Relating Bat and Bird Passage Rates to Wind Turbine Collision Fatalities

Report #2 to the East Contra Costa County Habitat Conservancy Science and Research Grant Program (Conservancy Contract 2016-03)

17 July 2019

K. SHAWN SMALLWOOD,[1] *3108 Finch Street, Davis, CA 95616, USA*
DOUGLAS A. BELL, *East Bay Regional Park District, 2950 Peralta Oaks Court, Oakland, CA 94605, USA*

Screen-shot from video taken with thermal-imaging camera of bat after passing through rotor plane of non-operative 1-MW Mitsubishi wind turbine at Buena Vista Wind Farm, Contra Costa County, California (Image: Shawn Smallwood).

[1] *Email: puma@dcn.org*

Relating Bat and Bird Passage Rates to Wind Turbine Collision Fatalities

ABSTRACT - As wind energy expands, the need grows for macro- and micro-siting of wind turbines to minimize impacts to nocturnal birds and bats. It remains unknown, however, whether activity patterns observed in preconstruction surveys can predict fatality rates. We related wind turbine passage rates of birds and bats observed via thermal-imaging camera to next-day fatality searches by detection dogs to test whether passage rates and rates of near misses, flights disrupted by blade sweeps or rotor wake turbulence, and dangerous behaviors can predict fatalities. Nocturnal bird and bat activity peaked together around the full moon and a shift in winds to more westerly origin. Nightly bat passes through operable wind turbine rotors correlated significantly with next-day counts of fatalities/ha of bats ≤3 days since death ($r = 0.44$, $P<0.05$) and of bats ≤7 days since death ($r = 0.35$, $P<0.05$), but not for bats >7 days since death or for birds. Logit regression revealed that the odds of dogs finding one or more freshly-killed bats were 4 times greater on mornings following nightly thermal imaging surveys when we counted 130 bat passes through the rotors as compared to nights when we counted 0 bat passes. The odds of next-day fatality finds increased with observed near-misses and disrupted flights, and more of these were recorded early during the migration season. Our rates of observed bat collisions would predict 4 times the fatalities that we found using dogs with a measured detection rate of 96%, and consistent with this prediction, our dogs found only 1 of 4 bats seen colliding with turbine blades. The possibility exists that our best estimates of bat fatalities are biased low by crippling bias.

INTRODUCTION

Based on different methods and data sources, USA wind turbines in 2012 were estimated to have killed 600,000 (Hayes 2013) to 888,000 (Smallwood 2013) bats, 214,000 to 368,000 small birds (Erickson et al. 2014), and 234,000 (Loss et al. 2013) to 573,000 (Smallwood 2013) birds of all sizes. Annual fatality numbers undoubtedly increased with the near doubling of installed wind energy capacity by 2018 (https://www.awea.org/wind-101/basics-of-wind-energy/wind-facts-at-a-glance, last accessed 27 February 2019). As wind energy continues to expand, it is imperative that scientists learn whether preconstruction surveys can predict wind turbine impacts on bats and migratory small birds (Kunz et al. 2007). It needs to be known whether preconstruction activity levels or passage rates through planned rotor-swept airspace correlate with post-construction fatality rates. Accurate fatality rate predictions are needed for deciding whether particular wind project sites would cause unreasonable impacts, and for informing micro-siting decisions (Smallwood and Neher 2017, Smallwood et al 2017) or operational curtailment strategies (Arnett et al. 2011, 2013; Behr et al. 2017) to minimize impacts.

Measured across multiple wind projects in Canada and the USA, bat fatality rates did not correlate significantly with preconstruction activity levels measured by bat acoustic detectors (Hein et al. 2013). No similar test has been reported for nocturnally active small birds, e.g., neotropical migrants, nor has a test been reported specific to passage rates through planned rotor-swept airspace for either bats or small birds. Preconstruction activity levels and passage rates could also be measured using radar or thermal-imaging cameras, but no matter how derived, preconstruction activity rates carrying error and potential biases would have to be related, one or more years later, to fatality rates carrying their own suites of error and biases (Smallwood 2007, 2013, 2017; Smallwood et al. 2013, 2018).

Adding to the frustrating result of Hein et al. (2013), fatality rates of bats and small birds measured from daily searches at 48 wind turbines in the Solano Wind Resource Area did not correlate significantly with the previous night's nocturnal activity rates measured by marine radar, acoustic bat detectors, and thermal-imaging goggles (Johnston et al. 2013). Activity rates and fatality rates measured more closely in time, as they were by Johnston et al. (2013), stood a better chance of revealing a correlation than would preconstruction activity levels and post-construction fatalities. Nevertheless, substantial biases and potentially large sources of error loom large when relating fatality rates to activity rates. Activity rates can be biased by placement of acoustic detectors due to limited range caused by sound attenuation (Adams 2013) and by variation in activities by height above ground among bat species (Weller and Baldwind 2011, Roemer et al. 2017). Ground-mounted detectors will miss bats flying at rotor height and nacelle-mounted detectors will miss bats flying through the outer two-thirds of modern turbine's rotor-swept airspace (or preconstruction equivalent) (Adams 2013). Detector range also varies by model, atmospheric conditions, and inter-specific variation in call frequencies (Adams 2013), and the same is true for thermal-imaging cameras. For both radar and thermal imaging, identifying targets to bats, birds, and insects requires accurate assumptions about size, flight speed and behavior. Exemplifying bias related to fatality rates, Johnston et al.'s (2013) fatality searches extended only to 60 m from each turbine, which would have missed many bat fatalities falling beyond 60 m from modern wind turbines (Smallwood 2013, Smallwood et al. in review).

Accurately predicting fatality rates from preconstruction activity levels or passage rates would require accurate fatality estimates, accurate identification of nocturnally observed subjects as bats, birds, or insects, appropriate sampling of the affected airspace, and confirmation that either activity levels and passage behavior would remain unchanged after wind turbines are installed and operative or the changes are predictable. Accuracy in fatality rate estimates increase by detecting more of the available fatalities (Smallwood 2017, Smallwood et al. 2018). Arnett (2006) and Matthews et al. (2013) argued that use of scent-detection dogs would increase carcass detection rates, a method that we employed to great effect by detecting nearly all volitionally-placed bats and small birds (Smallwood et al. in review). Another approach would be to decrease the time interval between searches to find more of the fatalities before vertebrate scavengers find and remove them (Smallwood et al. 2010, Smallwood 2017).

Using a thermal-imaging camera since 2012, Smallwood (2016) recorded bats passing through all parts of the rotor, more so at the edge of the rotor plane where nacelle-mounted acoustic detectors would fail to detect bat passages. Thermal-imaging enables the observer to see heat-distribution across the body, wing-flaps, and dangling legs of some insects – additional attributes useful for identifying subjects as bats, birds or insects. Thermal imaging can reveal behavior patterns that can be inferred as reactions to wind turbines, to prey, and to other bats or birds. Certain behaviors observable through thermal imaging might be more predictive of collision fatalities than simple passage rates, such as hovering near operative rotors, interacting with other bats or birds, chasing blades, repeatedly diving through the rotor plane, passing through the rotor parallel rather than perpendicular to the rotor plane, or approaching portions of the rotor emitting more heat (Kunz et al. 2007, Horn et al. 2008, Cryan et al. 2014). Whereas these types of behaviors are observable post-construction, their topographic and environmental contexts might help interpret preconstruction survey results.

