Skilled Dog Detections of Bat and Small Bird Carcasses in Wind Turbine Fatality Monitoring

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Collette Yee (Conservation Canines), Skye Standish and "Captain" engaged in carcass search, Buena Vista Wind Farm, Contra Costa County, California, 3 November 2017 (Photo: Shawn Smallwood).

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ABSTRACT - As wind turbine-caused mortality of birds and bats increases with increasing wind energy capacity, accurate fatality estimates are needed to assess impacts, identify collision factors, and formulate mitigation. Finding a larger proportion of wind turbine collision victims would improve fatality estimates, so we tested skilled detection dogs in trials involving randomly placed bat and small bird carcasses in routine fatality monitoring at the Buena Vista and Golden Hills Wind Energy projects, California. Of carcasses placed before next-day fatality searches and confirmed available, dogs detected 96% of bats and 90% of birds. At one project dogs found 71 bat fatalities in 55 searches compared to 1 found by humans in 69 searches within the same turbine search plots over the same season. Dog detection rates remained unchanged with distance from the turbine, but dogs found more fatalities at greater distances from the turbine. Patterns of fatalities indicated we missed 20% of birds and 14% of bats beyond our 105-m search radius at 1.79-MW turbines on 80-m towers and 20% of birds and 4% of bats beyond our 75-m search radius at 1-MW turbines on 55-m towers. Dogs also increased estimates of carcass persistence by finding carcasses that the detection trial administrator concluded had been removed. Whereas our bat fatality estimate equaled that of the monitor's at Golden Hills, our small bird fatality estimate was 3 times higher and both our bat and small bird fatality estimates far exceeded those based on earlier human searches at Buena Vista. Accuracy and precision of fatality estimates at wind projects would greatly improve by using scent-detection dogs guided by trained handlers.

INTRODUCTION

A potential bat mortality crisis lurks behind available estimates of wind turbine collision fatality rates (Kunz et al. 2007). Estimated annual wind turbine-caused bat fatalities in the USA was 888,036 (90% CI: 384,643 to 1,391,428) across 51,630 MW of installed wind energy capacity in 2012 (Smallwood 2013), but installed capacity increased to 96,488 MW by 2018 (https://www.awea.org/wind-101/basics-of-wind-energy/wind-facts-at-a-glance, last accessed 27 February 2019). If vulnerability of bats to wind turbine collision increased linearly with this increased wind energy capacity, and if we restrict mean fatality rates to those estimated from fatality search intervals <10 days (Smallwood and Neher 2017), then estimated annual fatalities in 2018 would have increased to 3,782,330 bats (90% CI: 2,074,492 to 5,490,167), or more than the estimated mortality caused by white nose syndrome (Hopkins and Soileau 2018). However, the Smallwood (2013) estimate was based on human searches for birds and bats around wind turbines – an approach prone to large biases and sources of uncertainty due to wide variation in fatality monitoring methods and poor detection of bats by human searchers (Smallwood 2007, Smallwood et al. 2010, 2013). Given the potential magnitude of wind turbine impacts on bats, and given the need to formulate mitigation measures based on inferences drawn from seasonal and spatial patterns of fatalities, it is imperative that fatality rates are accurately estimated.

Whether a crisis lurks behind wind turbine-caused small bird mortality remains less clear, partly due to high uncertainty in estimates based on human searchers and widely varying fatality monitoring methods (Smallwood 2007, 2013). Smallwood (2013) did not specifically estimate "small bird" fatalities in the USA, but had he done so, his estimate would have numbered more than the 214,000 to 368,000 estimated by Erickson et al. (2014) for North America's installed capacity of 63,023 MW in 2014. Projecting Erickson et al.'s 2014) estimate to the 96,488 MW of capacity in 2018 and the annual toll of small birds would have been 327,633 to 563,406. Whether this range of fatalities qualifies as a crisis depends on whether Erickson et al.'s (2014) estimate was accurate, and whether it threatens particular species or contributes cumulatively with other mortality factors to cause significant impacts. Of particular concern to us was low detection rates of human searchers compounded by relatively long search intervals typical of older studies serving as sources used by Smallwood (2013) and Erickson et al. (2014). In a study of overlapping fatality monitoring by two teams that differed in method only in one team averaging 5 days and the other 39 days between searches, the team with the shorter search interval contributed to a small bird fatality estimate numbering 2.3 times higher than the other team (Smallwood 2017). Considering the effect of long search interval alone, the true small bird fatality rate could be double the rate estimated by Erickson et al. (2014).

The accuracy of fatality estimates depends largely on (1) detecting as many of the available fatalities as possible, and (2) accurately adjusting for the proportion of fatalities not found (Smallwood et al. 2018). Finding more of the actual fatalities decreases the proportion of unfound fatalities, thereby minimizing inaccuracy caused by biases and error in the adjustment. Multiple steps can be taken to detect more of the available fatalities, including searching to a maximum radius around wind turbines that includes all deposited carcasses, searching along transects spaced closer together, searching more frequently, and searching with skilled detection dogs instead of only humans. Homan et al. (2001), Arnett (2006), Paula et al. (2011), and Matthews et al. (2013) found that using skilled dogs greatly increased carcass detection rates over human searchers, and Reyes et al. (2016) found that dogs improved searcher efficiency and were more likely to detect fatalities of rarely-represented species.

The scientific basis for deciding on a maximum search radius has been scarce. Hull and Muir (2010) proposed a method based on ballistics. However, ballistics cannot account for the collider's pre-mortem contribution to deposition distance, including staying aloft until farther from the turbine or continued movement on the ground post-deposition. An injured mobile bat can defy predictions of deposition patterns based on ballistics. Another approach is to observe the pattern of outcomes – where bat carcasses finally wind up within the wind project. Smallwood (2013) proposed such an outcomes method based on modeling the pattern of carcass deposition within previously searched areas, but the pattern could shift with increasing maximum search radius. Huso et al. (2014, 2017) also proposed modeling the pattern of carcass deposition, but the proposed metric consisted of the density of carcasses (carcasses/m^2) as opposed to Smallwood's (2013) cumulative number of carcasses with increasing distance from the turbine. Huso et al. (2014, 2016) further proposed that monitoring can be more efficient by concentrating efforts near the turbine tower where carcass densities were higher at one cited project site. Both the Smallwood (2013) and Huso (2014, 2016) approaches are also vulnerable to a potential bias caused by human searchers finding fewer fatalities farther from the wind turbines, a pattern that can result from decreasing ground visibility, searchers struggling to remain on the intended transect, and searchers shifting attention to navigating more difficult terrain farther from the turbine. If use of dogs greatly improves carcass detection (Arnett 2006, Mathews et al. 2013), then dogs might reveal truer patterns of carcass deposition around wind turbines.

Our primary study objectives were to (1) quantify detection rates of skilled dogs on volitionally placed bats and small birds within wind turbine fatality search plots; (2) compare detection rates of dogs by carcass time in the field, relative occlusion by vegetation, and size; (3) quantify bias in maximum search radii to adjust for proportion of bat fatalities that are undetected because they are outside the maximum search radius; (4) test the efficacy of using skilled dogs relative to human searchers to find available fatalities, (and (5) roughly estimate fatality rates. We note that our reference to dogs includes human handlers as part of a dog-human fatality detection team.

STUDY AREA

Our study involving dogs included 2 wind projects 8 km apart in the Altamont Pass Wind Resource Area (APWRA), California. The Buena Vista Wind Energy project (Buena Vista) consisted of 38 1-MW Mitsubishi wind turbines, 31 of which were accessible to us on land owned by East Bay Regional Park District, Contra Costa County. Two Mitsubishi turbines were on 45-m towers, 2 on 65-m towers, and 27 on 55 m towers. The Golden Hills Wind Energy project (Golden Hills) consisted of 48 1.79-MW General Electric (GE) wind turbines, 32 of which were accessible to us on privately held land in Alameda County. All GE turbines were on 80-m towers. Relying on data from Brown et al. (2016), we compared the pattern of fatalities found by human searchers with distance from the wind turbine at Vasco Winds Energy Project (Vasco Winds) to the pattern found by dogs at Buena Vista and Golden Hills. Vasco Winds consisted of 34 2.3-MW Siemens turbines on 80-m towers, located immediately west and south of Buena Vista in Contra Costa County. All 3 projects were on steeply rolling hills covered by cattle-grazed annual grasses. Elevations ranged 41 - 280 m at Buena Vista, 115 - 477 m at Golden Hills, and 54 - 402 m at Vasco Winds.

METHODS

Dog searches

We sought to maximize bat and small bird fatality finds by performing fatality searches through fall migration from 4 September through 15 November 2017 – a period of peak activity in our study area identified by nocturnal surveys using a thermal-imaging camera since 2012 (Smallwood 2016; Smallwood unpublished data). During daylight morning hours 5 days per week, we searched within 105 m of 2-3 turbines/day at Golden Hills, and within 75 m of 3-5 turbines/day at Buena Vista, achieving about a two week search interval at both projects. The maximum search radii were the same as those used by fatality monitors at the projects (Insignia 2011, H. T. Harvey & Associates 2018).

