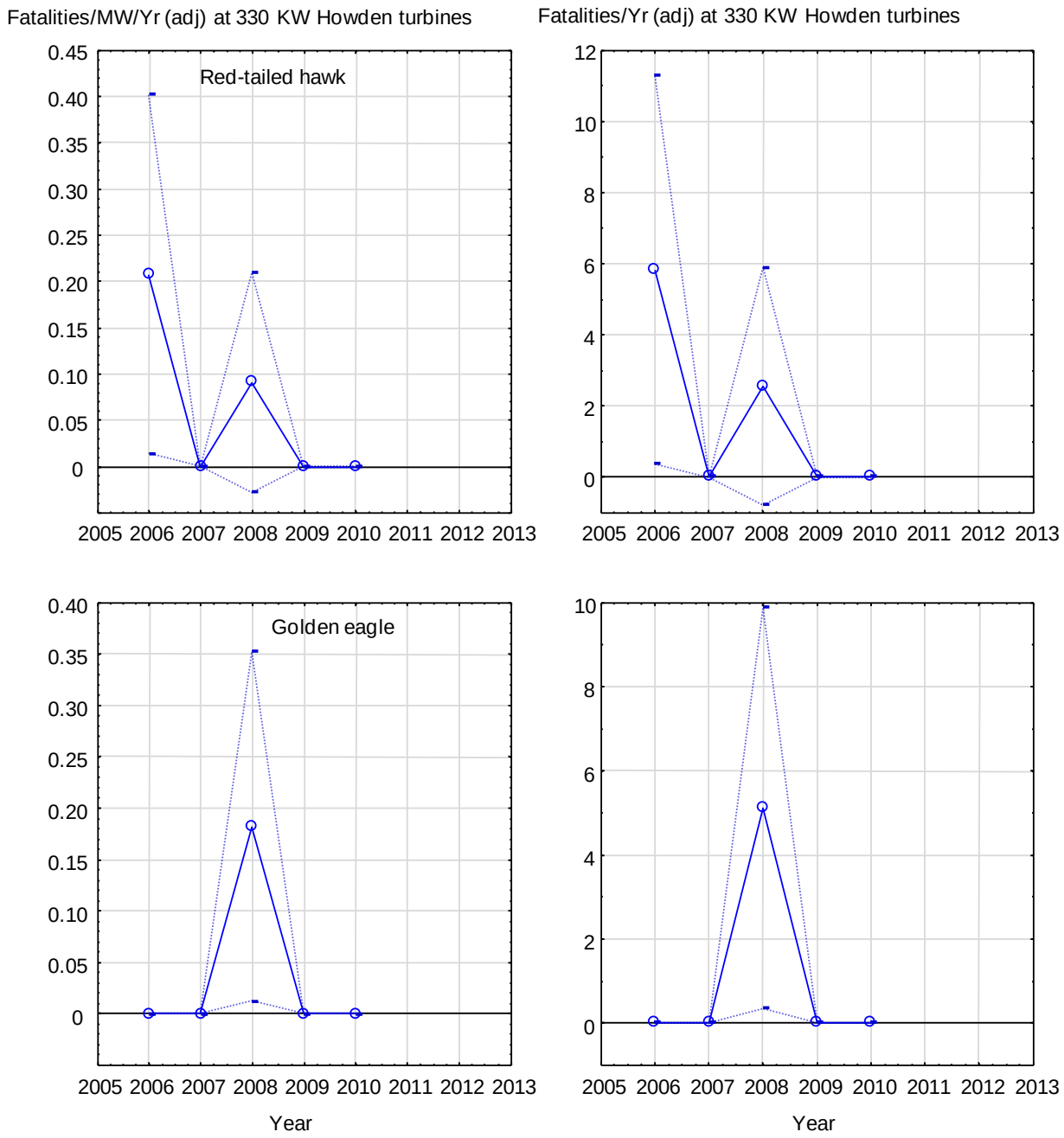

Figure A16. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 330 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

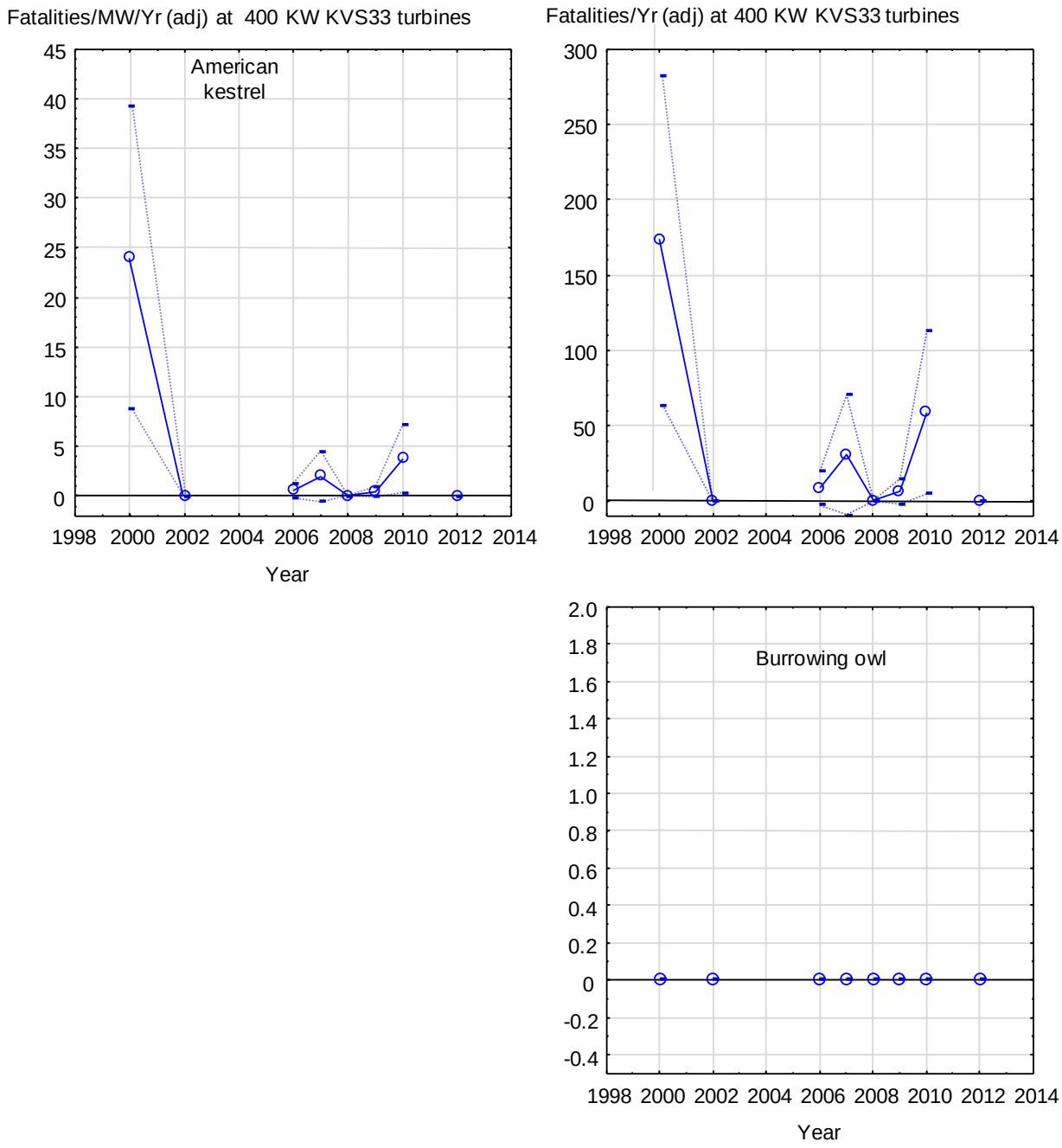

Figure A17. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 400 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

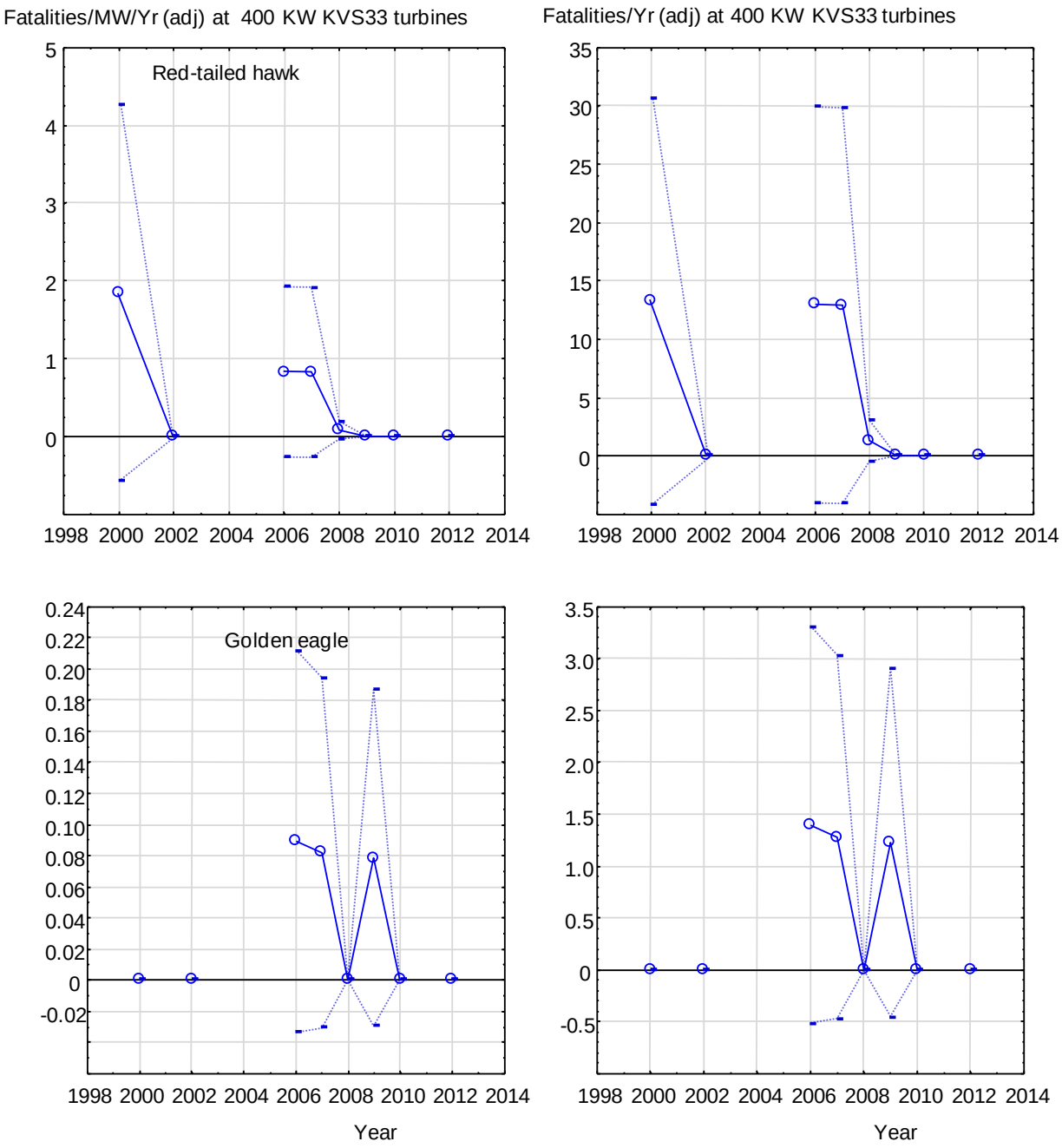

Figure A18. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 400 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

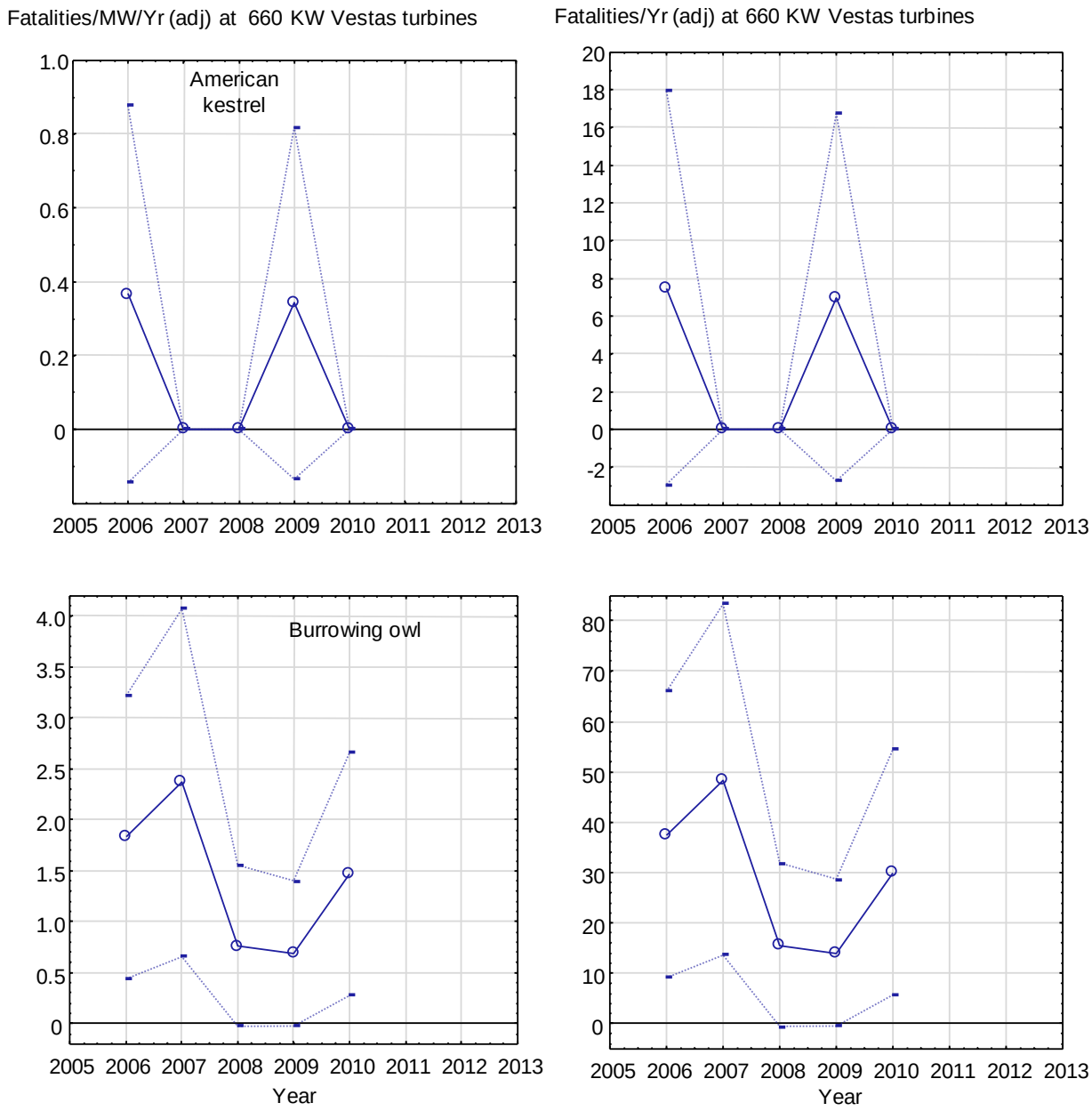

Figure A19. Estimates of fatalities per MW per year and total annual fatalities of American kestrel and burrowing owl at 660 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

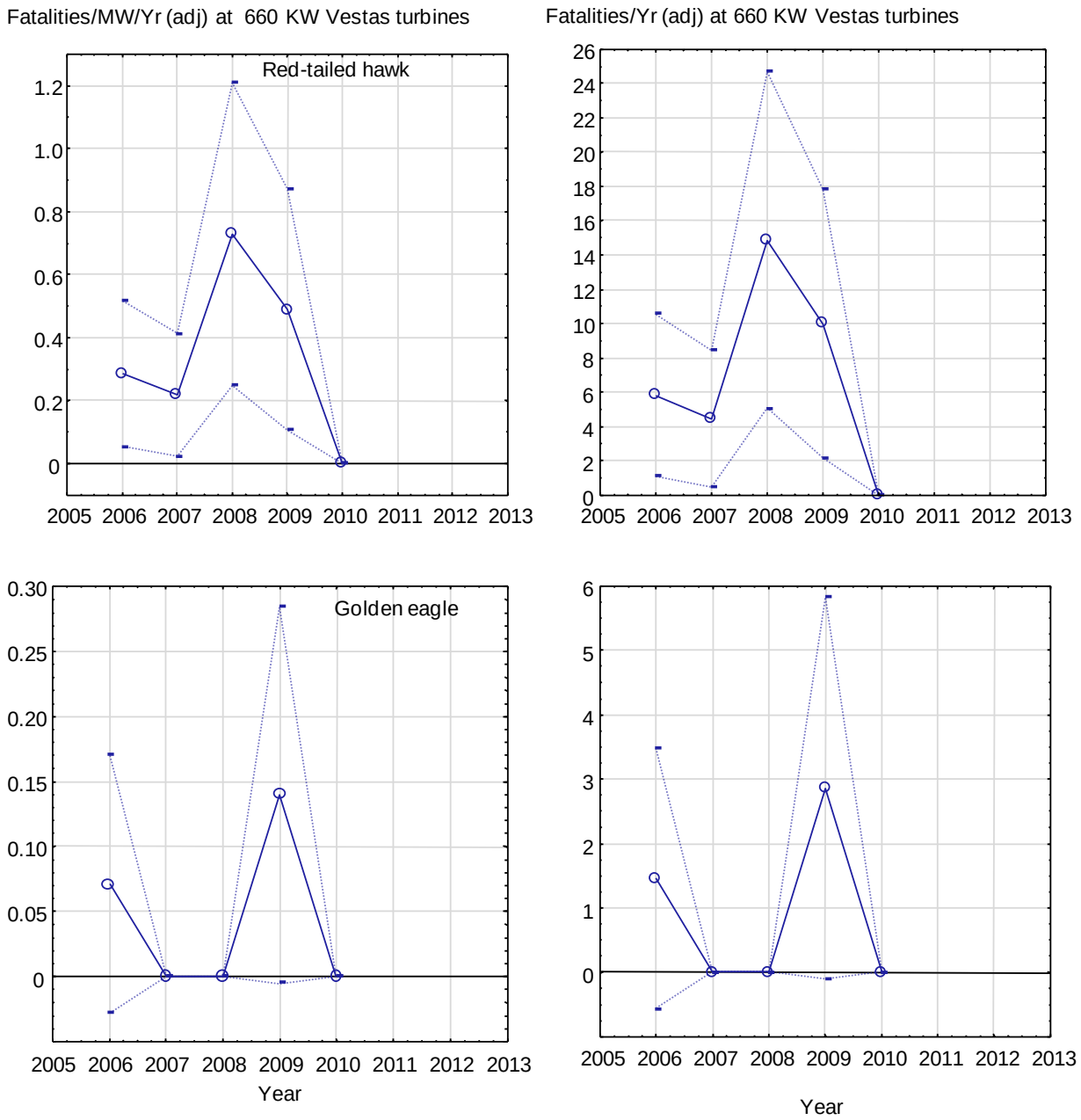

Figure A20. Estimates of fatalities per MW per year and total annual fatalities of red-tailed hawk and golden eagle at 660 KW wind turbines in the Altamont Pass WRA, where dotted lines denote 80% confidence limits and red line denotes mean fatality rates at the turbines the SRC rated 8-10 for collision hazard.