As higher-than-expected bat fatality rates emerged from monitoring at the APWRA's repowered wind turbines, the question arose whether macro- and micro-siting of wind turbines might help minimize impacts on bats and small birds. Micro-siting reduced raptor fatalities at a repowered wind project (Brown et al. 2016), and could minimize impacts at proposed new wind projects (Smallwood et al. 2017). Micro-siting for bats and migratory small birds requires flight behavior data more closely tied to fatality finds than was necessary for raptors because carcasses of bats and small birds do not persist long. As a first step toward macro- and micro-siting, fatality finds need to be compared to bat and small bird passage rates recorded over overlapping time periods to determine if a relationship exists.

We focused on whether post-construction fatality rates of bats and small birds can be estimated with sufficient accuracy to discover meaningful relationships with passage rates. Our primary objective was to relate fatality finds to patterns of bat and small bird activity at wind turbines during the night preceding fatality searches. We aimed to more closely compare wind turbine fatalities to passage rates or behavior rates, near-misses, or angles of entry to the rotor plane observed the night before each fatality search. To meet our objective, we followed each night's observations at specific wind turbines with next-morning fatality searches using scent-detection dogs.

STUDY AREA

Our study 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. The Golden Hills Wind Energy project (Golden Hills) consisted of 48 1.79-MW General Electric (GE) wind turbines, 32 or which were accessible to us on privately held land in Alameda County. Two Mitsubishi turbines were on 45-m towers, 27 on 55-m towers, and 2 on 65-m towers. All GE turbines were on 80-m towers. Both projects were on steeply rolling hills covered by cattle-grazed annual grasses. Elevations ranged 41 - 280 m at Buena Vista and 115 - 477 m at Golden Hills.

METHODS

To achieve our goal of comparing bat passage rates to fatality rates, we sought to maximize our variation in bat fatality finds by conducting fieldwork before, during, and after the seasonal peak of bat activity and previously documented fatalities in the APWRA. Bat activity peaks during the last week of September and first week of October, which also happens to generally coincide with a peak in nocturnal flights of small birds through the APWRA (Smallwood 2016). We surveyed for bats and small birds 15 September through 15 November 2018, 5 days per week. Nocturnal surveys lasted 3 hours per night, including at least 1 round of 5- to10-minute passage-rate scans per turbine per hour, covering 2 to 5 wind turbines per round. We searched for fatalities at the same turbines the following morning.

We performed nocturnal surveys between dusk and 3 hours after dusk, which is the time period corresponding with most bat activity (Limpens et al. 2013). Hourly we recorded each wind turbine's operational status, and air temperature, wind direction, and wind speed using a Kestrel wind meter. Using the thermal camera we also recorded temperatures of ground cover and the hottest portions of wind turbine nacelles, which were vents among Mitsubishi turbines and upper-rear flanks of nacelles among GE turbines. At intervals between timed passage rate surveys, we surveyed for individual bats and birds, which upon detection were tracked by panning the thermal camera to keep pace with the bat or bird to determine whether it targeted one or more wind turbines. We also video-recorded each timed passage rate survey to verify observations, assess degree of confidence in observed collisions, and to capture any missed bat or bird passages upon later viewing of the video.

A skilled dog handler – Collette Yee – and handler-in-training Skye Standish searched for fatalities using one of two scent-detection dogs at a time. The dogs – Captain and Jack – were trained by Conservation Canines with the Center of Conservation Biology, University of Washington. We searched in morning when conditions were optimal for scent detection. Each dog was given turns searching, then rested as the other dog took a turn. Search areas extended to 75 m from 31 1-MW Mitsubishi wind turbines in the Buena Vista Wind Energy project and to 105 m from 32 1.79-MW wind turbines in the Golden Hills Wind Energy project. Daily searches covered 2 to 3 turbines at Golden Hills or 3 to 5 turbines at Buena Vista. Dogs were led by leash along transects oriented perpendicular to the wind and separated by 10 m over most of the search area. Because few bat and small bird fatalities are found upwind of wind turbines (Smallwood 2016a, Brown et al. 2016), we allowed dogs off leash for a more cursory search within a 90° arc between 210° and 300° from the turbine, which corresponds to prevailing upwind directions in the APWRA. Within the intensive search areas we navigated transects using GPS and a Locus Map application on a phone along with visible flagging as needed. We tracked dogs using a Keychain Finder Transystem 860e GPS data logger. Standish mapped and photographed fatality finds using a Trimble GeoExplorer 6000 GPS, and identified carcasses to species. Found carcasses were left in place for possible repeat discovery.

We performed 151 fatality searches at 63 wind turbines from 4 September through 15 November 2017, 20 searches using only a human searcher through 13 September, and 131 searches using dogs thereafter. Standish searched 20 turbines once each from 4 through 13 September 2017. Our dogs searched 15 turbines once each and another 48 turbines twice to four times per turbine, averaging 25 days between searches (range 2 to 53 day intervals). At Golden Hills, we searched 12 turbines once, 17 turbines twice, and 3 turbines three times for a project total of 55 turbine searches. At Buena Vista, we searched 3 turbines once, 15 turbines twice, 9 turbines three times, and 4 turbines four times for a project total 76 turbine searches.

Buena Vista underwent a project-wide maintenance shutdown from 06:00 hours, 2nd October, through the end of our study. At Buena Vista we performed 28 turbine searches (26 turbines) and

48 turbine searches (31 turbines) before and after the shutdown, respectively, while at Golden Hills we performed 14 and 41 turbine searches (31 turbines) over the same time periods.

We related bat and bird fatality counts to the previous night's passages through the rotor plane of wind turbines, having also noted the wind turbine's operational status at the time of each passage. We defined passage as either a flight through the rotor plane or within 1 m of the rotor plane while flying parallel to the rotor axis, and we defined passage rate as the number of passages per hour per ha of rotor plane. We also related fatality counts to passage rates consisting of passages for which birds or bats nearly collided with a blade ("near misses") or were displaced or jostled by a blade sweep ("disrupted flights") or additionally exhibited "dangerous behaviors" such as chasing blades, investigating blades, interacting with other volant animals, fleeing, chasing or foraging for prey items, or other distracted behaviors. We also related fatality counts to observed collisions. After reviewing video of each animal passing through a rotor plane, we judged our accuracy of taxonomic identification on a percentage basis, and subsequently restricted most hypothesis-tests to birds and bats assigned ≥70% confidence.

RESULTS

Using dogs, we found 24 bat and 26 bird fatalities at Buena Vista and 71 bat and 63 bird fatalities at Golden Hills (Table 1). We estimated 59 bats (63%) and 20 birds (22%) died between 7 and 30 days of discovery, 14 bats (15%) and 4 birds (4%) died between 3 and 7 days, and 6 bats (6%) and 2 birds (2%) died within 3 days. Of the bird fatalities found by dogs, 74% were small (<280 g), but small birds composed 90% of birds estimated to have died between 7 and 30 days and 100% of birds estimated to have died both between 3 and 7 days and within 3 days of discovery.

Nightly counts of birds and bats peaked together around the time of a full moon and a shift in winds to more westerly origin (Fig. 1). Bat passage rates through operative wind turbine rotors correlated strongly between ≥70% and ≥90% confidence in subject identification as bats, but passage rates based on ≥90% confidence averaged 18% lower than those based on ≥70% confidence (Fig. 2).