Our search team included two trained scent detection dogs, worked one at a time by a trained handler and accompanied by a data collector. We led dogs by leash along transects oriented perpendicular to the wind and separated by 10 m over most of each search area. The exception was within a 90° arc between 210° and 300° from the turbine, which corresponds with prevailing upwind directions in the APWRA. Within this 90° arc we allowed dogs off leash for a more cursory search, because in our experience few bat and small bird fatalities are found upwind of wind turbines (Smallwood 2016, Brown et al. 2016). Within the intensive, on-leash search areas we navigated transects using GPS and a Locus Map application on a phone along with visible flagging as needed. We also tracked dogs using a Keychain Finder Transystem 860e GPS data logger to ensure complete search coverage. We mapped and photographed fatality finds using a Trimble GeoExplorer 6000 GPS unit, and identified carcasses to species. We left found carcasses in place for possible repeat discovery.

Our carcass detection trials varied slightly from the integrated detection trials of Smallwood et al. (2018). Within intensively searched areas downwind of wind turbines, our detection trial administrator (KSS) deposited carcasses of bats and small birds at randomized locations the day prior to each fatality search (Table 1). All carcasses had been frozen immediately post-mortem, but we deliberately placed older carcasses in some trials (described below). We weighed trial carcasses prior to placements, removed one foot from bats and clipped off tips of flight feathers of birds. Fatality searchers, who were blind to trials, reported found trial carcasses in the same manner as turbine-caused fatalities except for additionally reporting carcasses that were marked by removed foot or clipped flight feathers. At Buena Vista KSS checked on trial carcass status as long as carcasses persisted. At Golden Hills, KSS removed carcasses of bats but not birds following the dog team's next search, as required by the wind company.

We implemented two additional types of detection trial to test whether time since death and time in the field might affect detection rates. At Buena Vista, we placed fresh frozen bird carcasses on randomized days up to two weeks prior to the next fatality search to test whether carcasses persisting in the field longer than a day were detected at the same rates as those placed one day prior to the search. Because we were required to remove bat trial carcasses from Golden Hills after our next search following placement, we relocated persisting carcasses to Buena Vista to test whether carcasses thawed an extra 1 to 4 days prior to placement affected detection rates (Table 1). We also deliberately placed baby bats and flightless bird chicks to test whether detection dogs would detect them at lower rates than adult animals.

We also tested whether dog detection rates of trial carcasses varied by $\log_{10}$ mass of carcass, where carcasses were weighed at time of placement. We tested whether daily trial carcass detection rates might have increased or decreased with more finds of both trial carcasses and fatalities. Also, upon trial carcass placement we counted paces in 3 standard directions from each carcass until the carcass was no longer visible, and we related detection outcomes to mean number of paces to carcass occlusion. One direction for pacing was directly away from the turbine, and the other two directions were perpendicular to the first direction.

Human searches at Golden Hills

The 32 Golden Hills wind turbines searched by our dog team at 27-day intervals were also searched by humans (H.T. Harvey & Associates 2018) at 28-day intervals within the same maximum search radius of 105 m and the same transect spacing of 10 m. Human searchers and the dog team were blind to each other's fatality finds until the end of our study, but we informed the human searchers of our trial carcass placements. Human searchers removed carcasses they found, except for our trial carcasses. Over our study period we performed 55 searches with dogs at the same 32 turbines where human searchers performed 69 searches. We later compared fatality finds and fatality estimates between human searchers and our dog team.

Patterns of Searcher Detection and Fatalities around Wind Turbines

Humans also searched for fatalities at 34 turbines at Vasco Winds from May 2012 through May 2015, using the same maximum search radius and transect spacing as at Golden Hills, and using a similar detection trial protocol. We used Vasco Winds data to compare searcher detection rates by distance from the turbine between human and dog searchers. We also used Vasco Winds data to compare the pattern of found fatalities with distance from the turbine, where the pattern was derived from human searchers at Vasco Winds and dog searchers at Golden Hills.

Fatality rates are less comparable between wind projects unless one accounts for variation in combinations of tower heights, rotor diameters, and maximum search radii (Smallwood 2013, Hull and Muir 2010, Kitano and Shiraki 2013, Loss et al. 2013). These combinations partly determine the proportion of fatalities that are found, because some proportion of birds and bats end up outside the search area and are never discovered. To derive an adjustment factor, *d*, for the proportion of undetected fatalities among wind projects, Smallwood (2013) reviewed tables and appendices in available reports to obtain distances of fatalities from wind turbines. He 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 used least-squares regression analysis to fit logistic functions to the cumulative sum fatalities with increasing distance from the turbine, iteratively changing the upper bound value of the dependent variable in the model until the minimum root mean square error (RMSE) was obtained:

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

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

Smallwood (2013) then used the models to predict cumulative sum fatalities at 1-m intervals from the turbine, including at distances extended beyond the maximum search radii to predict asymptotic search radii including all fatalities. He divided predicted values at each 1-m interval into the model’s asymptotic value to represent the proportion of fatalities found within the maximum search radius, *d*. A potential bias resulting from this approach would be any shift in fatality detection as distance from the turbine increases. Because dog detection rates might differ from humans, we applied Smallwood’s (2013) approach to fatalities found by humans at Vasco Winds (Brown et al. 2016) and dogs at Golden Hills.

Fatality Estimation

We estimated fatalities $\hat{F}$ of bats and small birds by dividing the number of carcasses found F by carcass persistence rate R_C, searcher detection rate S, maximum search radius bias d, proportion of wind turbines in the project searched, and concurrent with our study period the proportion of fatalities found in 2017 by H.T. Harvey & Associates' (2018) dogs searching 14 Golden Hills turbines at 7-day intervals. We used 28-day R_C values to represent first visits, and R_C representing our average search interval for later visits. We did not attempt to estimate confidence intervals, which we felt were inappropriate for such a brief survey effort. Our intention was to roughly compare our point estimates to those of H. T. Harvey & Associates (2018) for Golden Hills and Insignia (2011) for Buena Vista, and to the predicted fatalities of Lamphier-Gregory et al. (2005) for Buena Vista prior to construction.

RESULTS

We performed 151 fatality searches at 63 wind turbines from 4 September through 15 November 2017, including 20 searches by humans through 13 September, and 131 searches by dogs thereafter. Our dog team searched 15 turbines once each and another 48 turbines twice to four times per turbine, averaging 25-day intervals between searches (range 2 to 53 day intervals). At Golden Hills, our dog team searched 12 turbines once, 17 twice, and 3 thrice, totaling 55 turbine searches. At Buena Vista, our dog team searched 3 turbines once, 15 twice, 9 thrice, and 4 four times, totaling 76 turbine searches. During the period of our fatality searches using dogs, we found 24 bats and 26 birds at Buena Vista and 71 bats and 63 birds at Golden Hills (Table 1). Based on carcass decay, we estimated that 9 bats and 43 birds had died prior to our study (Table 1).

Trial Carcass Detection Rates

Of 278 trial carcass placements, 214 were available to be found by dogs during at least one search. Of the remainder, 54 had been removed by scavengers prior to the first search, 7 were placed at turbines not subsequently searched as the study ended, and 3 were mistakenly placed outside search areas. Of carcasses placed before next-day fatality searches and confirmed available, dogs detected 96% of bats and 90% of birds between both projects. Dogs found 100% of 41 bats placed at Golden Hills and 93% of 54 bats placed at Buena Vista. They found 84% of 56 small birds placed at Golden Hills and 91% of 32 small birds placed at Buena Vista.

Of all searcher exposures to placed carcasses, whether just placed or persisting through multiple searches, dogs found 95% of 132 bat trials and 91% of 101 bird trials between both projects. Dogs found 100% of 44 bat trials at Golden Hills and 92% of 88 bat trials at Buena Vista. They found 88% of 57 small bird trials at Golden Hills and 95% of 44 small bird trials at Buena Vista.

Because we were required to remove bats soon after trial completion at Golden Hills, we relocated bats to Buena Vista to perform older-carcass trials, since they had already persisted 1 to 4 days at Golden Hills (Table 2). Dogs detected 87.5% of 24 relocated bats confirmed to be available for detection, or 5.5% lower than the fresh bat detection rate at Buena Vista.

We placed 36 bird carcasses on randomized days at Buena Vista to vary the days since placement by up to two weeks (Table 2). Dogs detected 36% of these carcasses, but they found 100% of 13 that had persisted through the next fatality search. The 64% that were undetected had not persisted until the next search, likely because scavengers removed them.