APPENDIX B: Raptor fatality rates by turbine field and turbine size

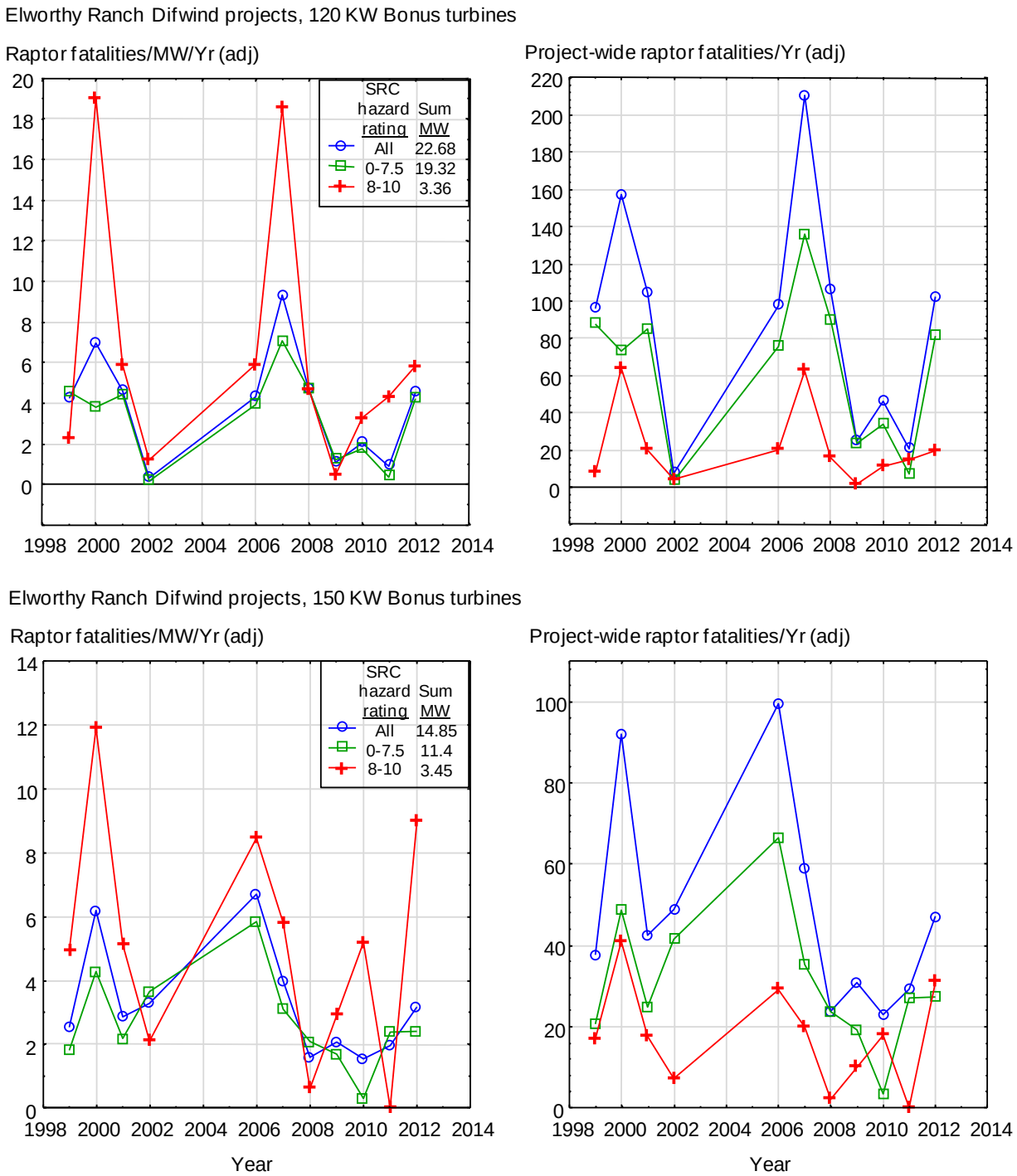

Figure B1. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the 120 KW (top) and 150 KW (bottom) Bonus turbines (Difwind projects) on the Elworthy Ranch, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

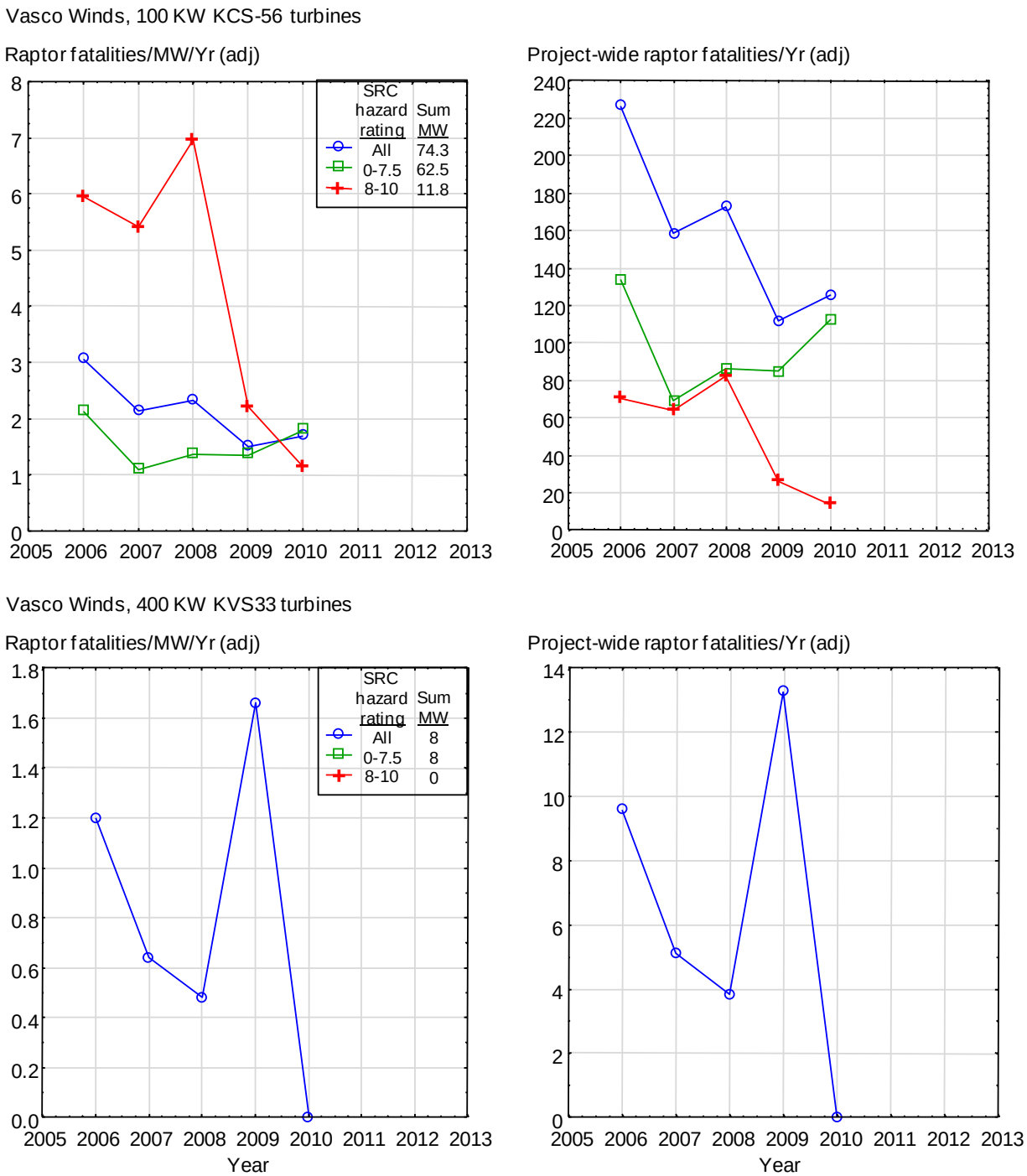

Figure B2. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the 100 KW KCS56 turbines (top) and 400 KW KVS-33 turbines (bottom) in the Vasco Winds Energy Project, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

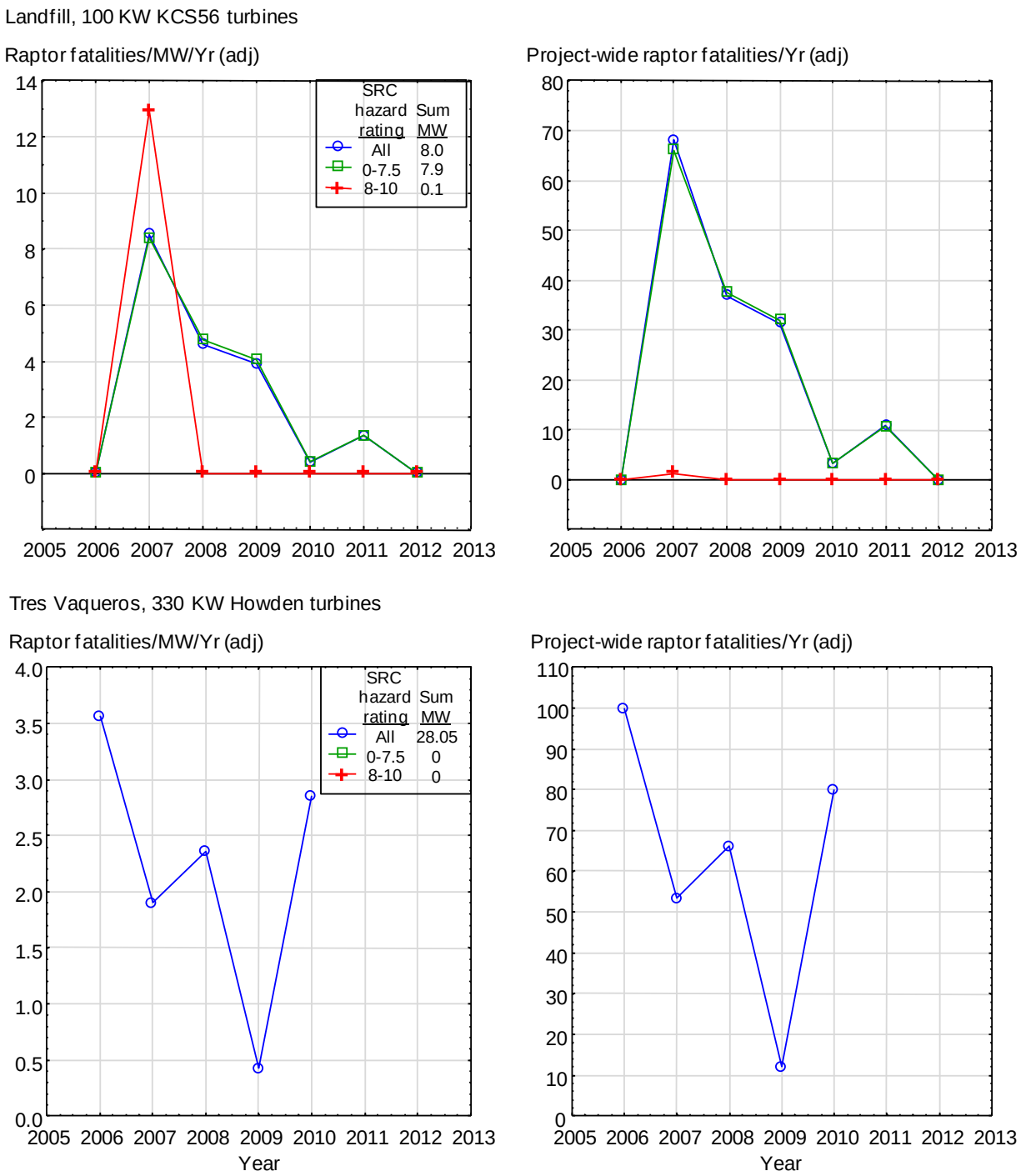

Figure B3. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the 100 KW KCS56 turbines on the Landfill property (top) and 330 KW Howden turbines in the Tres Vaqueros project (bottom), Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

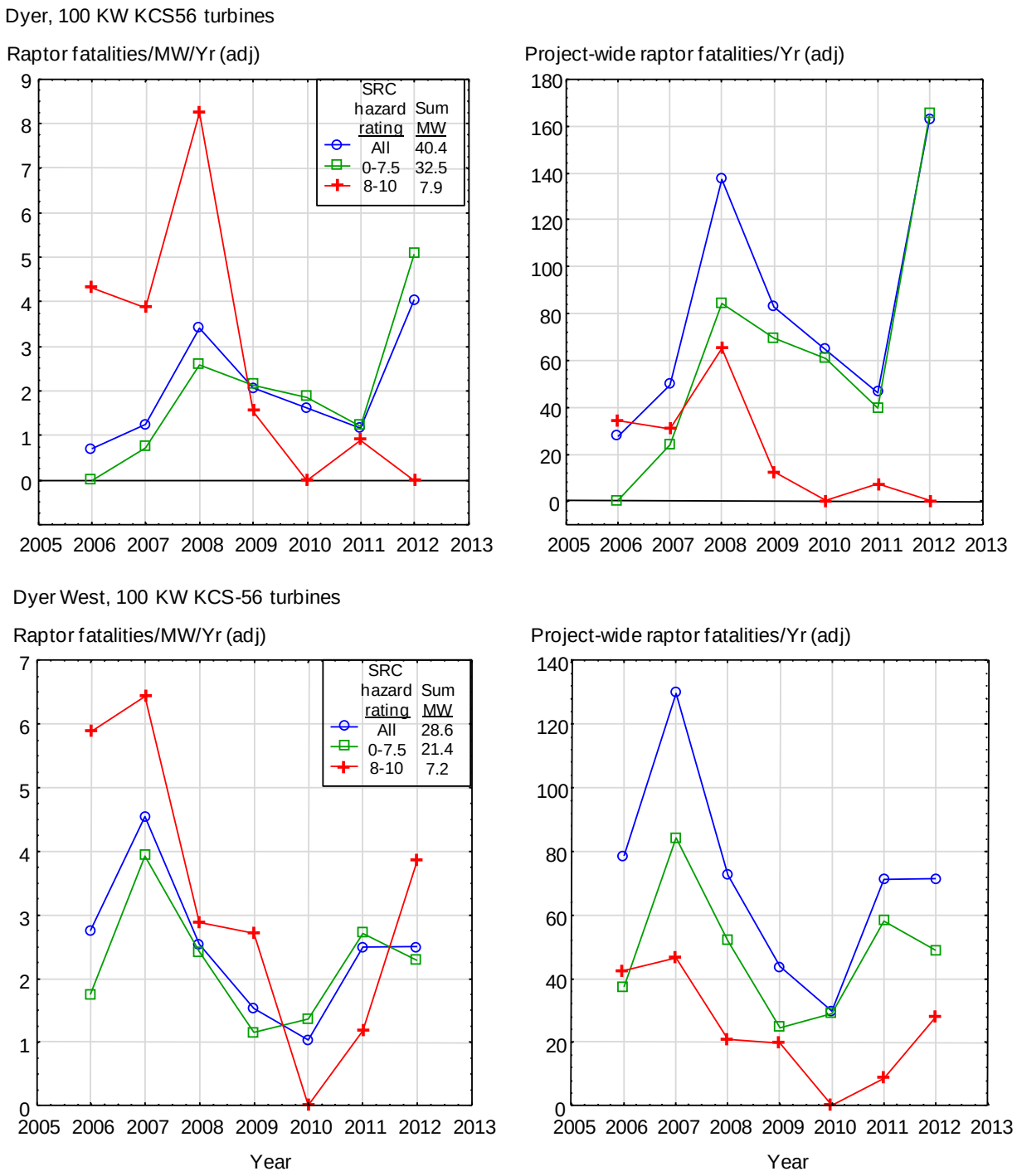

Figure B4. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the KCS56-100 KW turbines in the Dyer area (top) and west of Dyer Road (bottom), Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