Daily comparison of passage rates and fatality finds

Relating thermal imaging surveys to next-day fatality searches, nightly bat passes through operable wind turbine rotors correlated significantly with next-day counts of fatalities/ha of bats ≤3 days since death ($r = 0.44$, $P<0.05$) and of bats ≤7 days since death ($r = 0.35$, $P<0.05$), but we found no correlation for bats ≥7 days since death. For those surveys more closely covering the fall bat migration, from 20 September through 26 October, logit regression revealed that the odds of dogs finding one or more freshly-killed bats were 4 times greater on mornings following nightly thermal imaging surveys when we counted 130 bat passes through the rotors as compared to nights when we counted 0 bat passes (Figure 3). We found no significant correlations for small birds.

Daily comparison of passage rates and fatality finds by wind turbine

Throughout the study we found bird and bat fatalities judged to have died ≤7 days earlier (Figs. 4 and 5). During the same portion of the study period when we were seeing most of the near-misses and turbine-disrupted passage flights of bats, we found bat fatalities ≤7 days since death (Fig. 4). However, we did not find fresh bird fatalities until weeks after we saw most bird passages, including near-misses and disrupted flights through operative rotors. Most passages through operative rotors, including most of the near misses and disrupted flights, spanned the early portion of the bat and small bird migration peak when the waxing moon was <50% visible and winds were shifted to more westerly origin.

Our discovery of a bat fatality ≤3 days since death at a given wind turbine on a given day could be predicted from the previous night's bat passage rates through the rotor-swept airspaces of operative wind turbines (Table 2, Fig. 6), but not of inoperative wind turbines (Table 2). Our logit-regression models were not significant when restricting passages to observed collisions, likely due to insufficient sample size. Our best-fit logit regression included bat passages associated with ≥1 near miss or flight disruption (impact) caused by a passing blade's pressure wave or trailing vortex (Table 2). Logit regression models were either weak or not significant when relying on bat fatalities estimated as >3 days since death, or when relating bird fatalities to bird passage rates.

Fatality estimates from observed collisions

We sampled 0.36% of the 3,763 rotor-swept ha-hours between the 28 nights at Golden Hills and 10 nights pre-curtailment at Buena Vista totaling 114 hours of survey time (first 3 hours of darkness per night). The 4 bat collisions with wind turbines that we witnessed translated to 0.2939 collisions per rotor-swept ha-hours. This rate applied to the available 3,763 rotor-swept ha-hours, and assuming the first 3 hours of the night was when most bat collisions occurred, would predict 1,106 bat fatalities. The 1 observed collision at Buena Vista would predict 146 fatalities in 10 session-nights and the 3 observed collisions at Golden Hills would predict 910 fatalities in 28 session-nights, or 14.6/night at Buena Vista and 32.5/night at Golden Hills. Adjusting for project, size, observed collisions predict 0.384 fatalities/MW/night at Buena Vista and 0.378 fatalities/MW/night at Golden Hills. These rates multiplied by the number of turbine searches (26 at Buena Vista and 31 at Golden Hills during operable periods), the proportion of casualties deposited within the search radius (0.96 at Buena Vista and 0.86 at Golden Hills), and the first-night proportion of carcasses persisting (0.9) predict that we should have found 8.6 fresh bat fatalities at Buena Vista and 16.2 at Golden Hills. We found 2 fresh bat fatalities at Buena Vista and 4 at Golden Hills, where fresh included fatalities we judged having died within 3 days. Based on eye-witnessed collisions, we found 25% of the fresh bat fatalities that we should have found at both projects.

DISCUSSION

We were unable to predict small bird collision fatalities from previous-night's passage rates through wind turbines, but we were able to do so for recently-killed bats. Even with all bat species lumped together and a small number of bats found as fresh fatalities, bat fatality rates related significantly to the previous night's passage rates. Passage rates can be used to predict next-day bat fatalities, and predictions increase in accuracy when passage rates are defined by near-misses and turbine-disrupted flights. Wind direction and moon phase were also potentially predictive of fatalities. It remains to be determined, however, whether preconstruction passage rates through planned windswept airspace can also predict post-construction fatalities. It also remains to be determined whether passage rates can be used to predict collision risk based on wind turbine locations. Confounding these determinations is the fact that bats appear to target wind turbines by altering flight trajectories to pass through or near operating wind turbine rotors, likely on foraging runs (Foo et al. 2017).

Our inability to predict small bird fatalities from previous night's passage rates might have resulted from low accuracy in estimating time since death of found bird fatalities (Smallwood et al. 2018). Another likely contributing factor was frequent avoidance of operating wind turbines. Most incoming birds veered wide of, or ascended over, operating wind turbines. However, we confirmed what we earlier suspected -- that nocturnal migrants pass through the APWRA in a seasonal peak of abundance, and this peak generally corresponds with many small bird fatalities.

A question that emerged from our study was whether observed bat collisions serve as evidence that fatality monitoring might be underestimating bat impacts. Although our comparison of fatality estimates between dog searches and witnessed collisions lack confidence intervals, the difference was large enough to justify the question. Further justifying the question, of the 4 bat collisions we witnessed, next-morning dog searches found only 1 of them. Immediately following the standard search for one of the observed collision victims, Smallwood directed the dog team to the area where he saw the bat fall, and a second intensive search was performed without detecting the bat. That bat was either scavenged during the hours between its collision and the morning's fatality search, or it found refuge in one of the many available fossorial mammal burrows or left the site on its own volition. According to our detection trials using dogs, only 6% of bats are removed by scavengers within 1 day, so it was unlikely that scavengers removed all 3 carcasses of the witnessed collisions not found by next-morning dog searches. At the same time, if the bats were not removed, then our dogs likely would have found them because dogs found nearly all trial carcasses, including baby bats (Smallwood et al. In review). We found a live, injured Mexican free-tailed bat under the lip of a concrete pad supporting an electrical transformer box and a dead bat within a soil crack, and the dogs strongly indicated on a ground squirrel burrow, which we believe included a bat. Bats might often survive wind turbine injuries long enough to find cover within or outside the area searched by dogs. Bats struck by wind turbine blades sometimes dismember, and in high winds dismembered parts can drift far from the impact site, especially when the impact site is at the blade's 12:00 position (Smallwood unpublished data). We conclude that crippling bias (Smallwood 2007) and maximum search radius bias might often result in underestimated bat fatalities.

MANAGEMENT IMPLICATIONS

Although measured preconstruction activity levels of bats and small birds might facilitate decisions over the appropriateness of a proposed wind turbine project, they might never support micro-siting decisions. What might prove more instructive for micro-siting is discernment of spatial and temporal patterns of passage rates, near misses, and disrupted flights through existing wind turbine rotors. To this end, thermal imaging enables investigators to see bird and bat interactions with the entirely of wind turbine rotors, as well as flight behaviors and reactions. Thermal imaging also enables counts of insect passages. Combined with nacelle-mounted bat acoustic detectors, some of the bats observed via thermal-imaging camera could be identified to species, which would further elucidate the roles of terrain and location in passage rates, near misses and disrupted flights. Lastly, our observed collisions extrapolated from the sampled hr-ha of rotor-swept airspace during thermal-imaging surveys to the project-level operations over the surveyed periods predicted 4 times the number of bat fatalities than found by our dogs, and in fact our dogs found only 1 of 4 witnessed collision victims. The possibility exists that our best estimates of bat fatalities are biased low by crippling bias – either through the volitional departure of searchable areas by injured bats or their seeking refuge when grounded.