For bats, birds, and bats and birds pooled together, dog detection trial outcomes did not differ significantly by mean distance to carcass occlusion (t-tests, $P > 0.05$), by mean $\log_{10}$ body mass (t-tests, $P > 0.05$), nor by mean number of carcass (fatalities and trials) finds on a particular day (t-tests, $P > 0.05$).

Of the 7 bats missed by dogs, 3 had been relocated from Golden Hills to Buena Vista (they had been found at Golden Hills, but relocated to test dogs on bats that had been in the field >1 day). Missed relocated bats included 2 adult little brown bats and one adult Mexican free-tailed bat that had persisted at Golden Hills 2-4 days prior to relocation. Dogs missed 3 bats on the same day – 31 October 2017. Dogs missed 1 bat on a gravel turbine pad, 1 on a gravel access road, 1 in restored grassland, and 4 in established grassland. Only one of the missed bats was partially occluded by vegetation. Two of the missed bats were near the edge of the maximum search radius.

Dogs missed 8 birds ranging in size from a 3.7 g Bewick's wren to an 87.6 g Eurasian collared-dove. Dogs missed 2 birds on the same day – 23 October 2017, and 3 more on 13 November 2017. Dogs missed 2 birds on the non-gravel portions of turbine pads, 3 in reclaimed grassland, and 3 in established grassland. Three were partially occluded by vegetation, and 4 were on very steep slopes. Two of the missed birds were at the edge of the maximum search radius.

Of the 15 missed bat and bird trial carcasses, 4 bats and 6 birds (67% of misses) were missed on 8 (18%) search days when the dog team was accompanied by the dog handler's supervisor or a photographer. The misses occurred on such days of distraction nearly 4 times more often other than expected. Dogs missed another bat trial carcass during its first study day. Twelve (80%) of 15 trial carcass misses occurred at 3 of 21 (14%) same-day turbine search groups, or nearly 6 times more often other than expected at these turbine groups. Dogs missed 5 trial carcasses at Golden Hills turbines 4, 5 and 6 grouped for same-day searches, 4 at Buena Vista turbines C11 and C12, which were searched with C13 as a group, and 3 at Buena Vista turbines A14, A15, and A16, which were searched with A13 as a group. Common features of these turbine search groups were steep slopes and highest elevation peaks in the local area.

Searcher Detection by Distance from Turbine

Regardless of distance from the turbine, searcher detection of trial carcasses was higher for dogs than for humans, more so for bat carcasses than bird carcasses (Fig. 1, Table 3). Neither dog nor human searcher detection rates, *S*, changed significantly with increasing distance from the turbine, but human searcher detection rates tended to decline with increasing distance.

Carcass Persistence

Trial carcass persistence rates for bats were 87% at 1 day, 27% at 10 days, and 5% at 30 days, and for small birds they were 84% at 1 day, 34% at 10 days, and 11% at 30 days (Fig. 2A). When assuming constant daily fatality rates and averaging persistence rates by day, dog searches usually increased carcass persistence over trial administrator status checks at the search intervals typically used at wind projects (Fig. 2B, Table 4). The exception was daily searches for birds, where the mean daily persistence was equal. Dogs increased measured carcass persistence by 0.06 to 0.07 for bats and by 0.10 to 0.11 for birds at intervals longer than daily (Table 4).

Bats smaller and larger than 8 g persisted at nearly equal proportions through 14 days, after which a larger proportion of smaller bats persisted (Fig. 3). Higher proportions of the freshest bat carcasses persisted through 14 days, after which proportions persisting did not differ by freshness at placement time (Fig. 3). Our best-fit models for daily carcass persistence were $R[Bats] = 1.0186 \times 0.8998^{I}$ ($r^2 = 0.98$, RMSE = 0.11), and $R[Small\ birds] = 1 - 3.0732 \times \left(1 - e^{-0.0996 \times \log(I+1)}\right)$ ($r^2 = 0.99$, RMSE = 0.04). Predicted daily mean carcass persistence rates, R_C, were similar between bats and small birds (Fig. 4). Because our daily mean search interval, I, was 22 days at Buena Vista and 27 days at Golden Hills, our fatality adjustment for carcass persistence would be 0.40 and 0.35 for bats and 0.39 and 0.35 for small birds at Buena Vista and Golden Hills, respectively.

Patterns of Found Fatalities around Wind Turbines

With increasing distance from the turbine at Vasco Winds, human searchers found increasingly fewer bird and bat fatalities/ha (Fig. 5), but this density relationship reflected more of the change in search area than it did change in fatality finds with distance from the turbine at Vasco Winds (Fig. 5 inset). The cumulative number of human-found bats and birds increased with increasing distance from the turbine (Figure 5). Logistic models fit to found fatalities in 10-m distance intervals from the turbine indicated that all bats were likely found within the maximum search radius, but not all birds (Table 5).

Over the time period for which we were provided data at Golden Hills, human searchers found 1 bat and 21 birds. The single bat was found only 10 m from a turbine tower base, so the cumulative fatality count through 110 m was 1 for every 10-m increment. The best-fit logistic model fit to the human-found birds within 10-m distance increments indicated that the maximum search radius likely did not include all bird fatalities at Golden Hills (Table 5).

Fatality searches by dogs yielded patterns suggesting substantially more bats and birds would have been found beyond the maximum search radius at Golden Hills and Buena Vista (Fig. 6, Table 6). The pattern of dog-found fatalities at Golden Hills relative to human-found fatalities at Vasco Winds suggested that bats were deposited to nearly twice the distance from the turbine, 177 m (Table 5) versus 99 m (Table 6), respectively. The pattern of bird fatalities was similar between Vasco Winds and Golden Hills.

Using dogs, the number of bats that were found increased with increasing distance from the turbine at both Buena Vista and Golden Hills (Fig. 7). At Buena Vista, the number of birds found by dogs spiked between 40 and 50 m from the turbines (Fig. 7).

Comparing Found Fatalities of Dog Team with Human Searchers at Golden Hills

Our dog team found 8 (38%) of 21 birds reported to have been found and removed by human searchers at Golden Hills, half of which we found as whole carcasses and half as partial carcasses or feather piles. For example, we found 3 of 7 red-tailed hawks found by human searchers, 2 of which were found on the same day by our dog team and the monitor's human searcher. We found 2 of 3 burrowing owls found by human searchers, the one mallard, an American pipit, and 1 of 2 horned larks. We did not find the 1 golden eagle and 1 ferruginous hawk found and removed by human searchers. Of the 63 bird fatalities we found using dogs, the human searchers found 11 (17%). Bird fatality finds were skewed towards larger birds among human searchers, whereas dogs discovered most of the small birds (Fig. 8).

Our dog team failed to detect the one bat found by human searchers, because it had been found and removed by the human searchers 39 days before we searched that turbine. The human searchers found none of 71 bats found by our dogs and which we left in place to be potentially found by human searchers. Some of these bats were likely removed by scavengers in the time between our dogs finding them and the next human search.

Fatality Estimates

Based on our surveys we estimated 227.5 bat fatalities in 61 days in Fall 2017 at Golden Hills (Table 7). Over this same period, the dogs of H.T. Harvey & Associates (2018) found 47.5% of the bat fatalities in 2017 among the 14 Golden Hills turbines they searched weekly. Our fatality estimate adjusted for this percentage (converted to the proportion 0.475) yields an annual estimate of 479 bats (5.58 bat fatalities/MW/yr), which was midway between H.T. Harvey & Associates' (2018) year 1 and year 2 mean estimates of 468 and 500, respectively.

Applying the same adjustment approach to our estimated 86.7 bat fatalities at Buena Vista, but restricting it to the operable period preceding the shutdown, we estimate an annual fatality total of 262 bat fatalities at Buena Vista, or 6.89 bat fatalities/MW/yr. Our estimate was almost 14 times greater than the 3-year average based on human searches at 15-day intervals during 2008-2011 at the same project (Insignia 2011). It was also twice the upper-end and 6.5 times the lower end of the predicted range of annual fatalities for the project (Lamphier-Gregory et al. 2005).

Based on our surveys we estimated 243 small bird fatalities in 61 days in Fall 2017 at Golden Hills (Table 7). Over this same period, the dogs of H.T. Harvey & Associates (2018) found 18.5% of the small bird fatalities in 2017 among the 14 Golden Hills turbines they searched weekly. Our fatality estimate adjusted for this percentage yields an annual estimate of 1,314 small birds (15.29 small bird fatalities/MW/yr), which was >3 times more than H.T. Harvey & Associates' (2018) 2-year mean estimate of 421.

Applying this same adjustment approach to our estimated 54.3 small bird fatalities at Buena Vista, we estimate an annual fatality total of 295 small bird fatalities at Buena Vista, or 7.72 small bird fatalities/MW/yr. Our estimate was almost 6 times greater than the 3-year average based on human searches at 15-day intervals during 2008-2011 at the same project (Insignia 2011), although the Insignia estimate was for all birds other than raptors. Our estimate nearly equaled the upper-end of the predicted range of annual all-bird fatalities (Lamphier-Gregory et al. 2005).