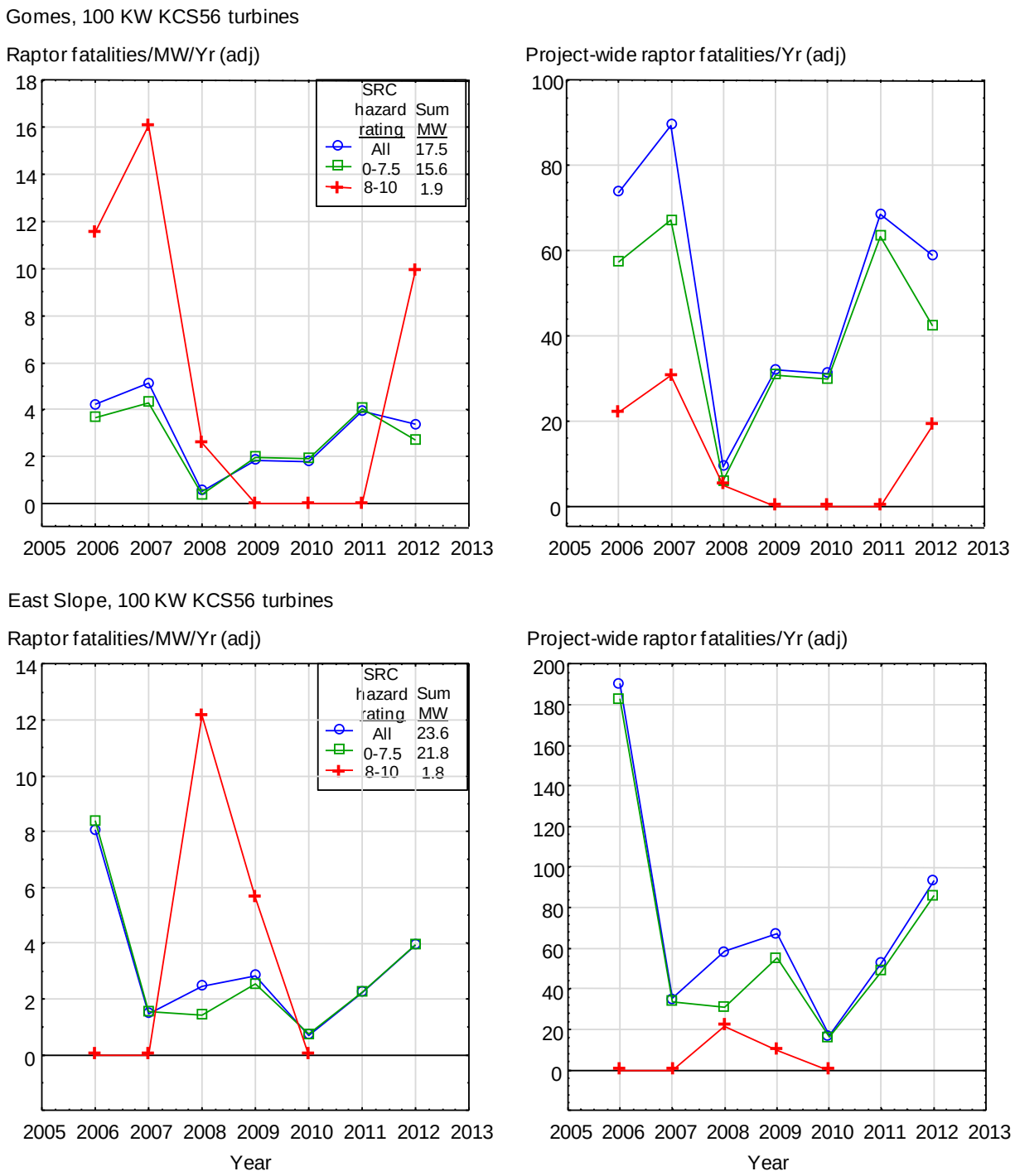

Figure B5. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the KCS56-100 KW turbines on Gomes Ranch (top) and on the East Slope (bottom), Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

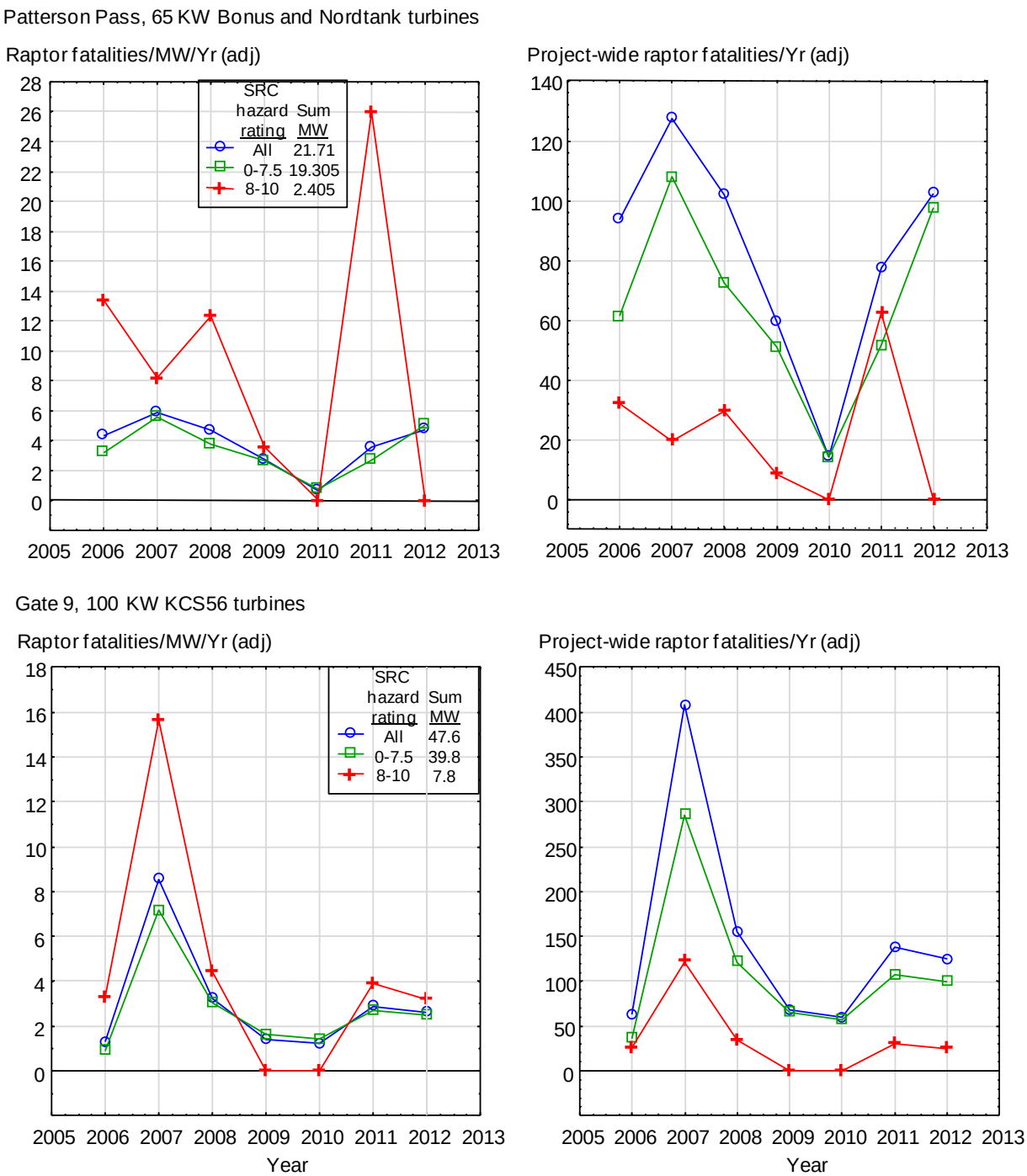

Figure B6. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the 65 KW Nordtank turbines in the Patterson Pass Wind Energy Project (top) and the KCS56-100 KW turbines south of Gate 9 (bottom), Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

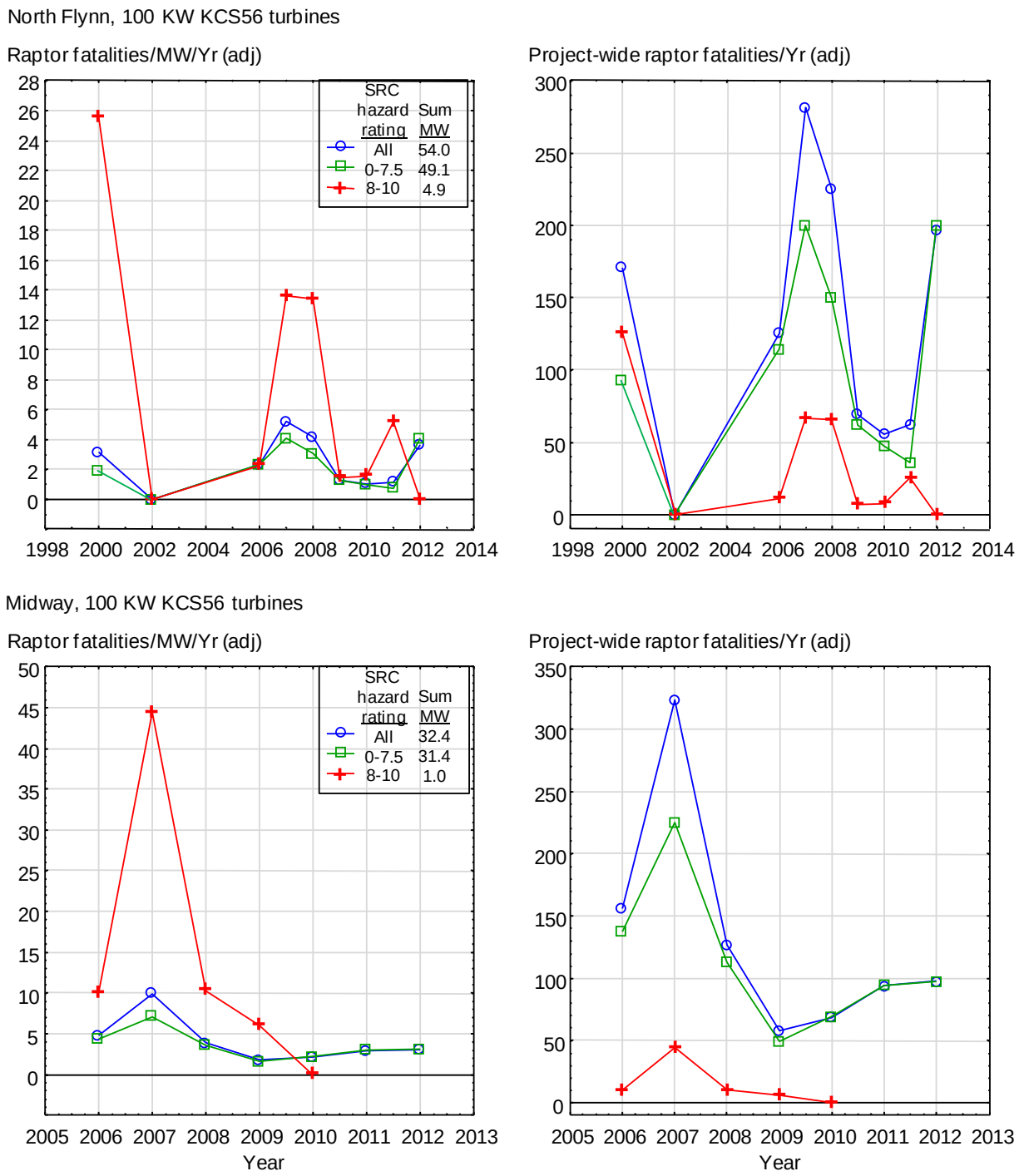

Figure B7. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the KCS56-100 KW turbines in the North Flynn (top) and Midway (bottom) areas, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

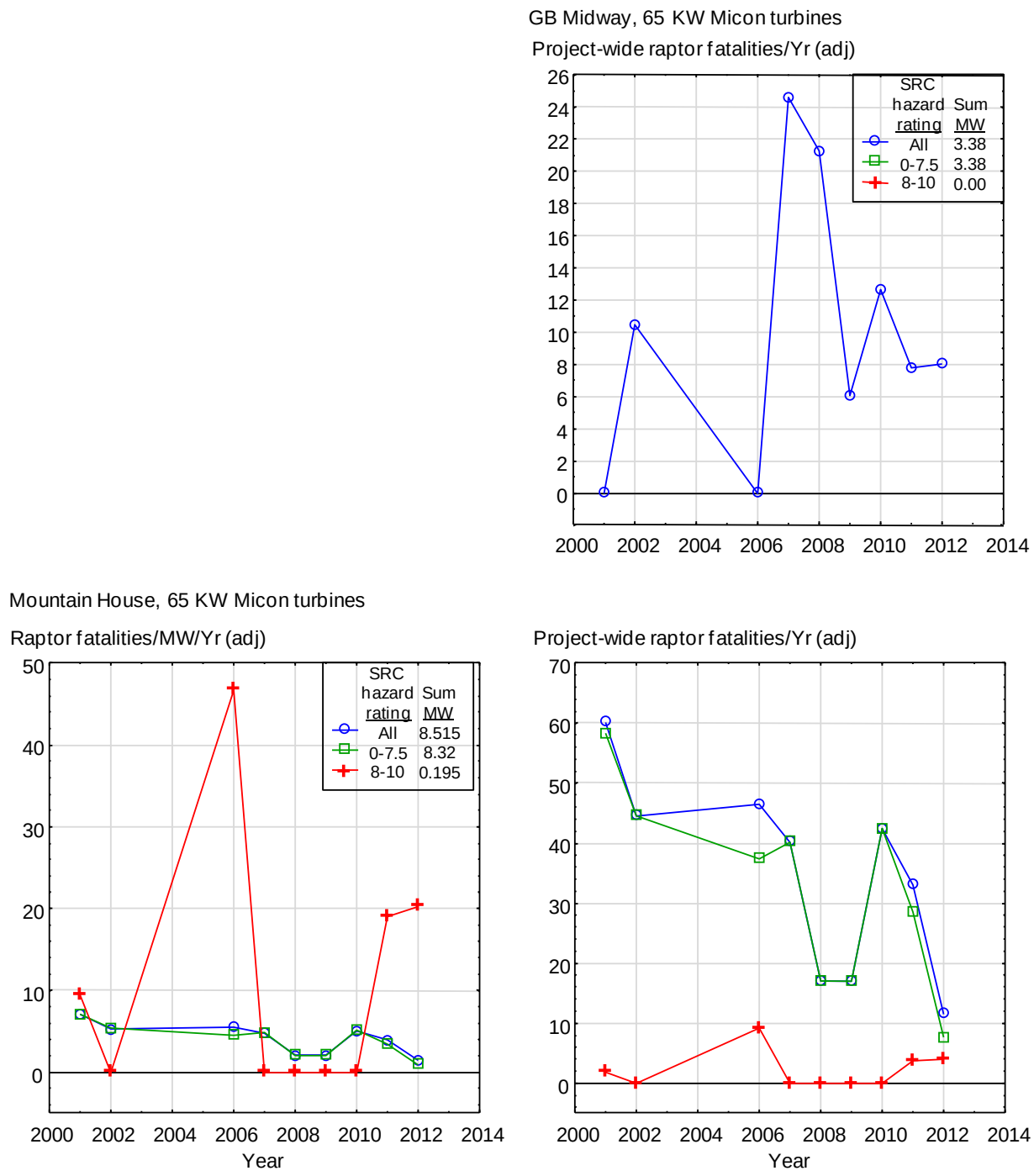

Figure B8. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the 65 KW Micon turbines at Forebay's GB Midway site (top) and Mountain House site (bottom), Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