ACKNOWLEDGMENTS

This research was funded in part by the Gordon and Betty Moore Foundation. We are grateful to the Gordon and Betty Moore Foundation for its financial support which was administered through the East Contra Costa County Habitat Conservancy Science and Research Grant Program (Conservancy Contract 2016-03). We also thank the East Bay Regional Park District for additional funding and for assistance with access to the Buena Vista Wind Energy project located on its property. We thank Bryan Maddock and Leeward Renewable Energy LLC for access and assistance at the Buena Vista Wind Energy project, and Renee Culver and NextEra Energy Resources for access and assistance at Golden Hills Wind Energy project. We thank Heath Smith, Collette Yee and Skye Standish of Conservation Canines, Center of Conservation Biology, University of Washington, for their highly skilled dog handling. We also thank Jeff Smith and H. T. Harvey & Associates for assistance at Golden Hills. Our study would not have been possible without the generous donations of bird carcasses by Native Songbird Care and bat carcasses by Dr. Deborah Cottrell at West End Animal Hospital. Use of animal carcasses was authorized under permits from the U.S. Fish and Wildlife Service (MB135520-0) and the California Department of Fish and Wildlife (SC-00737). We thank Jennifer Brown of the former agency and Carie Battistone, Esther Burkett, Justin Garcia and Scott Osborn of the latter agency, for assistance with permitting. We are indebted to Debbie Woollett for working with us to train a dog we ended up not using, but this effort was important to our development. We are also greatly indebted to Karen Swaim for her generous donation of living space for our dog handler and detection dogs throughout this study. Lastly, we are grateful to the spirited efforts given us by Captain and Jack in the face of high temperatures, rugged terrain, and rattlesnakes.

REFERENCES CITED

Adams, A. 2013. Assessing and analyzing bat activity with acoustic monitoring: challenges and interpretations. PhD Thesis, The University of Western Ontario.

Arnett, E. 2006. A Preliminary Evaluation on the use of dogs to recover bat fatalities at wind energy facilities. Wildlife Society Bulletin 34:1440-1445.

Arnett, E. B., M. M. P. Huso, M. R. Schirmacher, and J. P. Hayes. 2011. Altering turbine speed reduces bat mortality at wind-energy facilities. Frontiers in Ecology and the Environment 9:209-214. DOI:10.1890/100103

Arnett, E. B., G. D. Johnson, W. P. Erickson, and C. D. Hein. 2013. A synthesis of operational mitigation studies to reduce bat fatalities at wind energy facilities in North America. Report to The National Renewable Energy Laboratory, Golden, Colorado.

Behr, O., R. Brinkmann, K. Hochradel, J. Mages, F. Korner-Nievergelt, I. Niermann, M. Reich, R. Simon, N. Weber and M. Nagy. 2017. Mitigating Bat Mortality with Turbine-Specific Curtailment Algorithms: A Model Based Approach. Pages 135-160 in Köppel, J., Editor, Wind Energy and Wildlife Impacts: Proceedings from the CWW2015 Conference. Springer. Cham, Switzerland.

Brown, K., K. S. Smallwood, J. Szewczak, and B. Karas. 2016. Final 2012-2015 Report Avian and Bat Monitoring Project Vasco Winds, LLC. Prepared for NextEra Energy Resources, Livermore, California.

Cryan, P. M., P. M. Gorresen, C. D. Hein, M. R. Schirmacher, R. H. Diehl, M. H. Huso, D. T. S. Hayman, P. D. Fricker, F. J. Bonaccorso, D. H. Johnson, K. Heist, and D. C. Dalton. 2014. Behavior of bats at wind turbines. Proceedings National Academy of Science 111:15126-15131.

Erickson, W. P., M. M. Wolfe, K. J. Bay, D. H. Johnson, and J. L. Gehring. 2014. A comprehensive analysis of small-passerine fatalities from collision with turbines at wind energy facilities. PLoS One 9(9): e107491. doi:10.1371/journal.pone.0107491.

Foo, C. F., V. J. Bennett, A. M. Hale, J. M. Korstian, A. J. Schildt, and D. A. Williams. 2017. Increasing evidence that bats actively forage at wind turbines. PeerJ5:e3985;DOI 10.7717/peerj.3985

Hayes, M. A. 2013. Bats Killed in Large Numbers at United States Wind Energy Facilities. BioScience 63:975-979.

Hein, C., W. Erickson, J. Gruver, K. Bay, and E. B. Arnett. 2012. Relating pre-construction bat activity and post-construction fatality to predict risk at wind energy facilities. PNWWRM IX. 2013. Proceedings of the Wind-Wildlife Research Meeting IX. Broomfield, CO. November 28-30, 2012. Prepared for the Wildlife Workgroup of the National Wind

Coordinating Collaborative by the American Wind Wildlife Institute, Washington, DC, Susan Savitt Schwartz, ed.

Horn, J. W., E. B. Arnett, and T. H. Kunz. 2008. Behavioral responses of bats to operating wind turbines. Journal of Wildlife Management 72:123-132.

Johnston, D. S., J. A. Howell, S. B. Terrill, N. Thorngate, J. Castle, J. P. Smith, Todd J. Mabee, J. H. Plissner, N. A. Schwab, P. M. Sanzenbacher, and C. M. Grinnell. 2013. Bird and bat movement patterns and mortality at the Montezuma Hills Wind Resource Area. California Energy Commission Publication Number CEC-500- 2013- 015 .

Kunz, T. H., E. B. Arnett, W. P. Erickson, A. R. Hoar, G. D. Johnson, R. P. Larkin, M. D. Strickland, R. W. Thresher, and M. D. Tuttle. 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Frontiers in Ecology and the Environment 5:315-324.

Limpens, H. J. G. A., M. Boonman, F. Korner-Nievergelt, E. A. Jansen, M. van der Valk, M. J. J. La Haye, S. Dirksen and S. J. Vreugdenhil. 2013. Wind turbines and bats in the Netherlands - Measuring and predicting. Report 2013.12, Zoogdiervereniging & Bureau Waardenburg.

Loss, S. R., T. Will, and P. P. Marra. 2013. Estimates of bird collision mortality at wind facilities in the contiguous United States. Biological Conservation 168:201–209.

Mathews, F., M. Swindells, R. Goodhead, T. A. August, P. Hardman, D. M. Linton, and D. J. Hosken. 2013. Effectiveness of search dogs compared with human observers in locating bat carcasses at wind-turbine sites: A blinded randomized trial. Wildlife Society Bulletin 37:34-40.

Roemer, C., T. Disca, A. Coulon, and Y. Bas. 2017. Bat flight height monitored from wind masts predicts mortality risk at wind farms. Biological Conservation215:116-122.

Smallwood, K. S. 2007. Estimating wind turbine-caused bird mortality. Journal of Wildlife Management 71:2781-2791.

Smallwood, K. S. 2013. Comparing bird and bat fatality-rate estimates among North American wind-energy projects. Wildlife Society Bulletin 37:19-33. + Online Supplemental Material.