DISCUSSION

Skilled scent-detection dogs found 95% of placed bats and 91% of placed birds, despite our deliberate placements of carcasses of immature bats and birds, mostly small-bodied species, and some old carcasses, and despite inadvertent placement of some carcasses beyond the search radius. Dogs found 22 of 23 available immature bats averaging 3.46 g, and a desiccated bat carcass of only 1 g. Dogs found most of the relocated bats that had already decayed in the field for up to 4 days, and they found bats that disappeared into tall grass when dropped from shoulder-height – bats that no human could possibly have found. Among birds, dogs found hummingbirds and many chicks of various songbird species. Dogs found all available birds placed up to 2 weeks prior to their next search. Overall, dogs found the majority of trial carcasses, giving us confidence that they can find the majority of available carcasses representing wind turbine fatalities.

Our results were consistent with others who have used scent-detection dogs for fatality searches. At two wind projects, dogs found 71% and 81% of trial bat carcasses, whereas humans found 42% and 14%, respectively (Arnett 2006). At other wind projects, dogs found 96% of trial *Coturnix coturnix* carcasses compared to 9% found by humans (Paula et al. 2011), and 73% of trial bat carcasses compared to 20% found by humans (Mathews et al. 2013). In another study using untrained dogs, dogs found 92% of trial *Passer domesticus* carcasses compared to 45% found by humans (Homan et al. 2001). Our findings were similar to earlier comparisons between dogs and humans, although we note the disparity between dog and human detection rates increased with smaller-bodied animals. Where 55 of our dog searches overlapped 69 human searches at the same wind turbines, our dogs found 71 bat fatalities whereas human searchers found 1, our dogs found 47 small birds whereas human searchers found 11, and our dogs found 16 large birds whereas humans found 10 (4 were found by both dogs and humans). The 71-fold difference in found bats and 4-fold difference in found small birds represented substantial differences in searcher detection between dogs and humans – differences that were measured in actual concurrent fatality monitoring rather than in separate trials.

Our findings also differed largely from human searches performed at 15-day intervals 6 to 9 years earlier at Buena Vista. Over only 17 days of surveys at operable turbines, our dogs found more bat fatalities than Insignia's (2011) human searchers found in 3 years. Our fatality estimates were 14 times greater for bats and 6 times greater for small birds than estimated by Insignia (2011), and they exceeded predictions made prior to construction (Lamphier-Gregory et al. 2005). Using humans as searchers for bats and small birds leaves much to be understood about wind turbine impacts on small volant animals in the Altamont Pass.

Although our dog searches at Golden Hills translated into the same annual bat fatality estimate as reported by H.T. Harvey & Associates (2018), we found 3.7 times as many small birds per search over the same time period as did H.T. Harvey & Associates' dogs. This difference translated into an annual small bird fatality estimate that was more than 3 times larger than that produced by the other dog team. We posit that H. T. Harvey & Associates would find more of the available small bird carcasses by working dogs on leash and spending more time per search plot (H. T. Harvey & Associates established a 1-hour limit for searching each plot).

Searcher detection error was much lower for scent-detection dogs than for humans. Using skilled dogs, accounting for the undetected portion of fatalities narrows down to crippling bias (Smallwood 2007), carcass persistence, areas unsearched beyond the maximum search radius, and unsearchable areas within the maximum search radius, e.g., cliffs, impenetrable vegetation, tidal zone, and deep water. Crippling bias remains unquantified without detecting collisions in some way other than searches within plots, but the other contributing factors to the undetected portion of fatalities can be measured via integrated detection trials (Smallwood et al. 2018). Because so many of the available carcasses are found by dogs, fewer can persist undetected beyond the search interval, meaning carcass persistence adjustment is smaller and less prone to bias. And because dogs detect carcasses regardless of body mass, integrated detection trials using dogs no longer require body mass as an axis of similitude between trial carcasses and species represented by fatalities (Smallwood et al. 2018). Dogs also facilitate the search radius adjustment by providing truer characterizations of the pattern of fatalities between the wind turbine and the maximum search radius. Logistic models fit to these patterns can more accurately predict the portion of fatalities located beyond the maximum search radius.

Confident of no distance-from-turbine effect on dogs' detection of fatalities, our logistic models fit to the pattern of fatality disposition indicates our maximum search radius of 105 m was too short for encountering all fatalities of wind turbines on 80-m towers. Our models predicted that we did not find 14% of bats and small birds beyond 105 m, nor did we find 21% of large birds. Additional research is needed to determine just how far searches need to extend from turbines to potentially detect all of the available fatalities, and alternatively, to determine the proportion of fatalities undetected due to insufficient search radius. As argued in Smallwood (2013), the fitting of logistic functions to cumulative numbers of fatalities with increasing distance is an interim measure to the more exact approach of actually searching farther. Fitting a model to fatalities collected within a maximum search radius will yield different patterns and different distances associated with asymptotic cumulative fatality finds depending on the search effort, including duration of monitoring and the maximum search radius used. What is needed is a research effort that uses dogs to continue searching outward from turbines until no more fatalities are found.

Scent-detection dogs are needed for finding sufficient numbers of available bat and small bird fatalities to test hypotheses related to spatial distributions of fatalities deposited around and among wind turbines. Dogs are needed for finding enough of the available bats and small birds to reveal patterns that can improve fatality monitoring. Dogs are needed to reveal whether preconstruction bat activity patterns can predict post-construction impacts. Dogs are needed to find enough of the available bats for developing micro-siting strategies consistent with those developed for raptors (Smallwood et al. 2017) and for testing operational curtailment strategies in appropriate experimental designs (Sinclair and DeGeorge 2016).

Searching with dogs further revealed a substantial error associated with carcass persistence trials – an error first reported by Smallwood et al. (2018). Discounting two red-tailed hawks found by both the dog team and human searchers on the same search days, our dog team found 32% of the bird carcasses reported to have been removed by the human search team at Golden Hills. Similarly, our dog team revealed that our trial administrator, even knowing exactly where he placed carcasses, nevertheless falsely determined removals of 8.9% (11 of 123) of bird trial carcasses and 2.9% (3 of 105) of bat trial carcasses. This type of error is difficult to avoid because carcass remains often spread over large areas and some of the remains will be small and hidden in vegetation. Finding feathers and bones a month or two after the carcass was reported to have been removed can result in double-counting a fatality if it was falsely assumed to have been removed. Acknowledging the potential error associated with incomplete removals and false removal determinations, Brown et al. (2016) and Smallwood et al. (2018) left carcasses where found and relied on fatality photos and on tracking when and where remains were found to prevent double counting. Dogs, however, find almost all remains, including small pieces of bat wing or a few feathers of a small bird, and thus nearly eliminate detection trial administration error.

We concur with Paola et al. (2011) and Mathews et al. (2013) that fatality monitoring at wind turbines should be performed using scent-detection dogs and trained handlers, and we further concur that dogs should be carefully selected for the task (Beebe et al. 2016). Unlike humans, skilled dogs find almost all of the available carcasses. Some of our findings suggest that a skilled dog team might find even more of the available carcasses if the dog team is left undisturbed by colleagues. The much more accurate fatality estimates generated from dog searches can lead to more cost-effective monitoring and to insight about causal factors of collisions as well as reasonable solutions. Monitoring and mitigation solutions can be arrived at much more rapidly with the vastly superior data that dogs and their handlers can collect at wind turbine projects.

MANAGEMENT IMPLICATIONS

Many of the available fatality monitoring reports likely underestimated bat and small bird fatalities in North America because they relied on human searchers. Older reports likely underestimated fatalities even more so as fatality search intervals tended to be longer. The accuracy and precision of fatality estimates at wind projects would greatly improve by using scent-detection dogs guided by trained handlers and applied to shorter search intervals than typically used. Dog search teams should consider using leashed dogs for greater precision of areal searches, and should minimize distractions to the dogs. Dog searches can reveal spatial and temporal patterns of fatalities that can better support hypothesis-testing of causal factors and wind turbine micro-siting strategies.

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Table 1. Fatalities found by dogs at Buena Vista (BV) and Golden Hills (GH) Wind Energy Projects, Alameda and Contra Costa Counties, California, fall 2017.