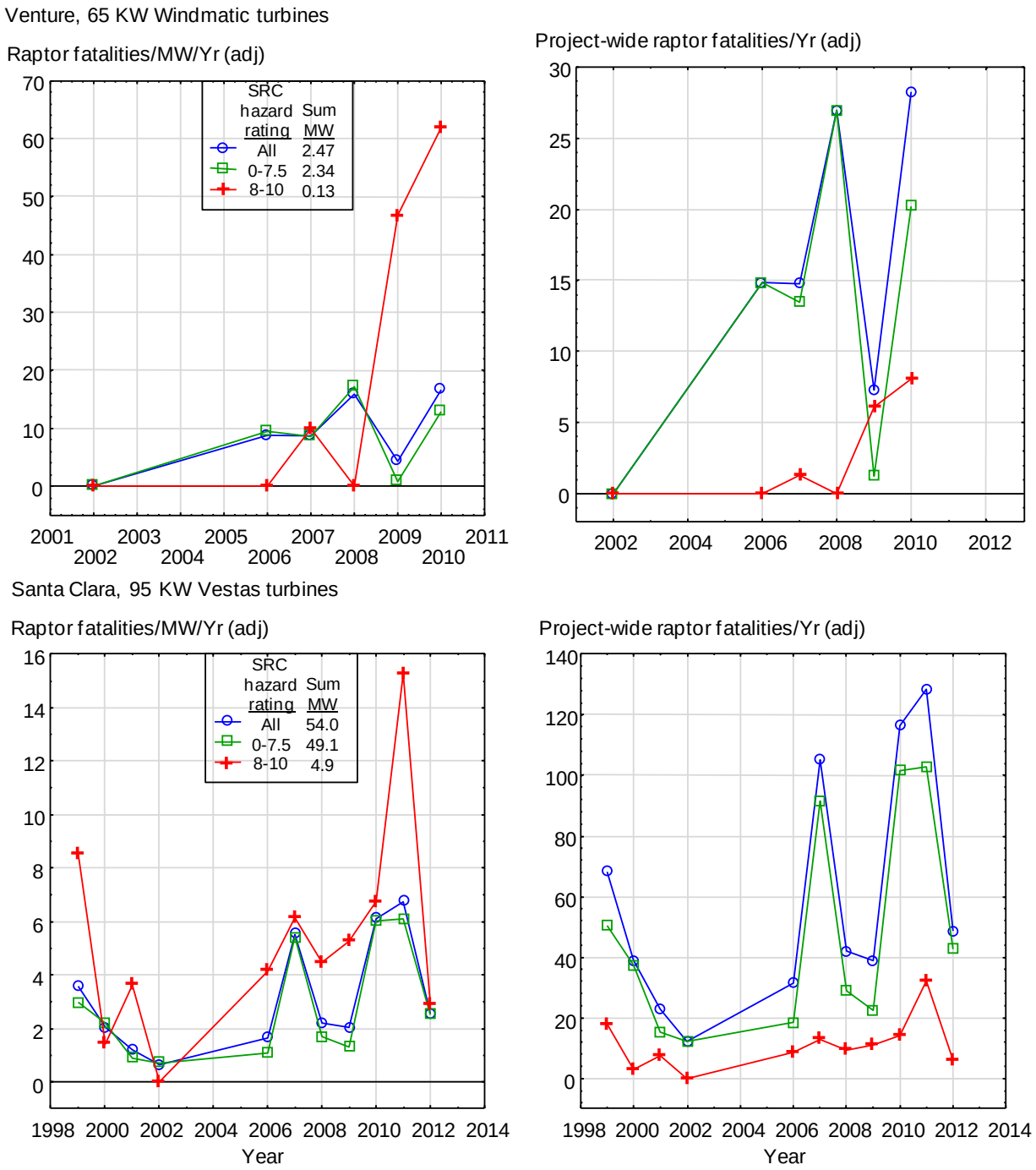

Figure B9. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the 65 KW Windmatic turbines at Forebay's Venture site (top) and the 95 KW Vestas turbines in the Santa Clara site (bottom), Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

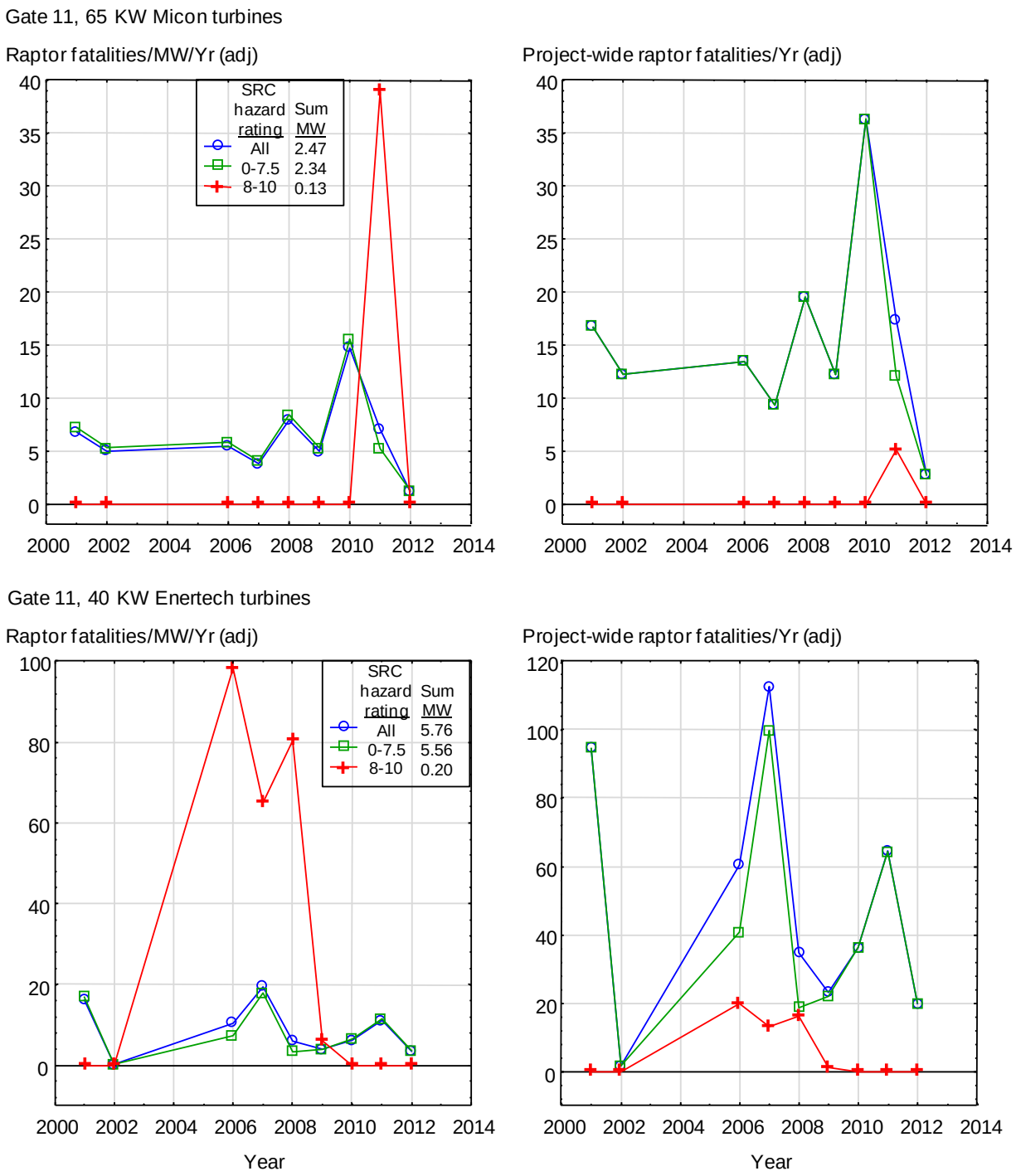

Figure B10. Estimates of raptor fatalities per MW per year and total annual raptor fatalities at the 65 KW Micon turbines in Forebay's Viking project (top) and 40 KW Enertech turbines in the Altech project (bottom), Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

Appendix C: Target species fatality rates by turbine field and turbine size

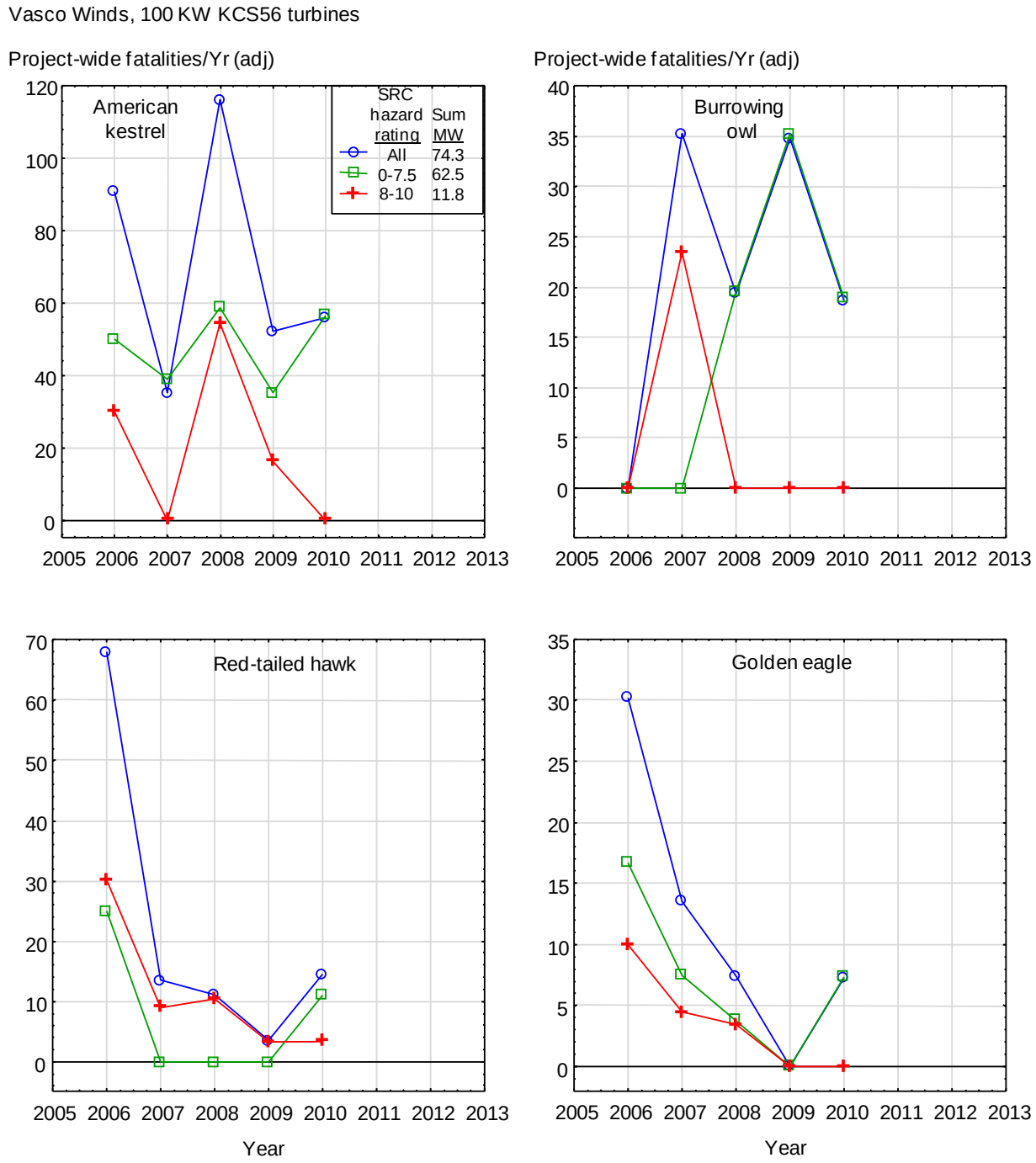

Figure C1. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS56-100 KW turbines in the Vasco Winds project, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

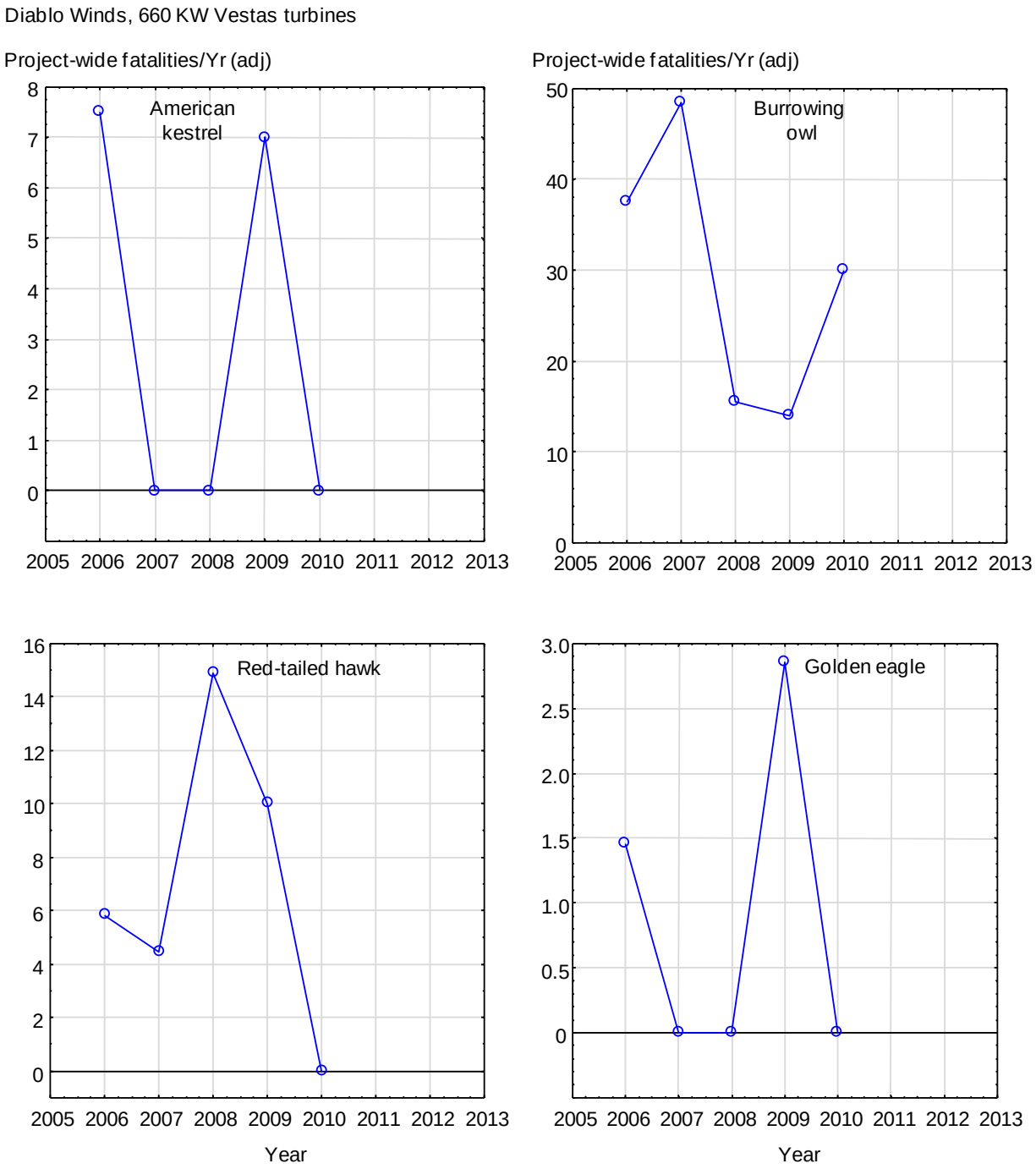

Figure C2. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at Vestas 660 KW turbines in the Diablo Winds project, Altamont Pass WRA.

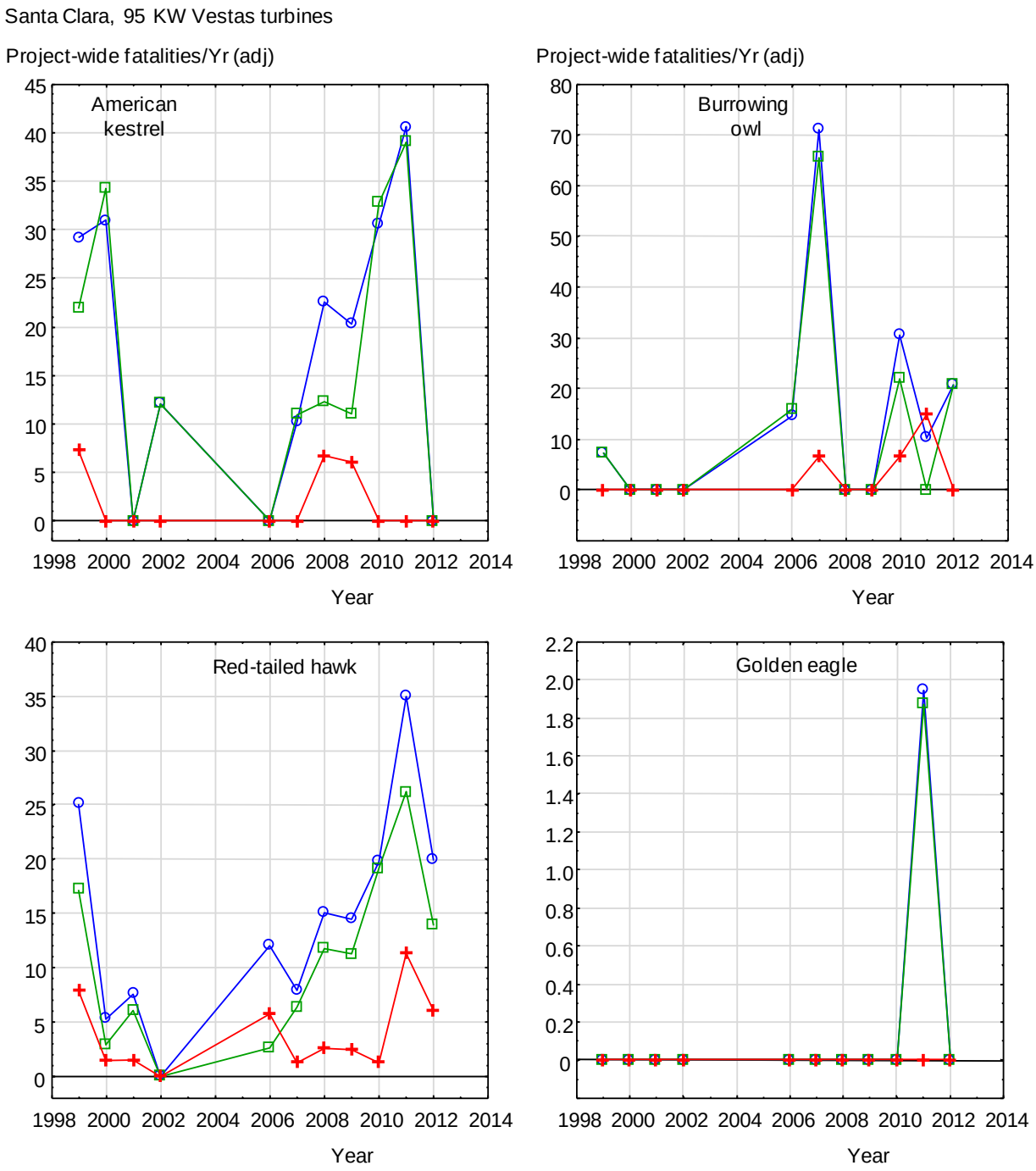

Figure C3. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at Vestas 95 KW turbines at the Santa Clara site, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