Smallwood, K. S. 2016. Bird and bat impacts and behaviors at old wind turbines at Forebay, Altamont Pass Wind Resource Area. Report CEC-500-2016-066, California Energy Commission Public Interest Energy Research program, Sacramento, California. http://www.energy.ca.gov/2016publications/CEC-500-2016-066/CEC-500-2016-066.pdf

Smallwood, K. S. 2017. Long search intervals under-estimate bird and bat fatalities caused by wind turbines. Wildlife Society Bulletin 41:224-230.

Smallwood, K. S., and L. Neher. 2017. Comparing bird and bat use data for siting new wind power generation. Report CEC-500-2017-019, California Energy Commission Public Interest Energy Research program, Sacramento, California. http://www.energy.ca.gov/2017publications/ CEC-500-2017-019/CEC-500-2017-019.pdf and http://www.energy.ca.gov/2017publications/CEC-500-2017-019/CEC-500-2017-019-APA-F.pdf

Smallwood, K. S., L. Neher, and D. A. Bell. 2017. Siting to Minimize Raptor Collisions: an example from the Repowering Altamont Pass Wind Resource Area. M. Perrow, Ed., Wildlife and Wind Farms - Conflicts and Solutions, Volume 2. Pelagic Publishing, Exeter, United Kingdom. www.bit.ly/2v3cR9Q

Smallwood, K. S., D. A. Bell, S. A. Snyder, and J. E. DiDonato. 2010. Novel scavenger removal trials increase estimates of wind turbine-caused avian fatality rates. Journal of Wildlife Management 74: 1089-1097 + Online Supplemental Material.

Smallwood, K. S., D. A. Bell, B. Karas, and S. A. Snyder. 2013. Response to Huso and Erickson Comments on Novel Scavenger Removal Trials. Journal of Wildlife Management 77: 216-225.

Smallwood, K. S., D. A. Bell, E. L. Walther, E. Leyvas, S. Standish, J. Mount, B. Karas. 2018. Estimating wind turbine fatalities using integrated detection trials. Journal of Wildlife Management 82:1169-1184.

Weller, T. J. and J. A. Baldwin. 2011. Using echolocation monitoring to model bat occupancy and inform mitigations at wind energy facilities. Journal of Wildlife Management 76:619-631.

Table 1. Summary of fatalities found by Conservation Canines' dog teams at Buena Vista (BV) and Golden Hills (GH) during fall 2017, and fatalities per search before and after the Buena Vista wind turbines were shut down on 2 October 2017.

Species		Fatalities found			Fatalities/search			
					Buena Vista		Golden Hills	
		Old	BV	GH	Before	After	Before	After
Western red bat	*Lasiurus blossevillii*	0	4	1	0.143	0.000	0.071	0.000
Myotis spp.	*Myotis*	0	0	1	0.000	0.000	0.071	0.000
Mexican free-tailed bat	*Tadarida brasiliensis*	3	6	29	0.214	0.000	1.214	0.220
Hoary bat	*Lasiurus cinereus*	1	2	13	0.071	0.000	0.429	0.146
Bat spp.		5	12	27	0.357	0.000	0.857	0.293
Grebe sp.	Podicipedidae	1	0	1	0.000	0.000	0.000	0.000
Mallard	*Anas platyrhynchos*	0	0	1	0.000	0.000	0.071	0.000
Turkey vulture	*Cathartes aura*	2	0	2	0.000	0.000	0.000	0.000
Northern harrier	*Circus cyaneus*	1	1	0	0.000	0.000	0.000	0.000
White-tailed kite	*Elanus leucurus*	1	1	0	0.000	0.000	0.000	0.000
Red-tailed hawk	Buteo jamaicensis	0	0	3	0.000	0.000	0.143	0.024
Large raptor		1	0	1	0.000	0.000	0.000	0.000
American kestrel	*Falco sparverius*	2	4	1	0.071	0.000	0.071	0.000
Prairie falcon	*Falco mexicanus*	1	1	0	0.000	0.000	0.000	0.000
Rock pigeon	*Columba livia*	1	1	0	0.000	0.000	0.000	0.000
Barn owl	*Tyto alba*	0	1	0	0.036	0.000	0.000	0.000
Burrowing owl	*Athene cunicularia*	1	0	4	0.000	0.000	0.214	0.000
White-throated swift	*Aeronautes saxatalis*	1	1	0	0.000	0.000	0.000	0.000
Pacific-slope flycatcher	*Empidonax difficilis*	0	1	0	0.036	0.000	0.000	0.000
Horned lark	*Eremophila alpestris*	10	2	10	0.000	0.000	0.071	0.024
Northern rough-winged swallow	*Stelgidopteryx serripennis*	0	0	2	0.000	0.000	0.000	0.049
Bewick's wren	*Thryomanes bewickii*	0	0	1	0.000	0.000	0.071	0.000
House wren	*Troglodytes aedon*	0	0	1	0.000	0.000	0.071	0.000
Ruby-crowned kinglet	*Regulus calendula*	0	0	2	0.000	0.000	0.000	0.049
American pipet	*Anthus rubescens*	1	0	2	0.000	0.000	0.000	0.024
Warbler sp.	Parulidae	0	0	1	0.000	0.000	0.071	0.000
Black-throated gray warbler	*Dendroica nigrescens*	1	0	1	0.000	0.000	0.000	0.000
Townsend's warbler	*Dendroica townsendi*	0	1	0	0.036	0.000	0.000	0.000
Lincoln's sparrow	*Melospiza lincolnii*	0	0	1	0.000	0.000	0.000	0.024
Dark-eyed junco	*Junco hyemalis*	0	0	1	0.000	0.000	0.000	0.024
Blackbird sp.	Icteridae	1	0	1	0.000	0.000	0.000	0.000
Brown-headed cowbird	*Sturnella neglecta*	1	0	1	0.000	0.000	0.000	0.000
Western meadowlark	*Molothrus ater*	6	7	7	0.107	0.063	0.000	0.049
Large bird		8	2	7	0.000	0.000	0.000	0.024
Medium bird		0	0	1	0.000	0.000	0.071	0.000
Small bird		3	3	11	0.036	0.021	0.286	0.122
All bats		9	24	71	0.786	0.000	2.643	0.659

Species		Fatalities found			Fatalities/search			
					Buena Vista		Golden Hills	
		Old	BV	GH	Before	After	Before	After
All small birds		27	19	47	0.286	0.083	0.857	0.366
All large birds		16	7	16	0.036	0.000	0.286	0.049
All birds		43	26	63	0.321	0.083	1.143	0.415

Table 2. Six fatalities of bats ≤3 days since death logit-regressed on the previous night's counts of bats with ≥70% or ≥90% confidence in taxonomic assignment passing through the rotor-swept airspace of operative, inoperative or any (all) wind turbines and also observed colliding with a blade or displaced or jostled by blade's pressure wave or trailing vortex (flight impact) or otherwise experiencing ≥1 near miss or displaying distracted behavior such as approaching wind turbine parts in an investigative manner or interacting with another volant animals such as mobbing, harassing, following, approaching, fleeing, or pursuing prey. Under Logit regression, *a* and *b* represent model parameter estimates, final loss value was derived from a maximum likelihood function, and χ^2 measured the goodness of fit with 1 DF and t indicated $0.05 < P < 0.10$ and * indicated $P < 0.05$.