Species name	Scientific name	Old fatalities	New fatalities	
			BV	GH
Western red bat	*Lasiurus blossevillii*	0	4	1
Myotis spp.	*Myotis*	0	0	1
Mexican free-tailed bat	*Tadarida brasiliensis*	3	6	29
Hoary bat	*Lasiurus cinereus*	1	2	13
Bat spp.		5	12	27
Mallard	*Anas platyrhynchos*	0	0	1
Grebe	Podicipedidae	1	0	1
Turkey vulture	*Cathartes aura*	2	0	2
Northern harrier	*Circus cyaneus*	1	1	0
White-tailed kite	*Elanus leucurus*	1	1	0
Red-tailed hawk	*Buteo jamaicensis*	0	0	3
Large raptor		1	0	1
American kestrel	*Falco sparverius*	2	4	1
Prairie falcon	*Falco mexicanus*	1	1	0
Rock pigeon	*Columba livia*	1	1	0
Barn owl	*Tyto alba*	0	1	0
Burrowing owl	*Athene cunicularia*	1	0	4
White-throated swift	*Aeronautes saxatalis*	1	1	0
Pacific-slope flycatcher	*Empidonax difficilis*	0	1	0
Horned lark	*Eremophila alpestris*	10	2	10
Northern rough-winged swallow	*Stelgidopteryx serripennis*	0	0	2
Bewick's wren	*Thryomanes bewickii*	0	0	1
House wren	*Troglodytes aedon*	0	0	1
Ruby-crowned kinglet	*Regulus calendula*	0	0	2
American pipit	*Anthus rubescens*	1	0	2
Warbler	Parulidae	0	0	1
Black-throated gray warbler	*Dendroica nigrescens*	1	0	1
Townsend's warbler	*Dendroica townsendi*	0	1	0
Lincoln's sparrow	*Melospiza lincolnii*	0	0	1
Dark-eyed junco	*Junco hyemalis*	0	0	1
Blackbird	Icteridae	1	0	1
Western meadowlark	*Sturnella neglecta*	6	7	7
Brown-headed cowbird	*Molothrus ater*	1	0	1
Large bird		8	2	8
Small bird		3	3	11
All bats		9	24	71

Species name	Scientific name	Old fatalities	New fatalities	
			BV	GH
All small birds		27	19	47
All large birds		16	7	16
All birds		43	26	63

Table 2. Carcasses placed in detection trials at Golden Hills and Buena Vista Wind Projects, 5 September through 15 November 2017, Alameda and Contra Costa Counties, California. Bat species are listed in order of number placed, then birds. Sample sizes were N_1 for placements of fresh frozen carcasses the day before the search, N_2 for placements on randomized days within two weeks of the search, and N_3 for relocations of carcasses from Golden Hills to Buena Vista the day before the search.

Species	Placed			Body mass (g)		
	N_1	N_2	N_3	Mean	Low	High
Mexican free-tailed bat, *Tadarida brasiliensis*	71		17	7.5	1.9	15.6
Evening bat, *Nycticeius humeralis*	25		11	6.0	1.7	11.4
Little brown bat, *Myotis lucifugus*	6		5	2.2	1.0	3.5
Seminole bat, *Lasiurus seminolus*	3		1	15.1	9.1	19.8
Eastern pipistrelle, *Pipistrellus subvlafus*	2			5.2	4.6	5.8
Cliff swallow, *Hirundo pyrrhonota*	12	1		15.1	10.7	19.0
Oak titmouse, *Parus inornatus*	8	1		12.0	6.9	15.6
House finch, *Carpodacus mexicanus*	5	4		19.9	15.6	23.9
Anna's hummingbird, *Calypte anna*	5	3		3.6	2.5	5.7
Northern mockingbird, *Mimus polyglottos*	4	3		38.0	32.2	47.0
Bushtit, *Psaltriparus minimus*	4	3		4.3	3.7	5.0
Vaux's swift, *Chaetura vauxi*	4	2		12.5	11.1	14.9
Wilson's warbler, *Wilsonia pusilla*	3	2		5.9	4.9	7.7
Bewick's wren, *Thryomanes bewickii*	5			7.4	3.7	8.6
Swainson's thrush, *Catharus ustulatus*	3	2		54.0	38.1	69.0
Western bluebird, *Sialia mexicana*	3	1		20.6	17.8	25.5
Black-headed grosbeak, *Pheucticus melanocephalus*	3	1		39.7	34.2	50.8
Violet-green swallow, *Tachycineta thalassina*	2	2		14.2	11.6	18.0
Barn swallow, *Hirundo rustica*	2	2		16.4	14.4	18.3
Western scrub-jay, *Aphelocoma coerulescens*	2	1		59.2	55.5	64.9
American robin, *Turdus migratorius*	2	1		61.0	49.6	70.3
Black phoebe, *Sayornis nigricans*	1	2		15.8	14.5	17.9
Eurasian collared-dove, *Streptopelia decaocto*	3	1		73.3	44.3	90.0
Cedar waxwing, *Bombycilla cedrorum*	3			24.6	23.7	26.3
White-breasted nuthatch, *Sitta carolinensis*	2			14.0	13.6	14.3
Hooded Oriole, *Icterus cucullatus*	2			16.4	15.5	17.2
Golden-crowned sparrow, *Zonotrichia atricapilla*	2			14.9	7.7	22.0
California towhee, *Piplio fuscus*	2			35.8	28.0	43.6
Acorn woodpecker, *Melanerpes formicivorus*	2			69.3	57.6	81.0
Say's phoebe, *Sayornis saya*	2			25.3	4.9	45.6

Chestnut-backed chickadee, *Parus rufescens*	2			5.4	5.4	5.4
Prairie falcon, *Falco mexicanus*	1			57.4	57.4	57.4
Budgerigar, *Melopsittacus undulatus*	0	1		20.3	20.3	20.3
American goldfinch, *Carduelis tristis*	0	1		9.4	9.4	9.4
Mountain bluebird, *Sialia currucoides*	0	1		26.0	26.0	26.0
Western flycatcher, *Empidonax difficilis*	1			9.7	9.7	9.7
Hermit thrush, *Catharus guttatus*	0	1		17.4	17.4	17.4
American crow, *Corvus brachyrhynchos*	1			179.8	179.8	179.8
Mourning dove, *Zenaida macroura*	1			107.9	107.9	107.9
White-crowned sparrow, *Zonotrichia leucophrys*	1			20.4	20.4	20.4
California quail, *Callipepla californica*	1			184.5	184.5	184.5
Northern rough-winged swallow, *Stelgidopteryx serripennis*	1			13.9	13.9	13.9
Spotted towhee, *Piplio erythrophthalmus*	1			27.8	27.8	27.8
Brewer's blackbird, *Euphagus cyanocephalus*	1					

Table 3. Searcher detection rate, *S*, regressed on increasing 10-m distance increments from wind turbine.

Searcher	Trials	a	b	r^2	SE	P
Dog team	Bats	1.000	-0.0000	0.00	0.00	
Dog team	Birds	0.970	-0.0020	0.04	0.16	
Humans	Bats	0.174	-0.0015	0.16	0.08	<0.10
Humans	Birds	0.612	-0.0031	0.21	0.15	<0.10

Table 4. Proportion of trial carcasses remaining and mean daily proportion of carcasses remaining when measured by trial administrator carcass checks only and by combined carcass checks and dog search detections at the Golden Hills and Buena Vista Wind Energy Projects, Altamont Pass Wind Resource Area, California, Fall 2017.

Taxa	Search interval (*I*, days)	Proportion carcasses remaining (R_i)		Mean daily proportion carcasses remaining (R_C)	
		Carcass checks	Carcass checks and dog searches	Carcass checks	Carcass checks and dog searches
Bats	1	0.86	0.90	0.88	0.94
Bats	7	0.39	0.40	0.68	0.74
Bats	14	0.18	0.19	0.48	0.55
Bats	28	0.03	0.04	0.36	0.43
Birds	1	0.76	0.80	0.87	0.87
Birds	7	0.35	0.41	0.58	0.68
Birds	14	0.21	0.27	0.43	0.54
Birds	28	0.07	0.12	0.34	0.45

Table 5. Logistic models of cumulative human-found fatalities in 10-m distance increments from wind turbines to the maximum search radius at Vasco Winds (VW) and Golden Hills (GH) Energy Projects, Altamont Pass Wind Resource Area, California, 2012-2015.

Site	Taxa	Model coefficients			r^2	RMSE	Model-predicted asymptote of cumulative fatalities	
		μ	a	b			Distance from turbine (m)	Proportion within max search radius
VW	Bats	45.39	0.29	0.937	0.96	90.76	99	1.00
VW	Small birds	84.58	0.15	0.957	0.99	42.77	159	0.89
VW	Large birds	60.43	0.12	0.966	0.97	75.27	173	0.84
GH	All birds	21.90	0.61	0.953	0.98	11.15	119	0.92

Table 6. Logistic models of cumulative dog-found fatalities in 10-m distance increments from wind turbines to the maximum search radius at Golden Hills (GH) and Buena Vista (BV) Energy Projects, Altamont Pass Wind Resource Area, California, fall 2017.