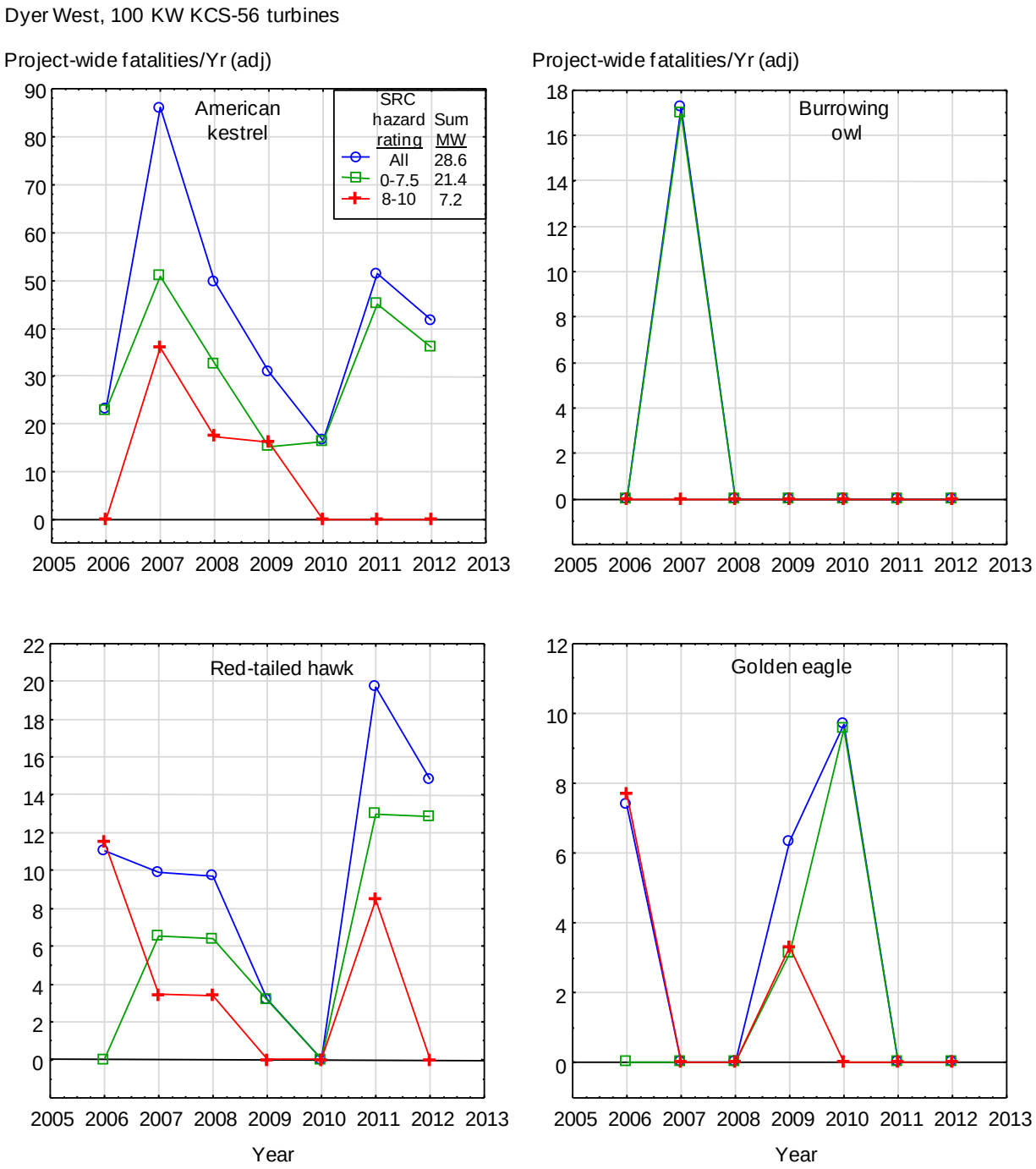

Figure C4. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS56-100 KW turbines west of Dyer Road, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

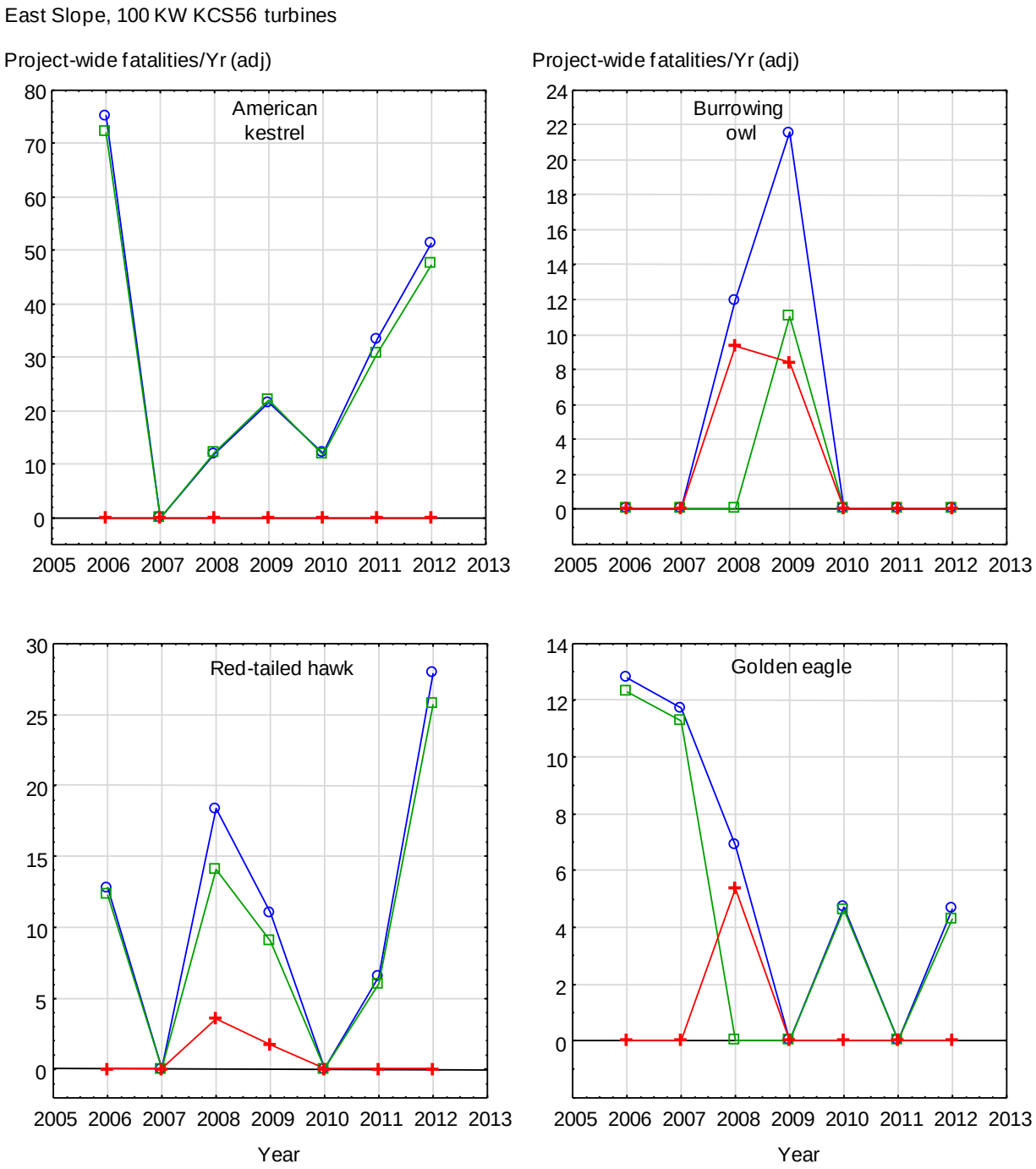

Figure C5. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS56-100 KW turbines on the East slope, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

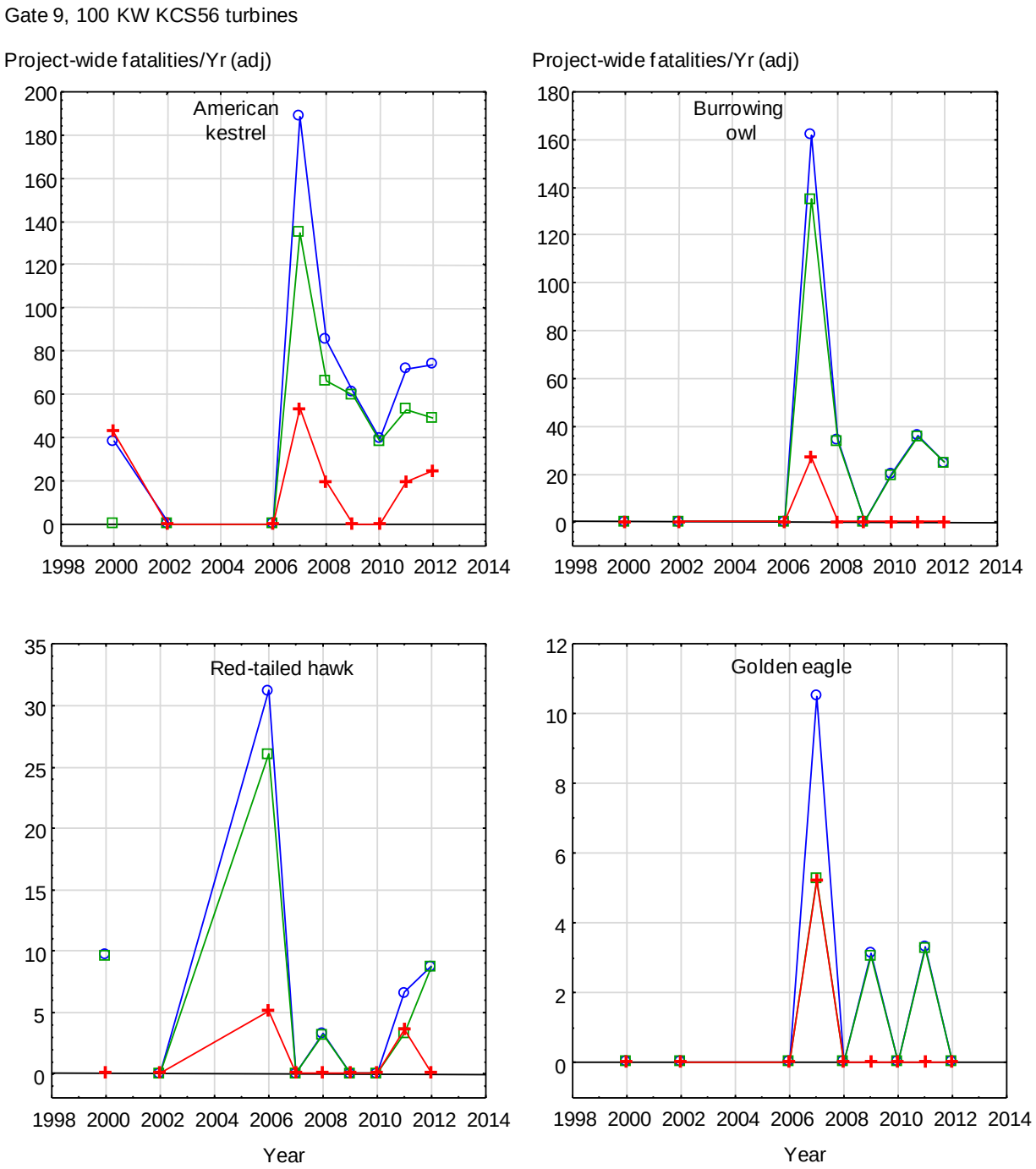

Figure C6. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS56-100 KW turbines south of Gate 9, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

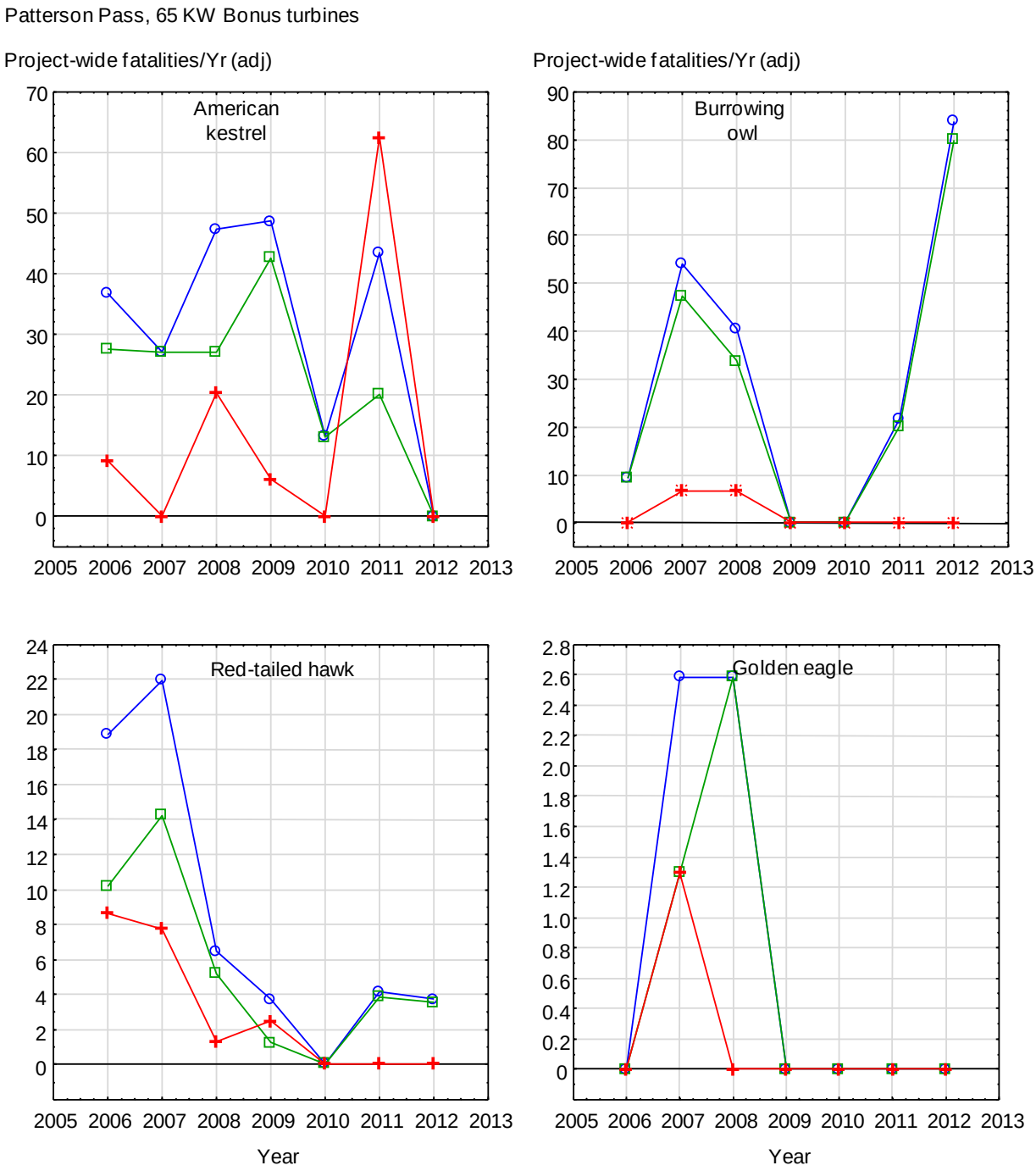

Figure C7. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 65 KW Nordtank turbines in the Patterson Pass project, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