Minimum confidence in bat ID (%)	Wind turbine status	Additional observation on passage hazard	Logit regression			
			a	b	Final loss	χ^2
70	Operative	None	-3.5491	0.0134	21.73	5.44*
90	Operative	None	-3.5621	0.0176	21.69	5.52*
70	All	None				NS
90	All	None				NS
70 or 90	Inoperative	None				NS
70	All	Collided	-3.2424	0.1818	22.67	3.57^t
90	All	Collided	-3.2424	0.1818	22.67	3.57^t
70	Operative	Flight impact or ≥1 near miss	-3.4827	0.0234	21.22	6.47*
90	Operative	Flight impact or ≥1 near miss	-3.5383	0.0323	20.94	7.02*
70	Operative	Flight impact or ≥1 near miss or distracting behavior	-3.4119	0.0132	22.53	3.86*
90	Operative	Flight impact or ≥1 near miss or distracted behavior				NS

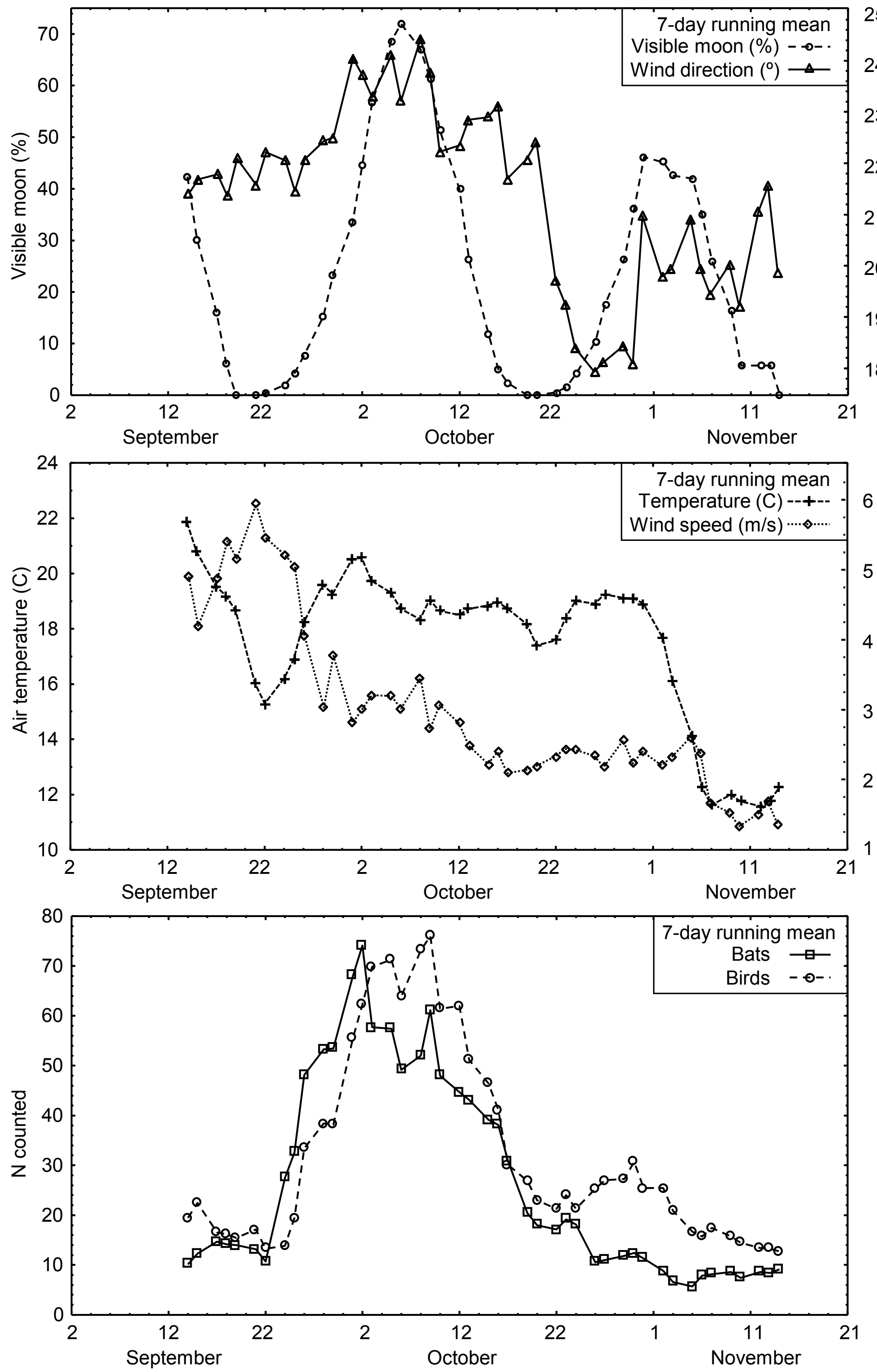

Figure 1. Running means (7-days) of visible moon and wind direction (top graph), air temperature (C) and wind speed (m/s) at ground level (middle graph), and nightly counts of all bats and birds observed flying (bottom graph) during surveys in the Altamont Pass Wind Resource Area, California, 4 September through 14 November 2017.

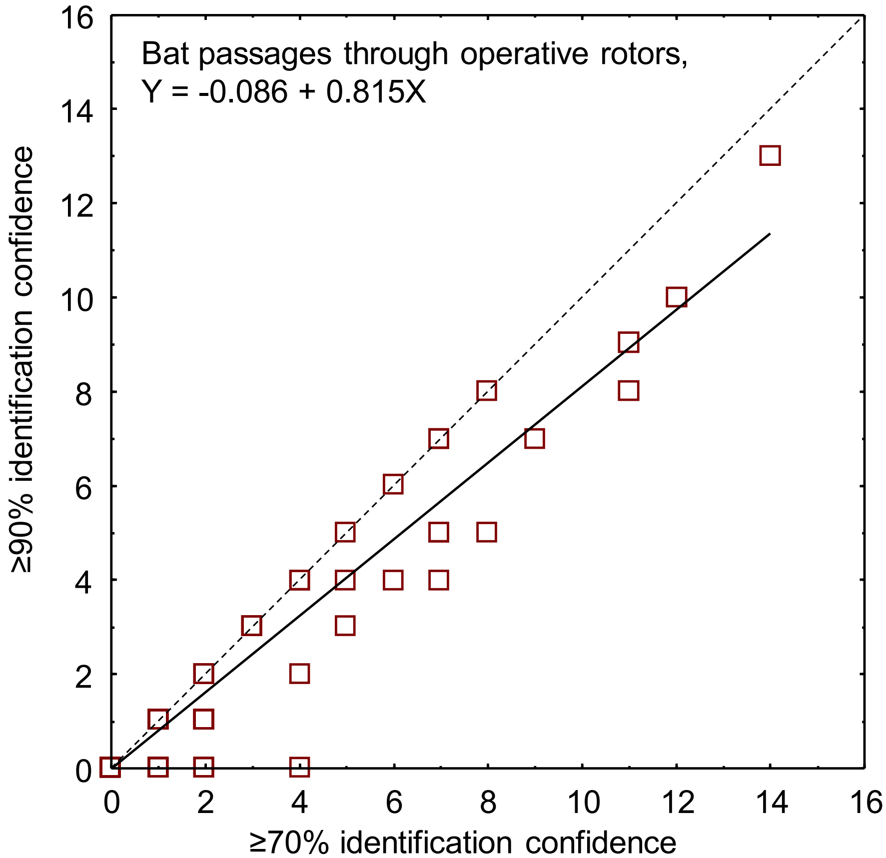

Figure 2. Bat passage rates through operative wind turbine rotors correlated strongly between volant animals having been assigned ≥90% and ≥70% confidence in correct identification as bats in the Buena Vista and Golden Hills Wind Energy Projects, Altamont Pass Wind Resource Area, California, Fall 2017.