		Model coefficients					Model-predicted asymptote of cumulative fatalities	
Site	Taxa	μ	a	b	r^2	RMSE	Distance from turbine (m)	Proportion within max search radius
GH	Bats	78.86	0.16	0.962	0.98	109.14	177	0.86
GH	Small birds	52.15	0.58	0.954	0.99	24.77	156	0.86
GH	Large birds	17.93	9.18	0.942	0.98	6.02	120	0.79
GH	All birds	73.89	0.48	0.956	0.99	29.71	173	0.80
BV	Bats	25.96	1.22	0.915	0.99	5.16	76	0.96
BV	Small birds	21.63	3.36	0.936	1.00	0.61	110	0.74
BV	Large birds	7.91	18.74	0.917	0.98	1.12	80	0.89
BV	All birds	28.79	3.13	0.929	1.00	2.55	108	0.80

Table 7. Estimated fatalities $\hat{F}$ of bats and small birds killed by wind turbines during our Fall 2017 study at operational wind turbines in the Buena Vista (BV) and Golden Hills (GH) projects in the Altamont Pass Wind Resource Area, California, where the number of carcasses found F was divided by carcass persistence rate R_C, searcher detection rate S, maximum search radius bias d, and proportion of wind turbines in the project searched. We used 28-day R_C values to represent first visits, and R_C representing average search interval for later visits.

Taxa	Project	Search	No. found, F	Adjustments			Sampled portion of project	Point estimate, $\hat{F}$
				R_C	S	d		
Bats	BV	1st	17	0.43	0.93	0.96	0.658	67.3
Bats	BV	2nd	1	0.55	0.93	0.96	0.105	19.4
Bats	GH	1st	39	0.43	1.00	0.86	0.667	158.1
Bats	GH	2nd	13	0.55	1.00	0.86	0.396	69.4
Small birds	BV	1st	10	0.45	0.84	0.74	0.658	54.3
Small birds	BV	2nd-3rd	0	0.54	0.84	0.74	0.105	0
Small birds	GH	1st	22	0.45	0.91	0.86	0.667	93.7
Small birds	GH	2nd-3rd	25	0.54	0.91	0.86	0.396	149.4

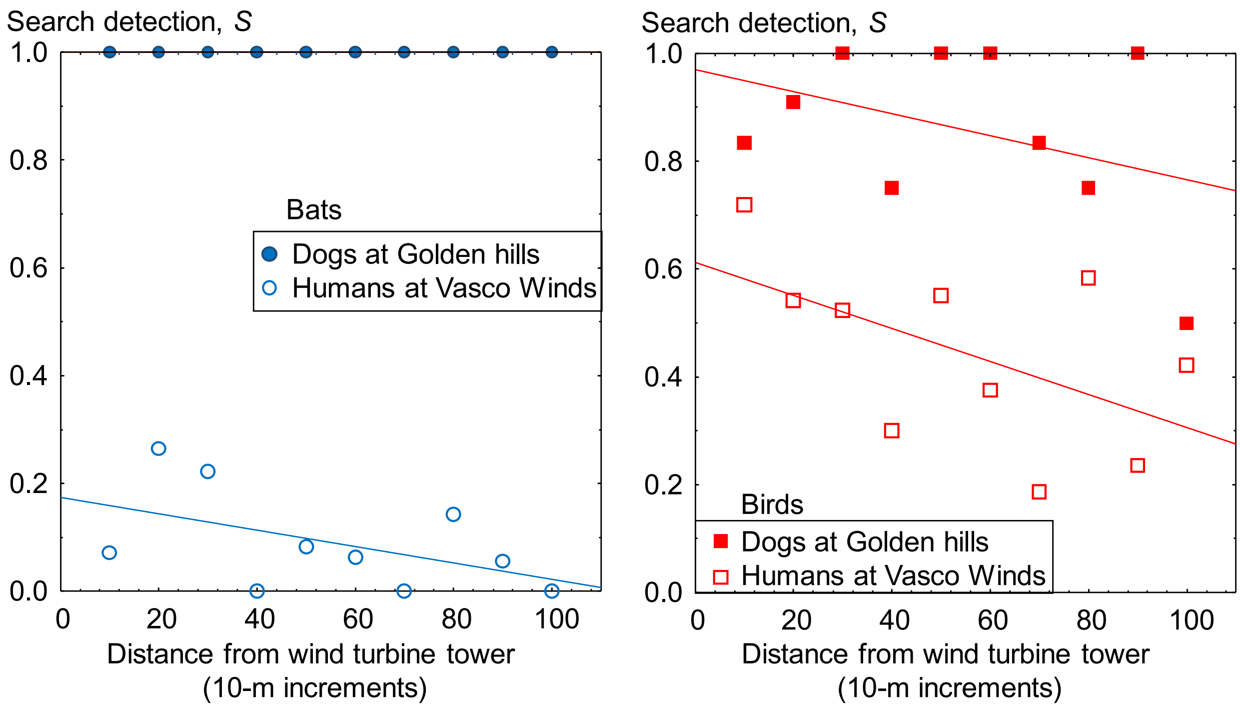

Figure 1. Searcher detection rates of bats (left) and birds (right) did not change significantly with increasing distance from the wind turbine at Vasco Winds, where humans were the searchers, and Golden Hills, where dog teams were the searchers. However, searcher detection using dogs was higher for trial bird carcasses and much higher for trial bat carcasses.

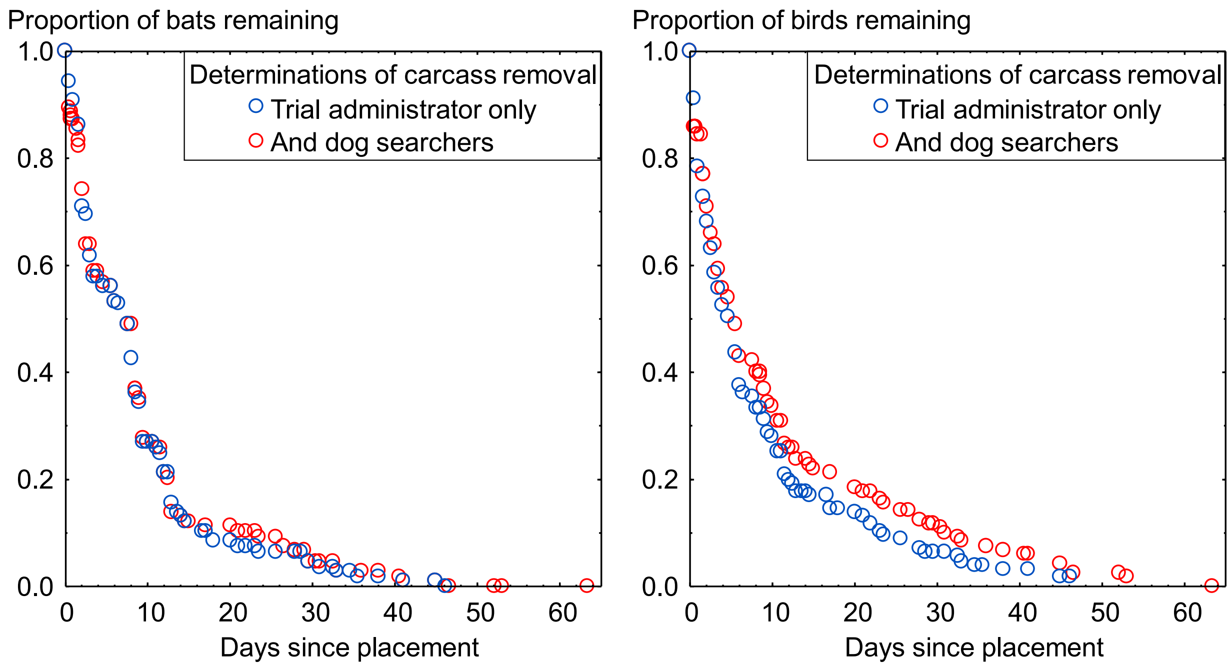

Figure 2. Carcass persistence by day since placement for bats (left) and small birds (right) and as determined by the trial administrator's carcass checks (blue) and both the trial administrator's carcass checks and fatality searches using dogs (red) at Golden Hills and Buena Vista Wind Projects, 2017.