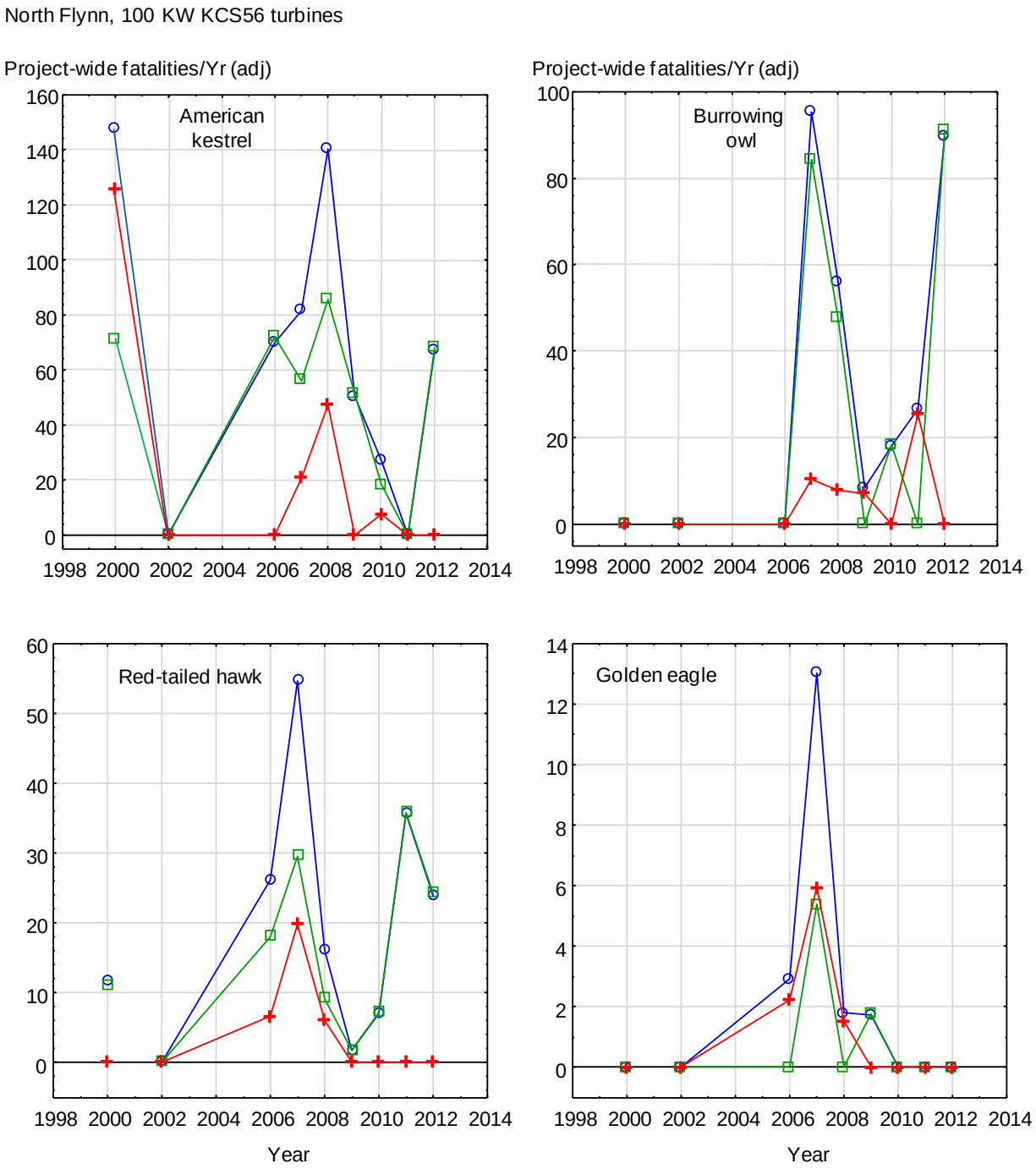

Figure C8. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS56-100 KW turbines at North Flynn, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

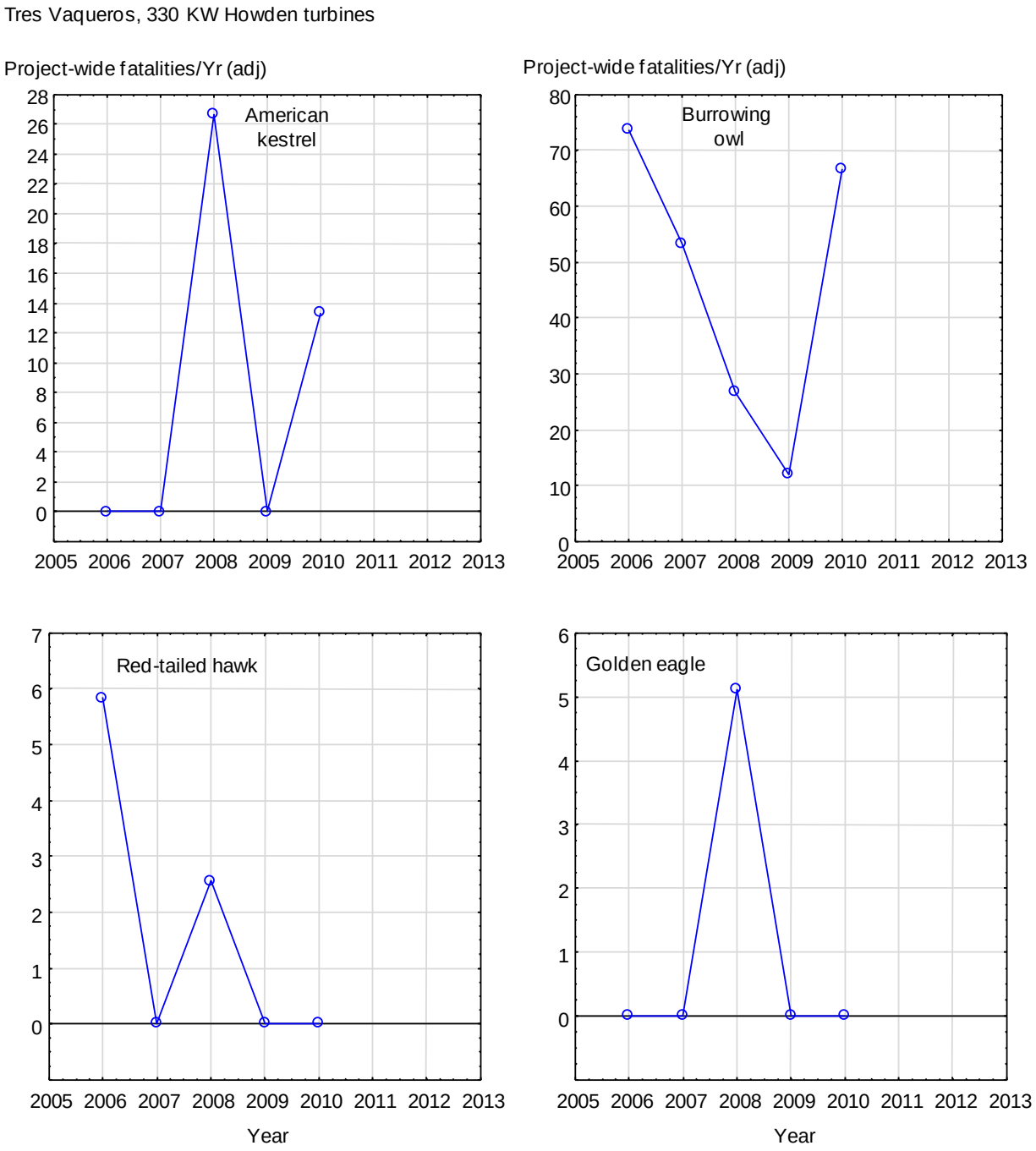

Figure C9. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at Howden 330 KW turbines in the Tres Vaqueros project, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

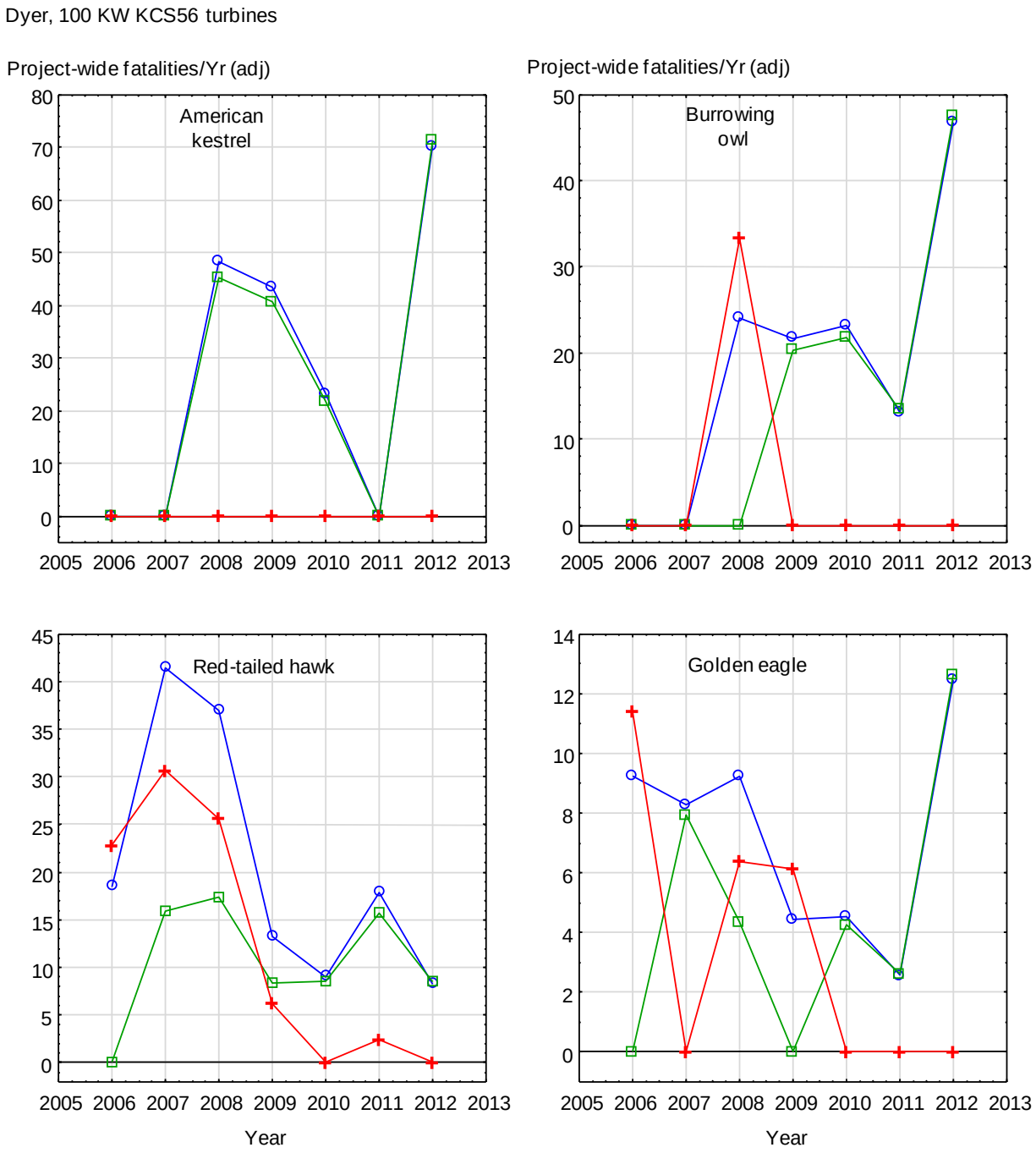

Figure C10. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS56-100 KW turbines north and east of Dyer Road, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

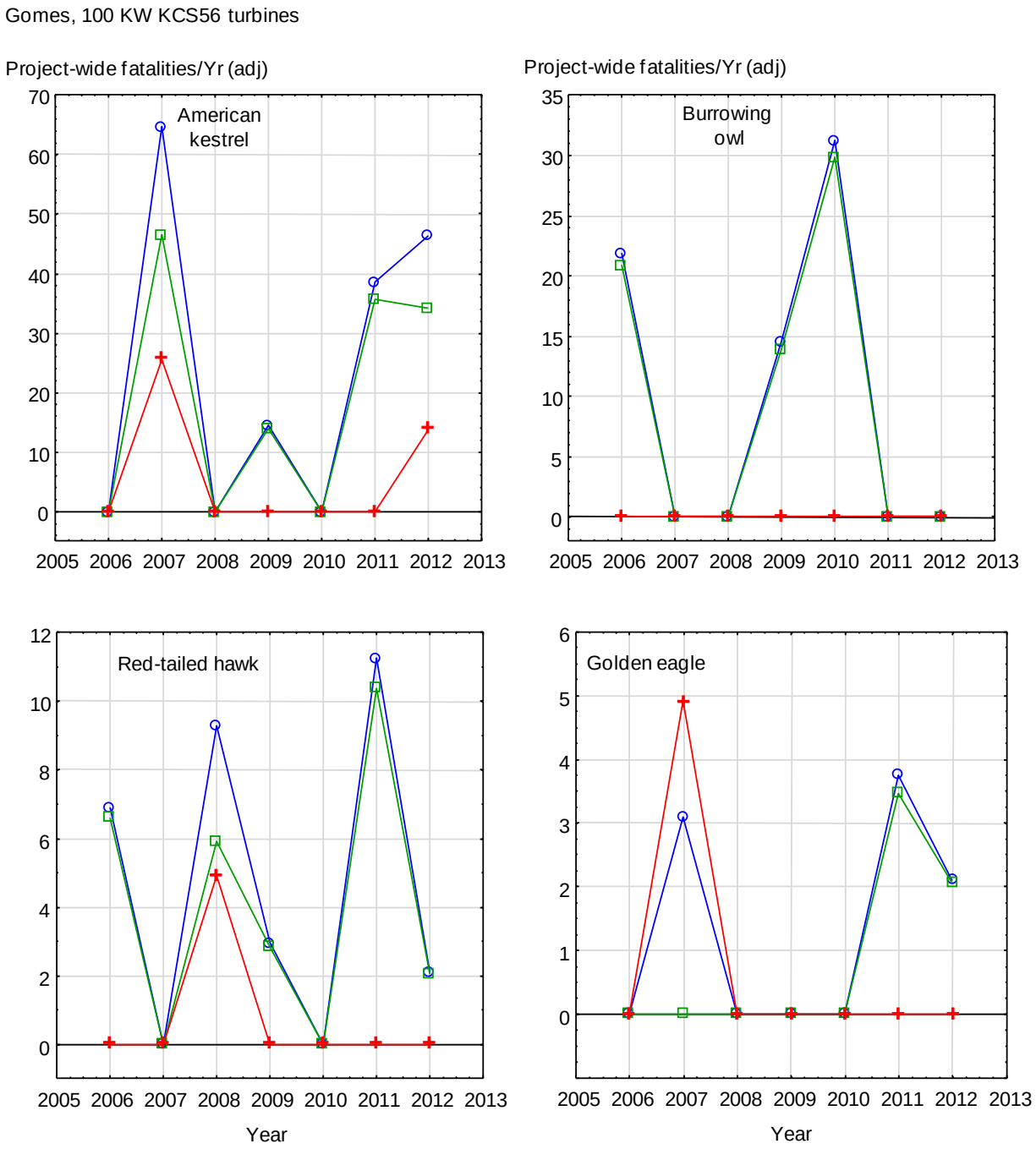

Figure C11. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS56-100 KW turbines on Gomes Ranch, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

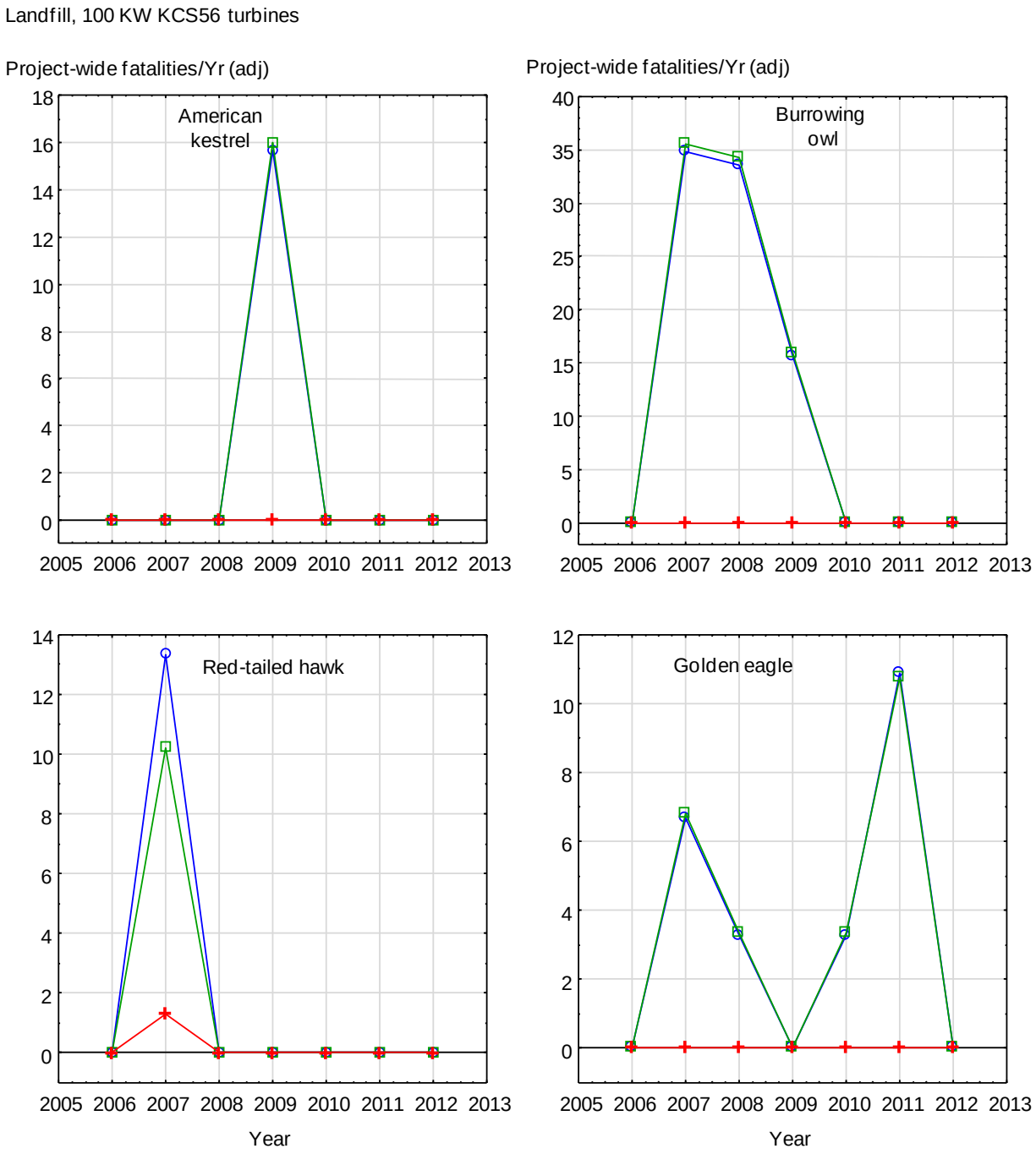

Figure C12. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS56-100 KW turbines on the Landfill property, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