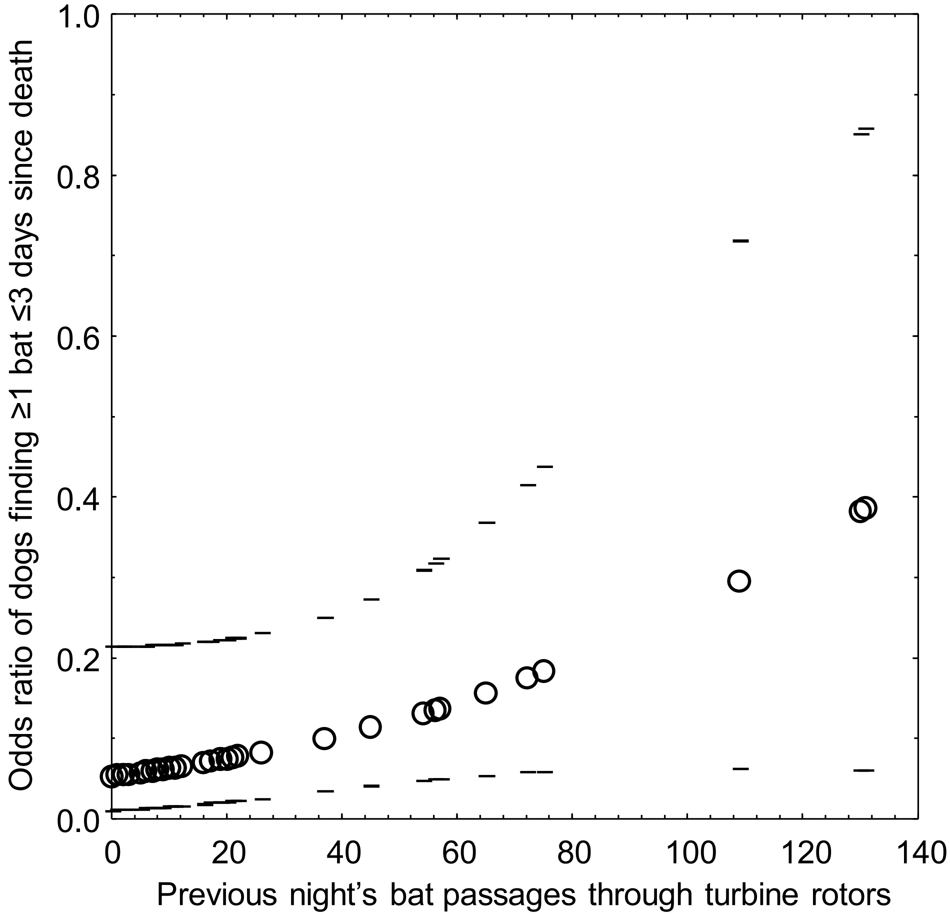

Figure 3. Odds ratio (95% CI) of finding at least 1 bat dead ≤3 days logit-regressed on the number of previous-night bat passes through rotors of the same wind turbines searched by dogs for fatalities at Golden Hills and Buena Vista Wind Energy projects, 20 September through 26 October, 2017.

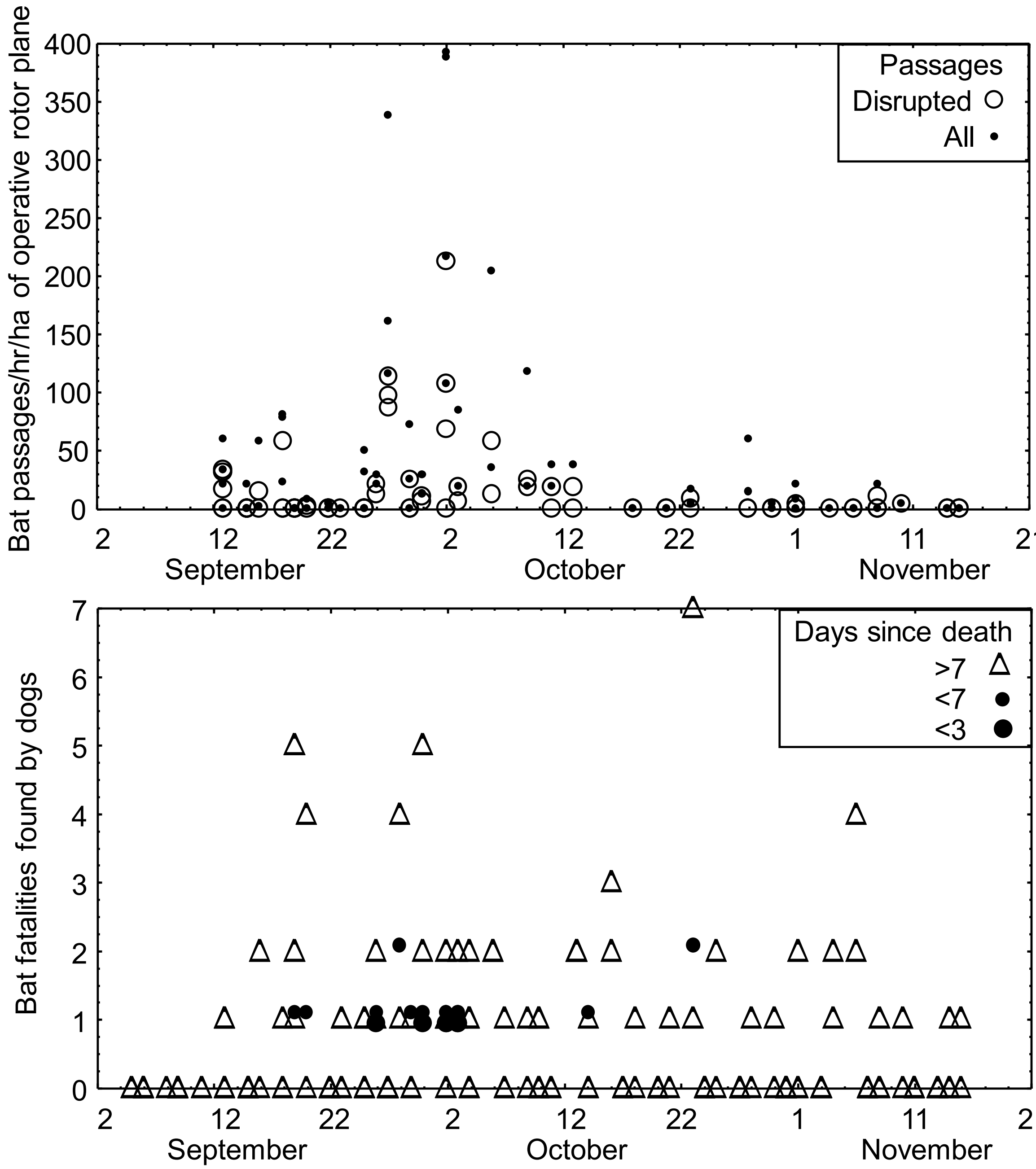

Figure 4. Bat passage rates through operative wind turbine rotors (top) corresponded with next-day fatalities of bats estimated to have died within a week (bottom) in 2017 in the Golden Hills and Buena Vista Wind Projects, Contra Costa and Alameda Counties, California.