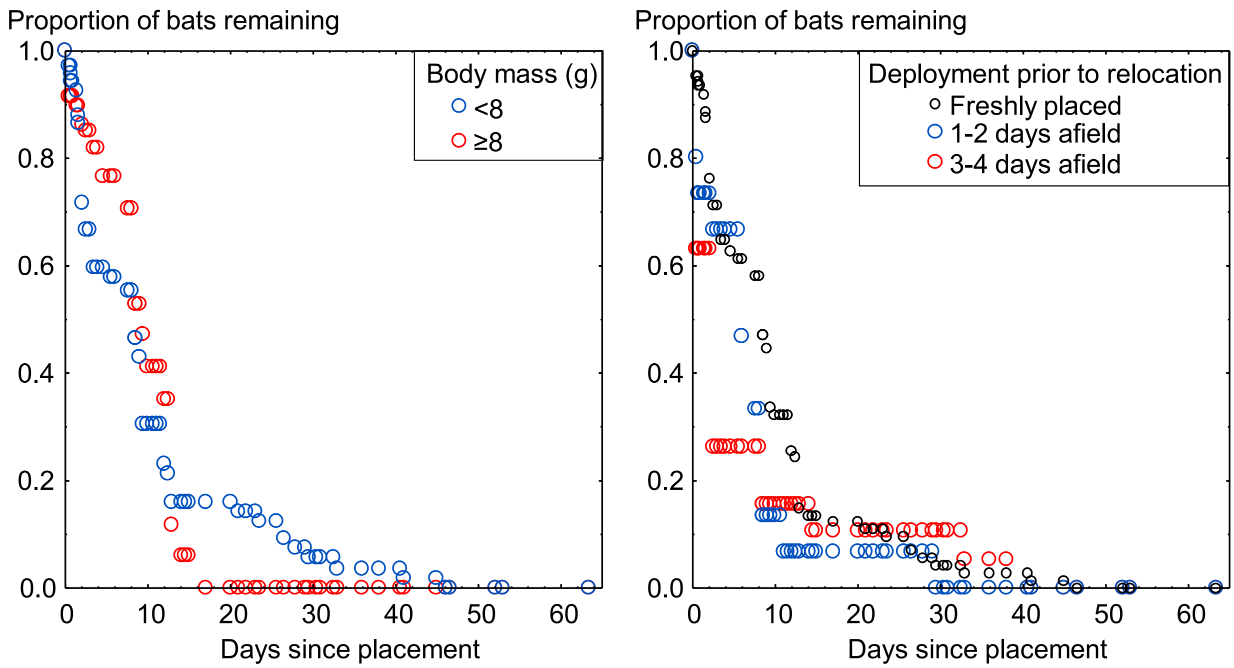

Figure 3. Bat carcass persistence by body mass (left graph) and freshness when placed (right graph) at Golden Hills and Buena Vista Wind Projects, 2017, as status-checked by both a trial administrator and the dog team fatality searches.

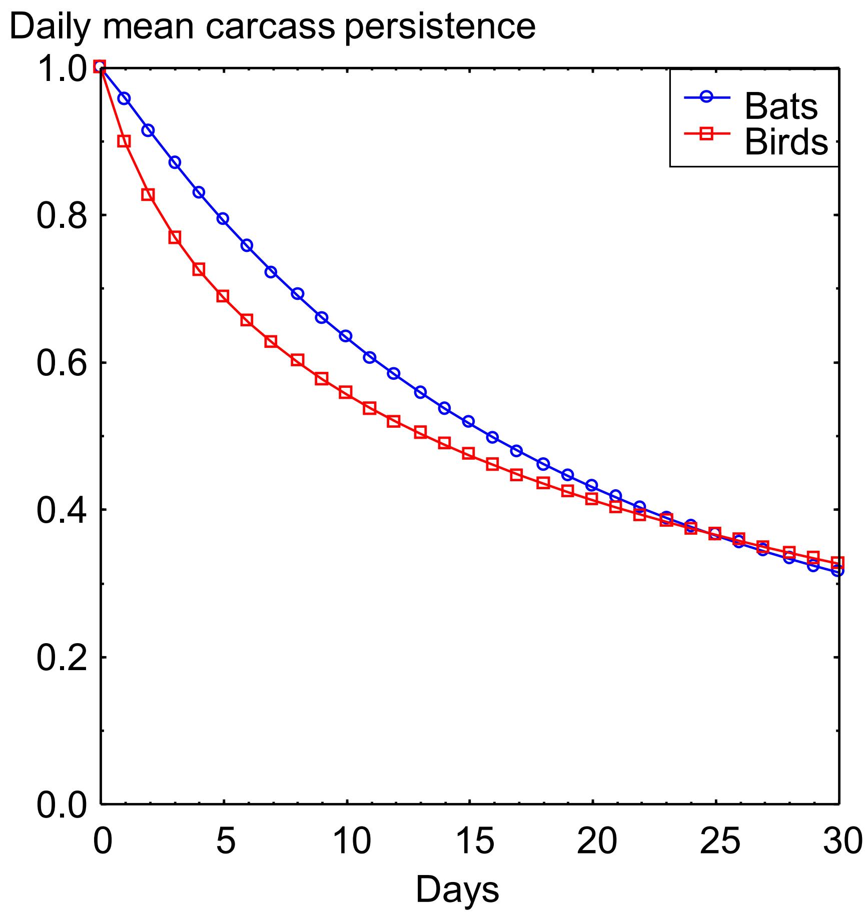

Figure 4. Daily mean carcass persistence rates, R_C, of bats and small birds placed in detection trials and status checked by both a trial administrator and the dog team fatality searches. Only freshly thawed bat carcasses were used for this graph.

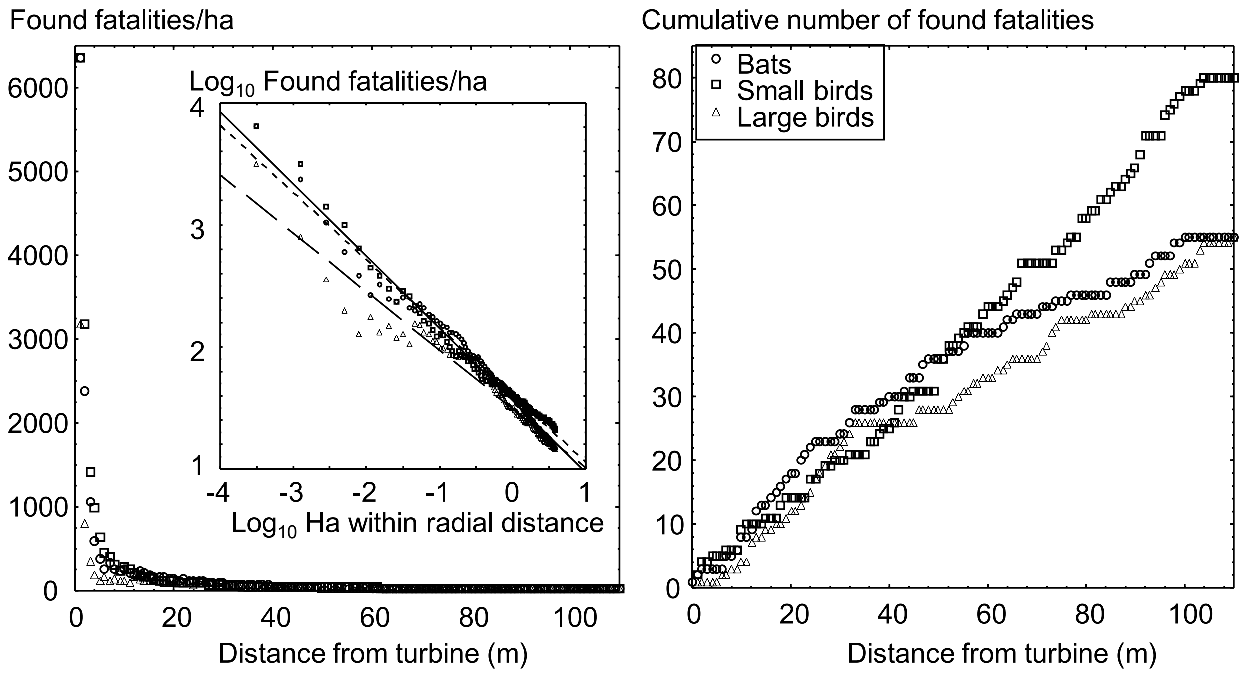

Figure 5. Found fatalities/ha found by human searchers at Vasco Winds declined rapidly with increasing distance from the turbine for bats and birds (left graph), consistent with characterizations by Huso (2010) and Huso et al. (2014, 2016). However, the density metric – fatalities/ha – was a function of the area within incrementally larger radial distances from the turbine (inset, left graph; solid line fit to bats, short dashed line fit to small birds, long dashed line fit to large birds). Cumulative numbers of found fatalities increased nearly linearly with increasing distance from the turbine (right graph).