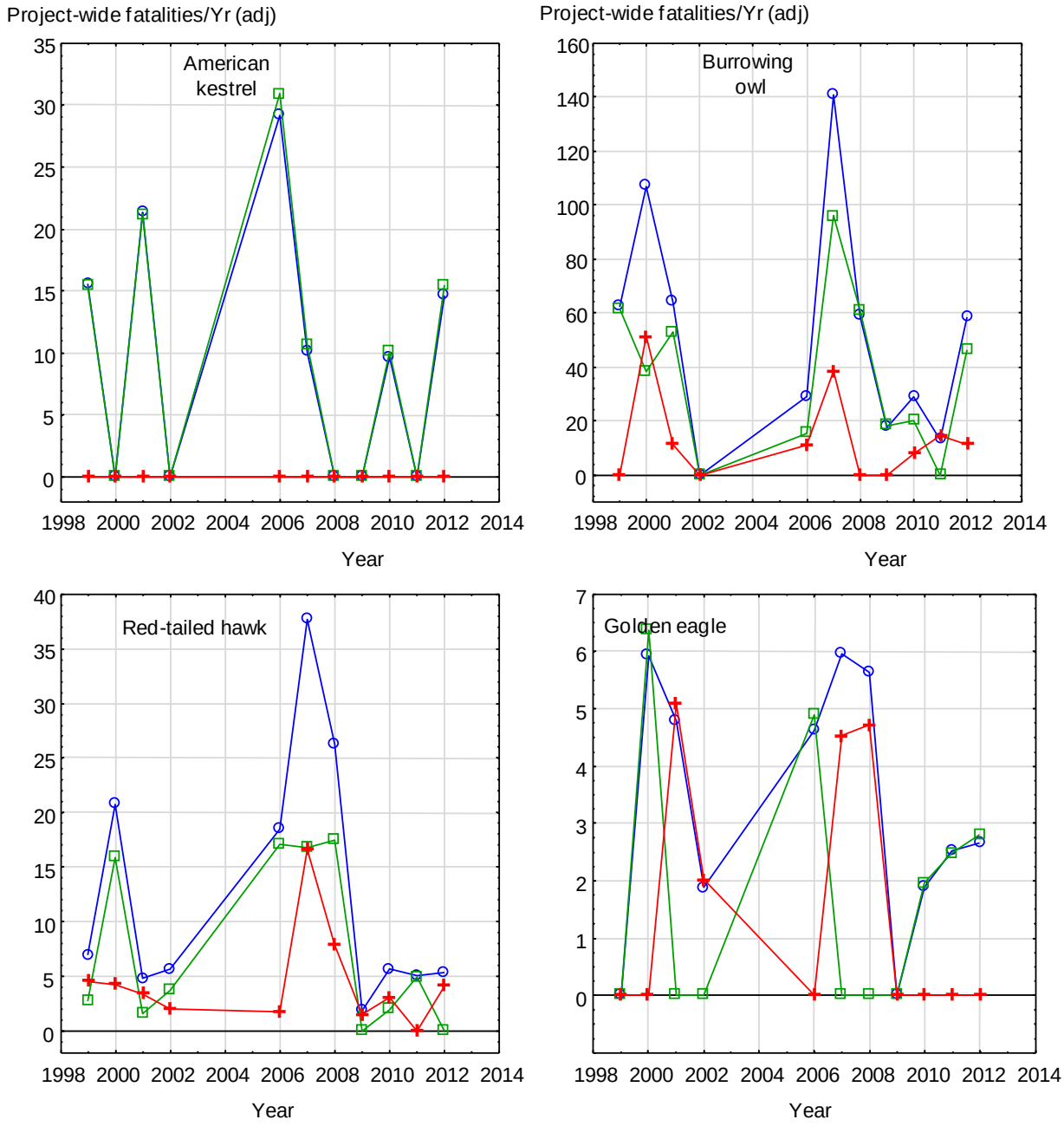

Figure C13. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 120 KW Bonus turbines on Elworthy Ranch, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

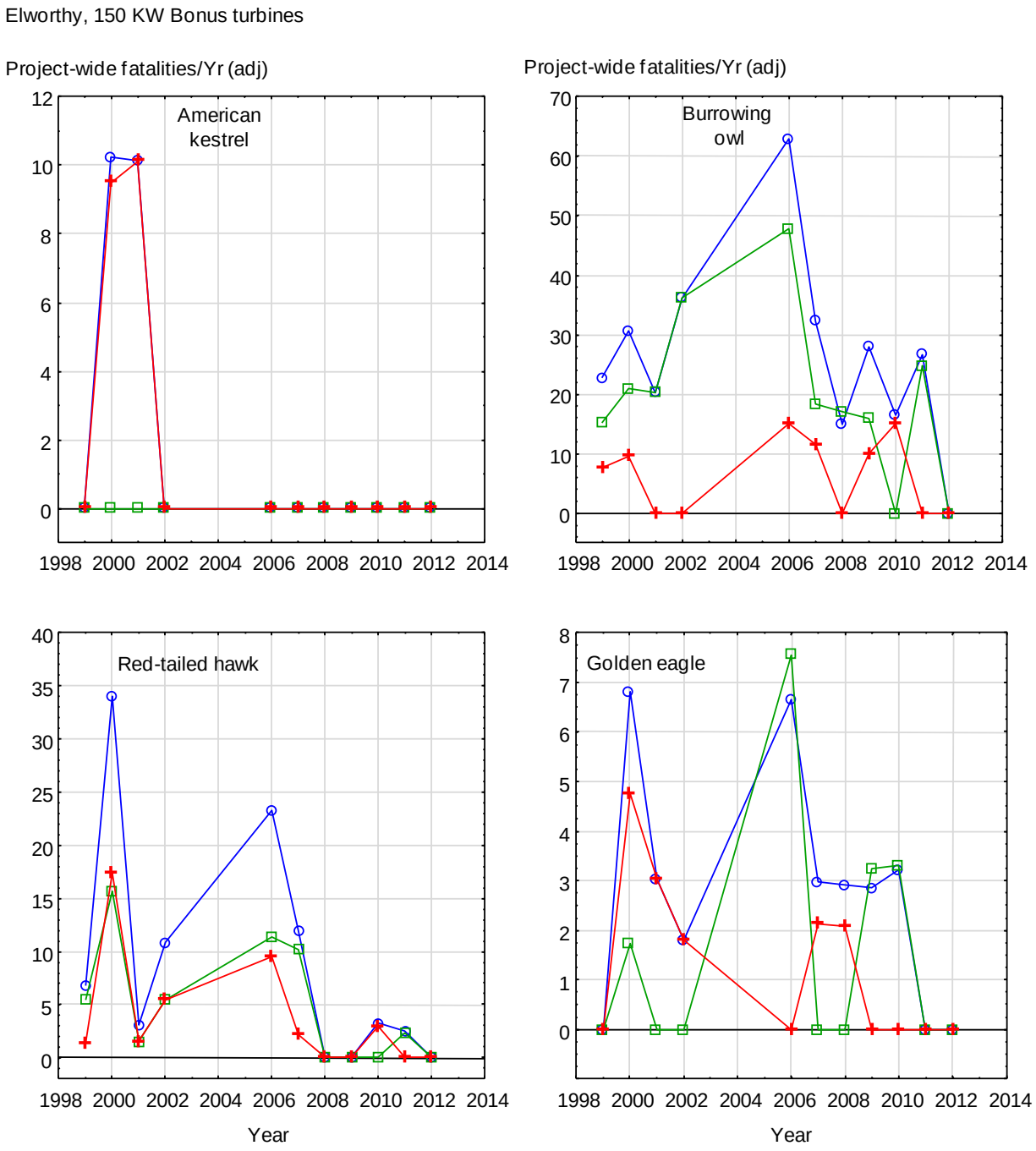

Figure C14. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 150 KW Bonus turbines on Elworthy Ranch, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

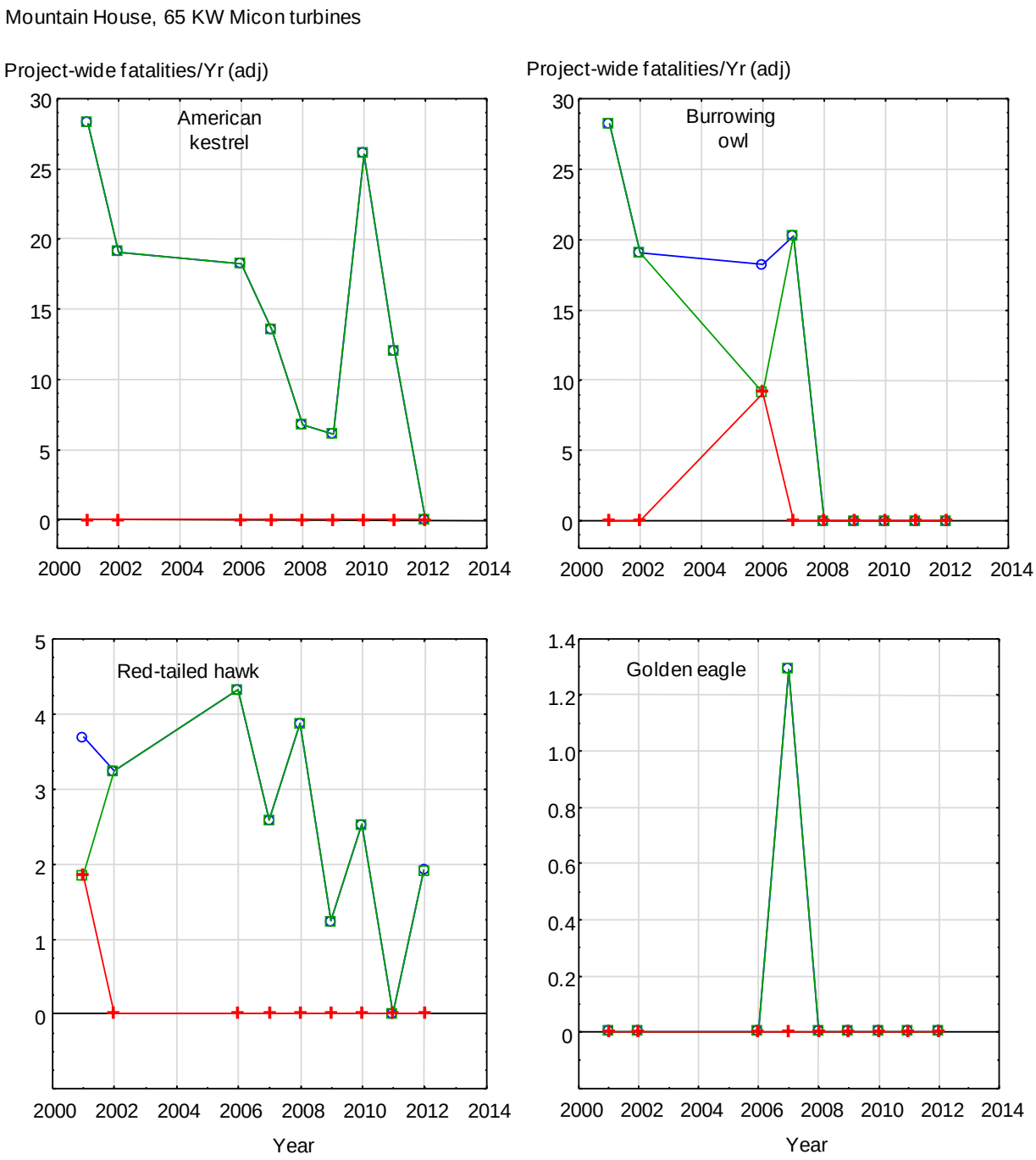

Figure C15. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 65 KW Micon turbines on Forebay's Mountain House site, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

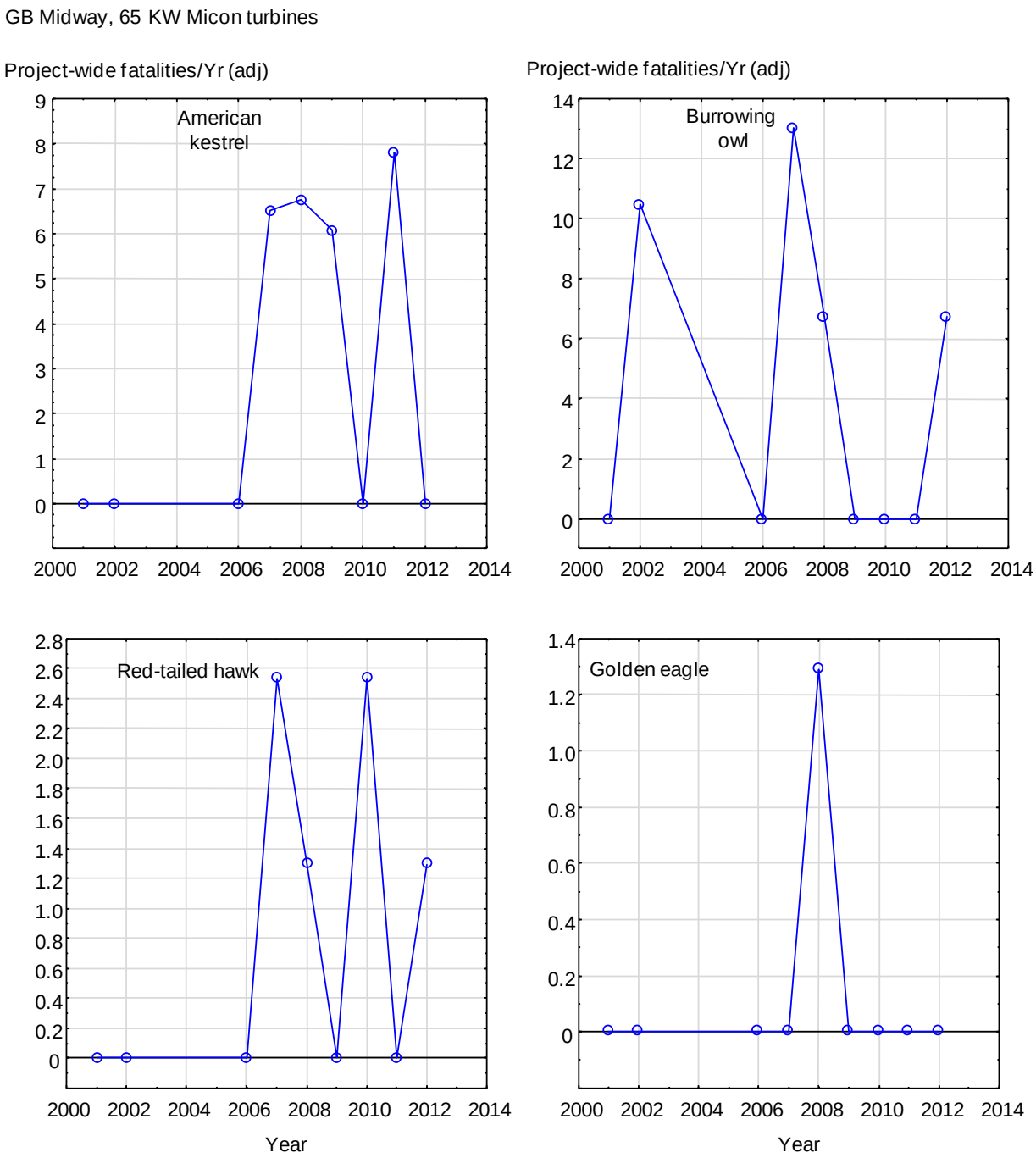

Figure C16. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 65 KW Micon turbines on Forebay's GB Midway site, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

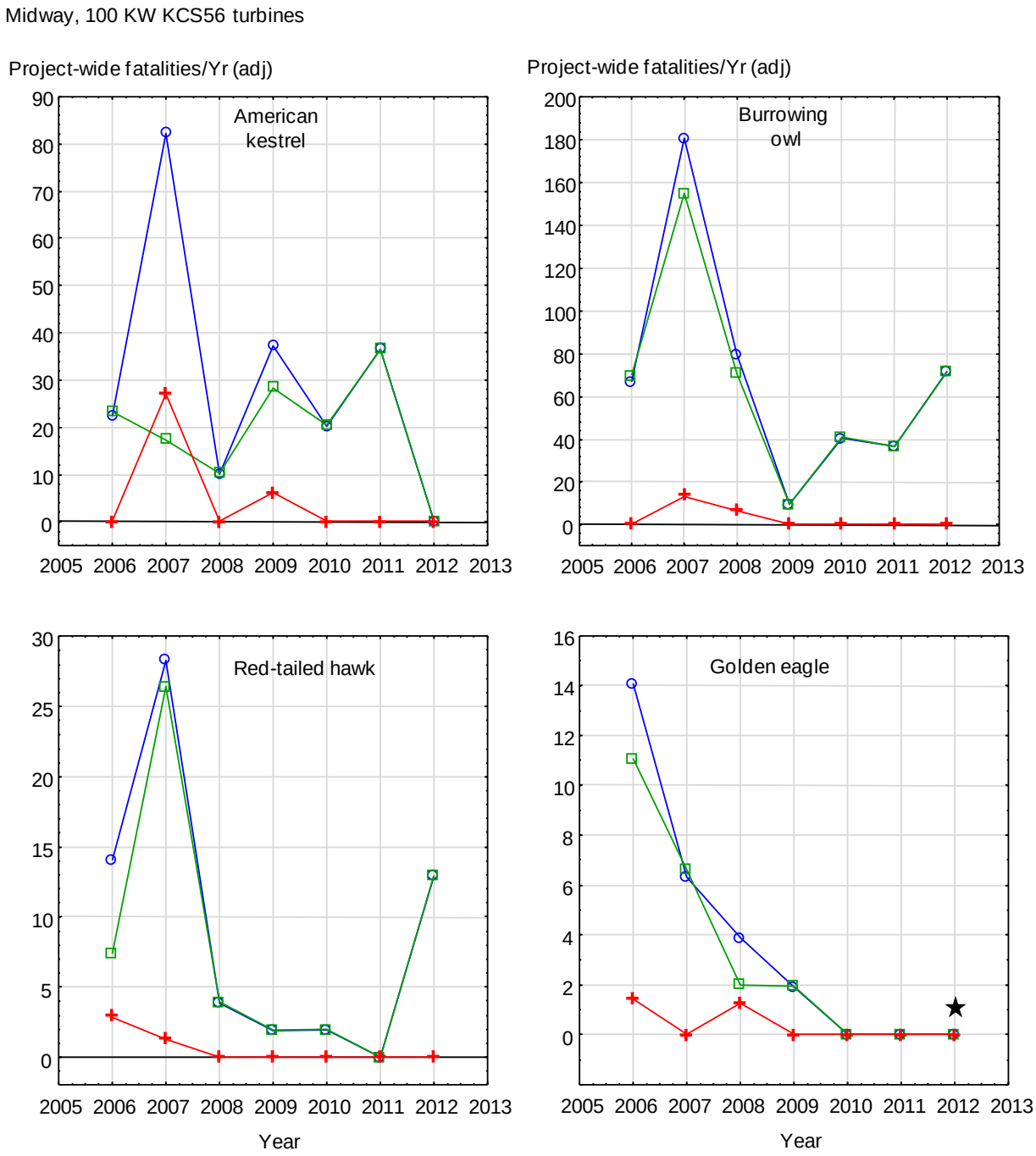

Figure C17. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at KCS-56 100 KW turbines at Midway site, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines). The star represents a golden eagle found outside fatality monitoring.