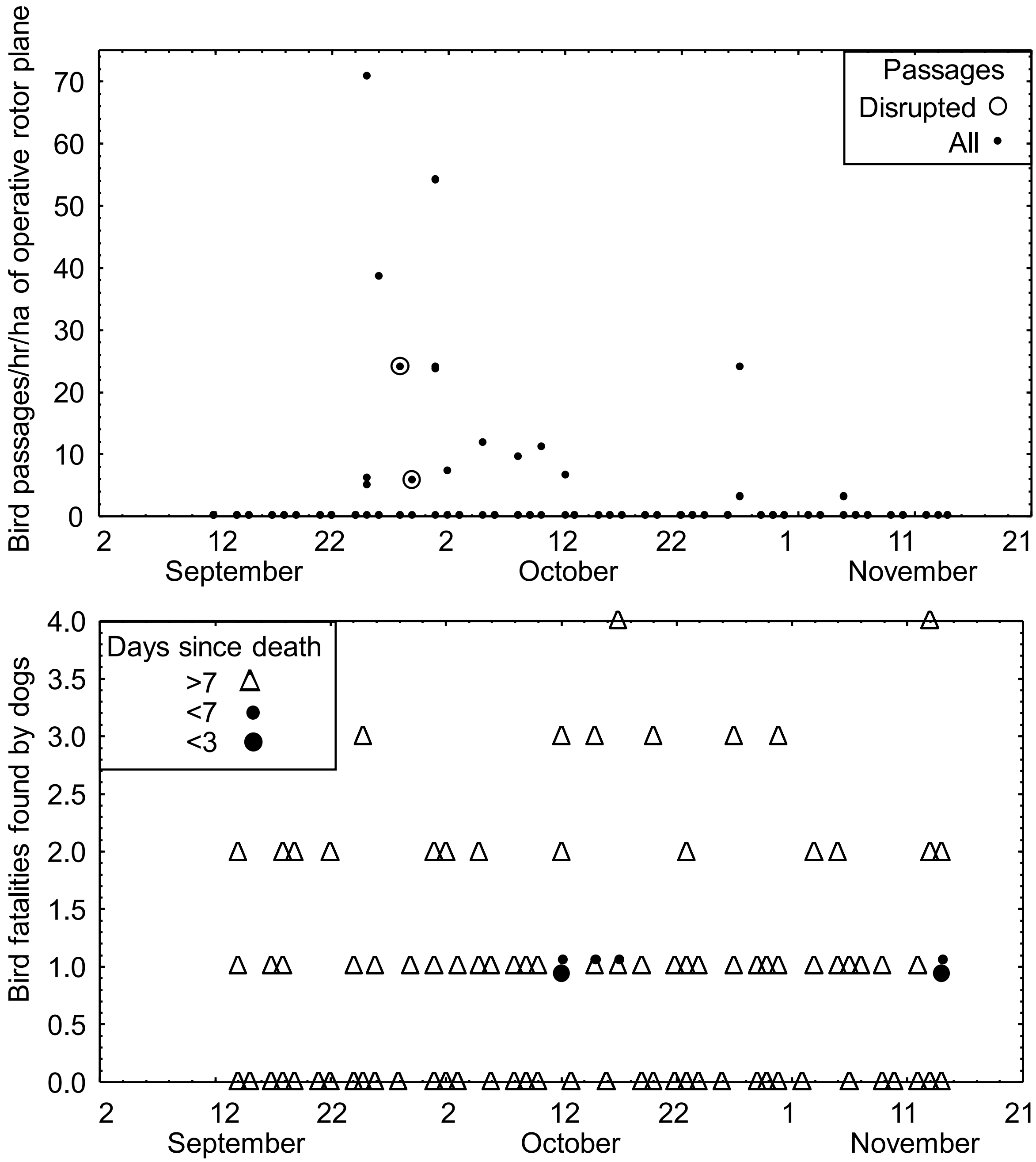

Figure 5. Bird passage rates through operative wind turbine rotors (top) did not correspond with next-day fatalities of birds estimated to have died within a week (bottom) in 2017 in the Golden Hills and Buena Vista Wind Projects, Contra Costa and Alameda Counties, California.

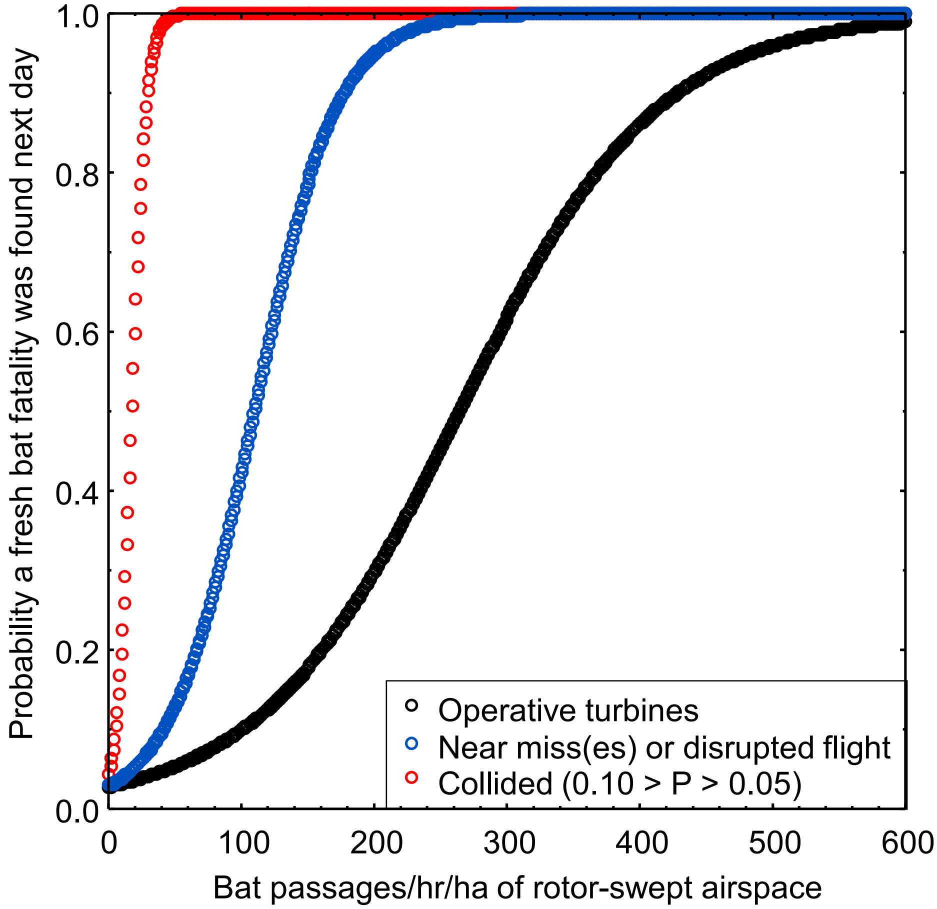

Figure 6. Logit-regression model predictions of the odds of dogs finding fresh bat fatalities the morning after thermal-imaging survey-counts of bats passing through operative turbine rotors (black), bats nearly colliding or experiencing disrupted flights due to pressure waves of passing blades or wake turbulence (blue), and bats seen colliding with a blade (red) in California's Altamont Pass Wind Resource Area, 15 September through 15 November 2017.