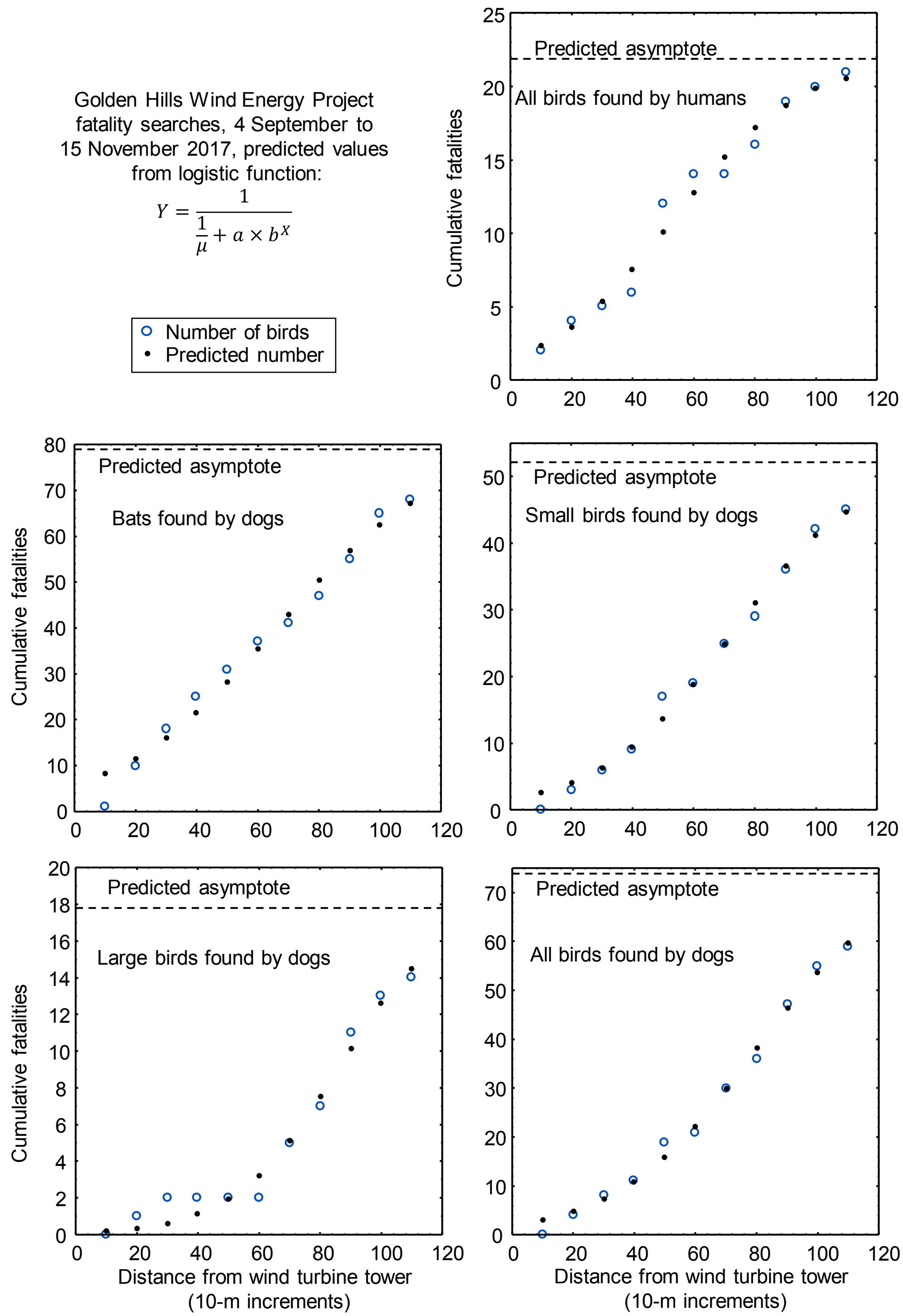

Figure 6. Cumulative numbers of fatalities found at Golden Hills based on human searchers (top right graph) and dog teams (other graphs).

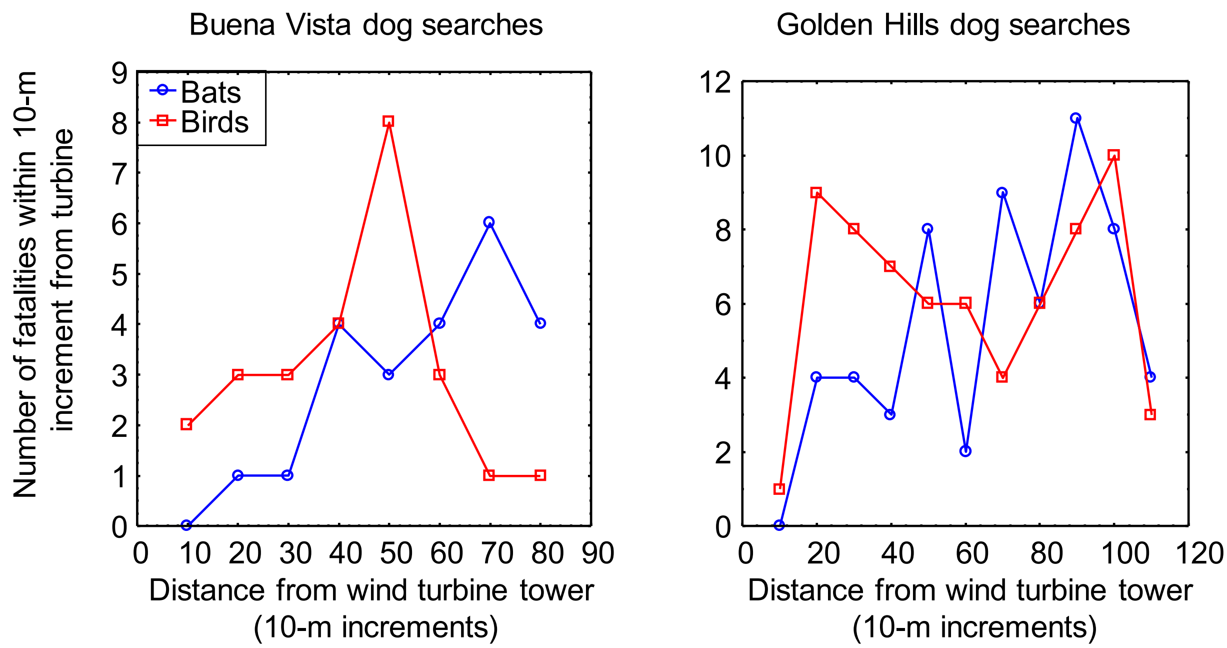

Figure 7. Comparisons of dog team fatality finds by distance from the turbine between Buena Vista (left graph) and Golden Hills (right graph).

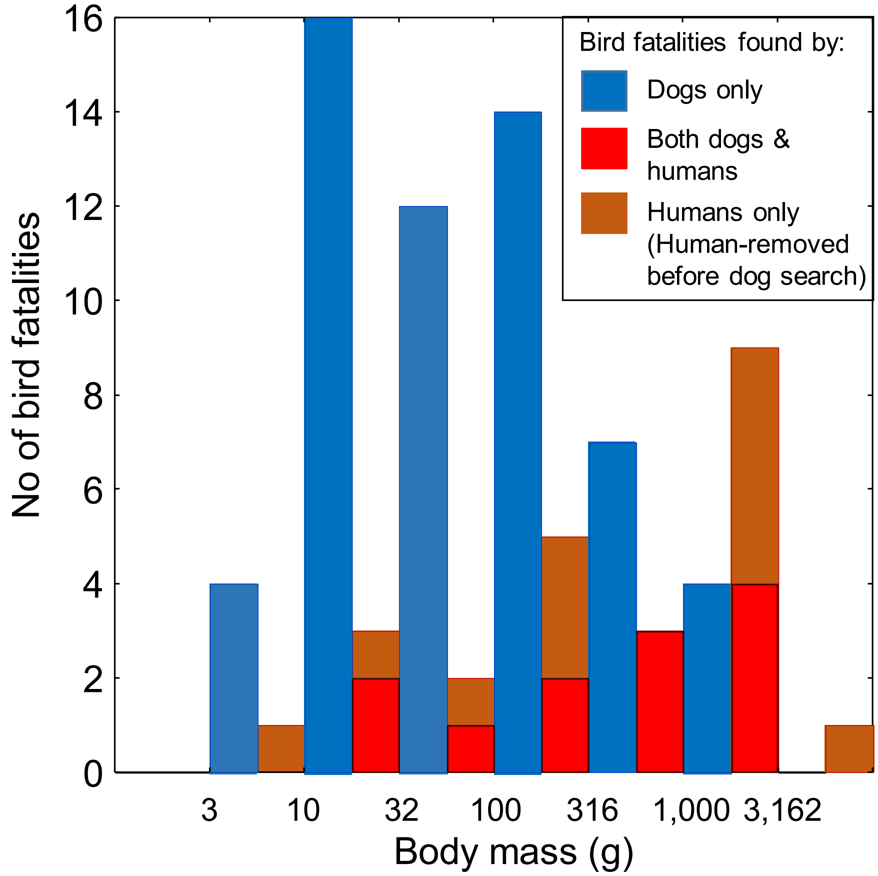

Figure 8. Bird fatality finds by human searchers were skewed toward larger birds, whereas dogs found increasingly larger proportions of small birds with decreasing body mass at Golden Hills during overlapping monitoring efforts between the human searchers and dog team.