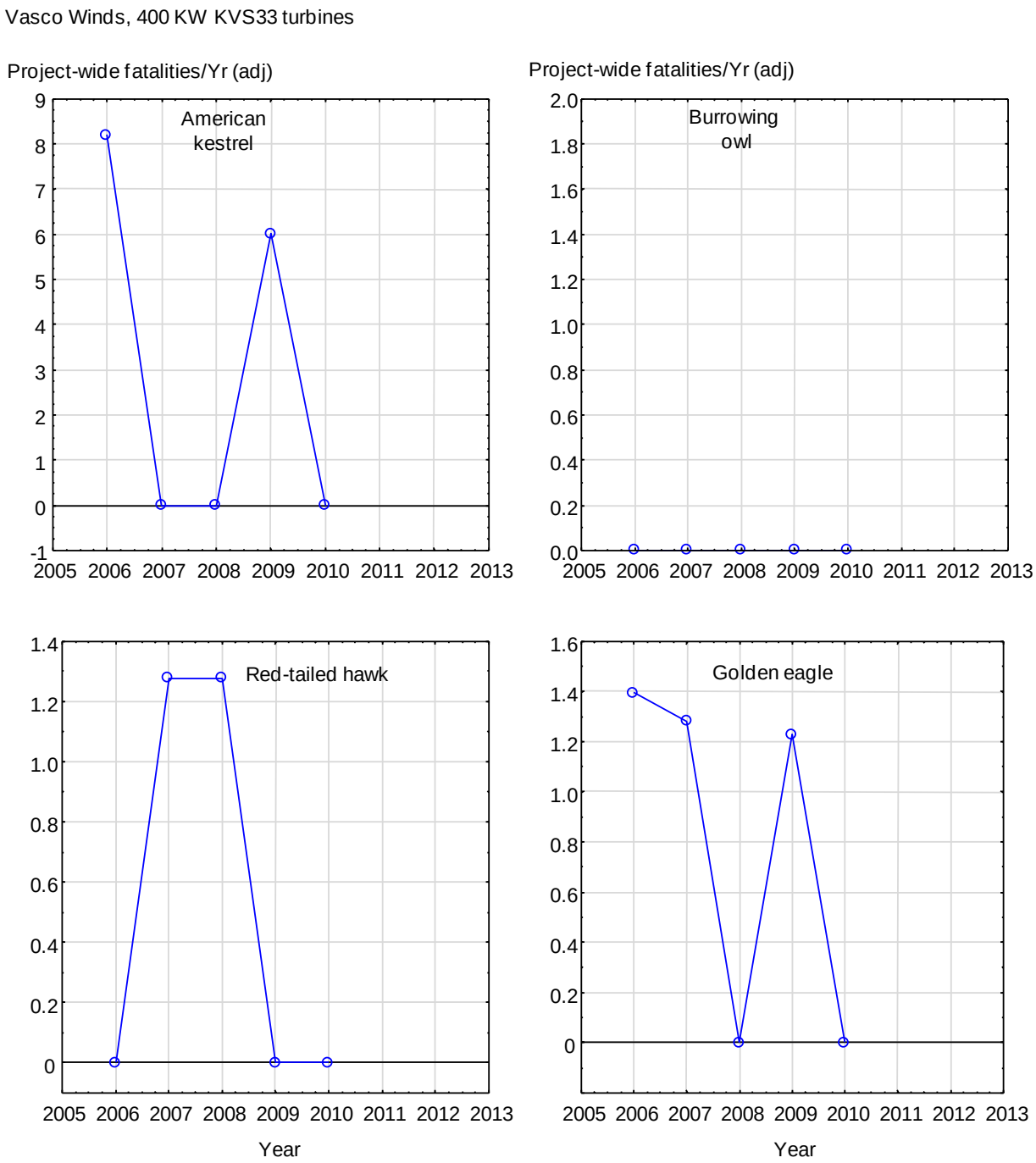

Figure C18. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 400 KW KVS33 turbines at Vasco Winds, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

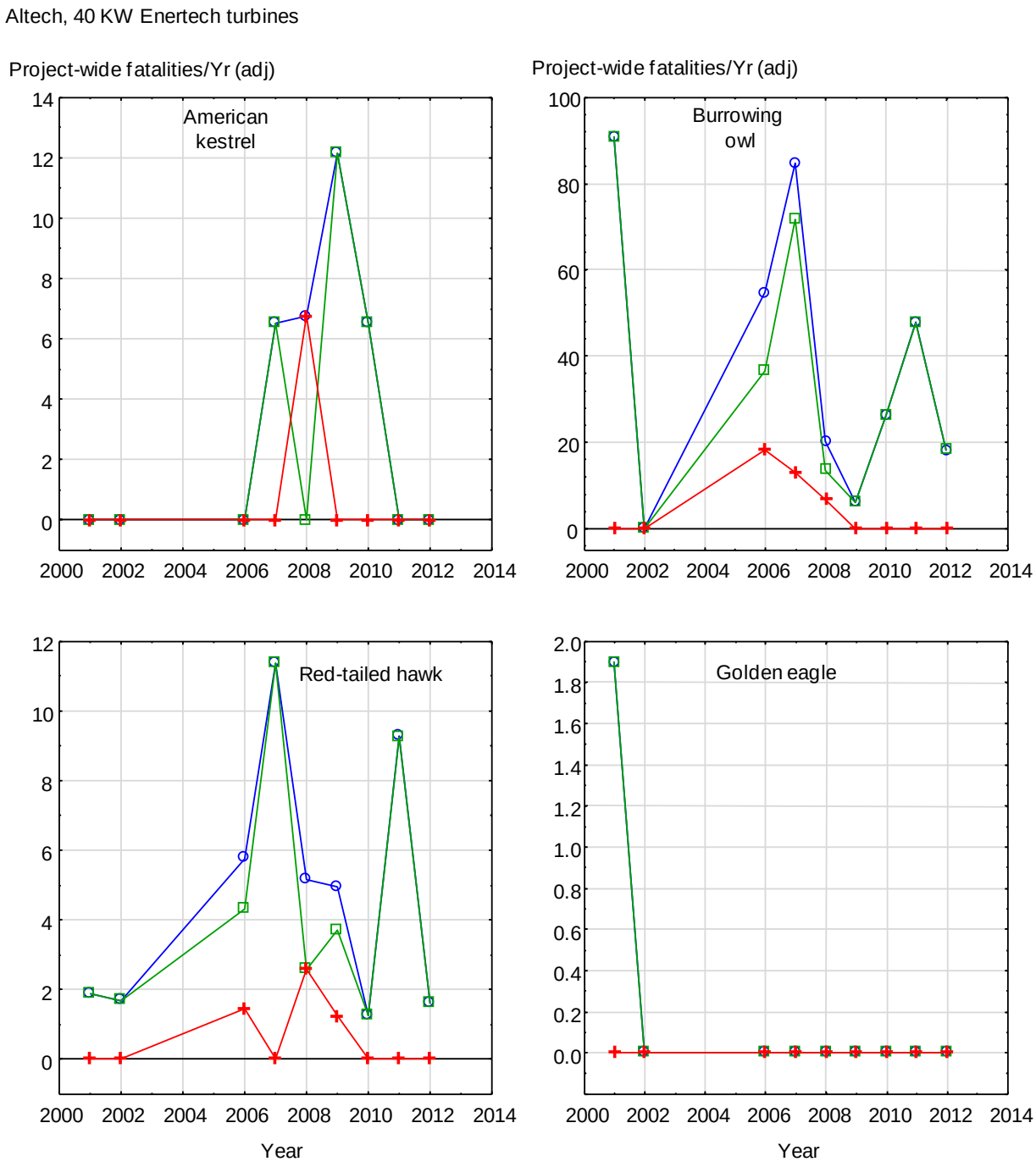

Figure C19. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 40 KW Enertech turbines in Forebay's Altech project, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

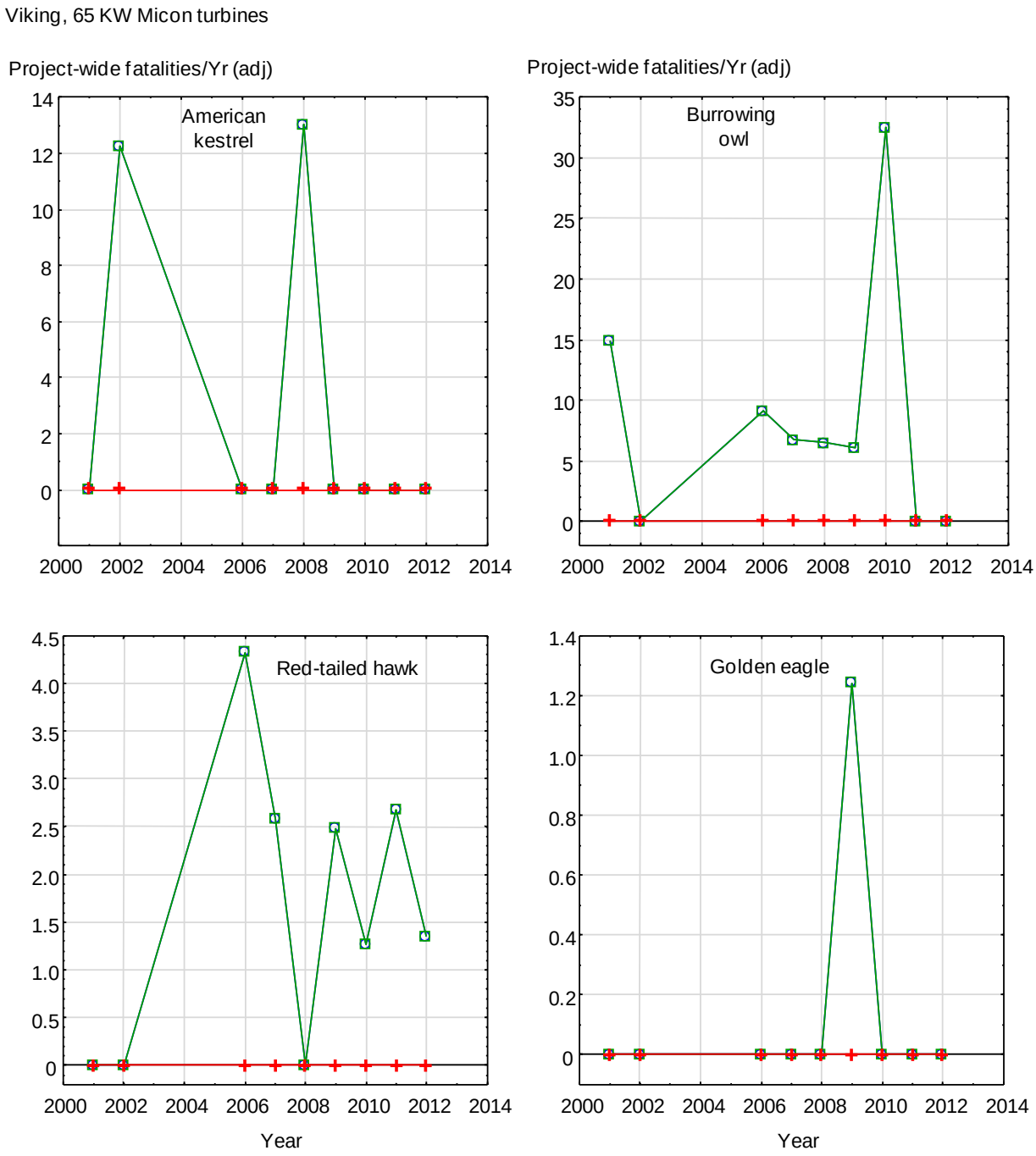

Figure C20. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 65 KW Micon turbines in Forebay's Viking project, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).

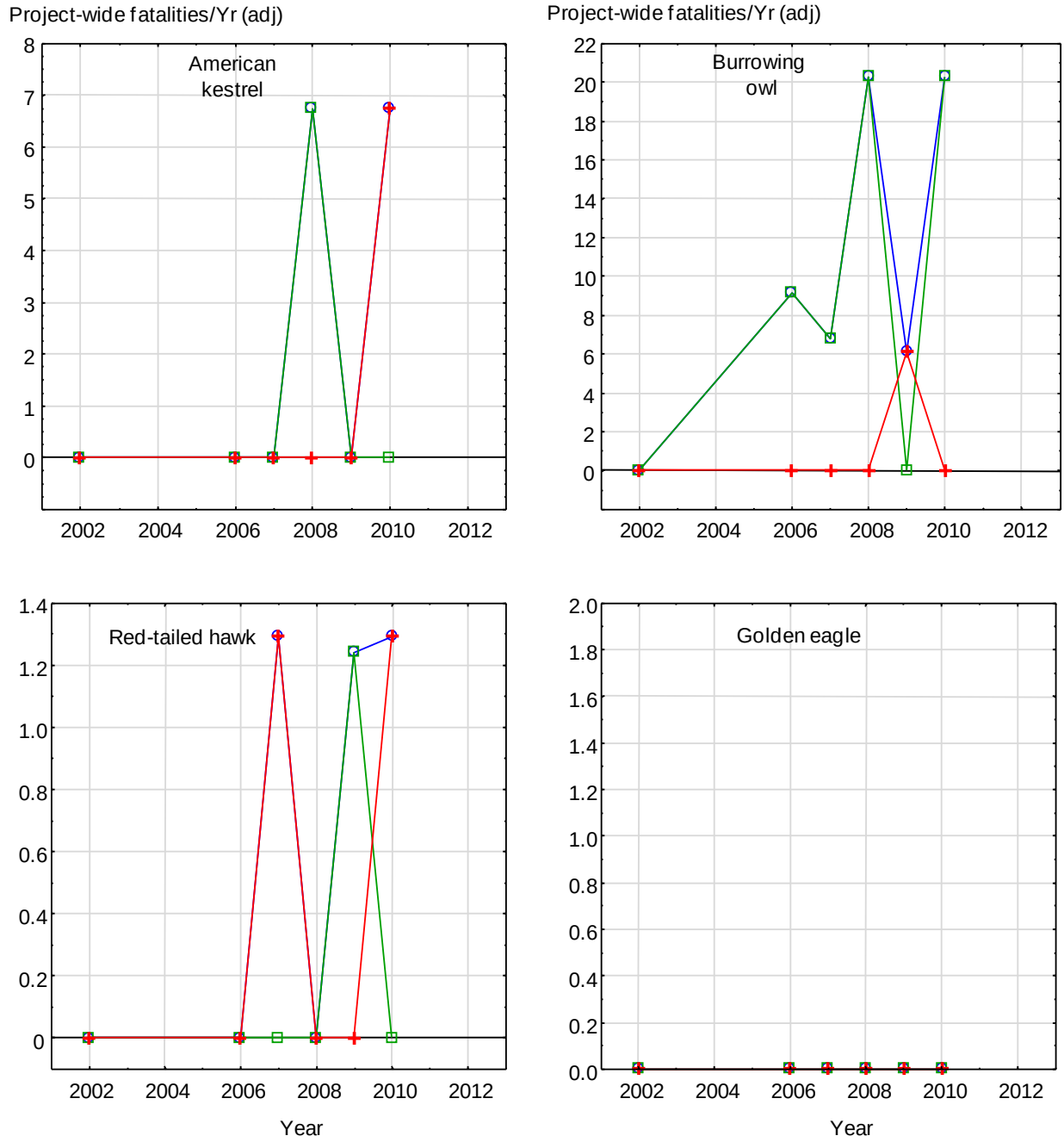

Figure C21. Estimates of annual fatalities of American kestrel (top left), burrowing owl (top right), red-tailed hawk (bottom left), and golden eagle (bottom right) at 65 KW Windmatic turbines in Forebay's Venture project, Altamont Pass WRA. Fatality rates were estimated for wind turbines rated 8-10 for collision hazard (red lines), those rated 0-7.5 (green lines), and all turbines combined (blue lines).