AWWI TECHNICAL REPORT:

A Summary of Bat Fatality Data in a Nationwide Database

Prepared By:

Taber Allison, PhD, AWWI Director of Research

Ryan Butryn, AWWIC Program Manager

7/25/2018

AWWI Technical Report:

A Summary of Bat Fatality Data in a Nationwide Database

American Wind Wildlife Institute
1110 Vermont Ave NW, Suite 950
Washington, DC 20005
www.awwi.org

For Release July 25, 2018

AWWI is a partnership of leaders in the wind industry, wildlife management agencies, and science and environmental organizations who collaborate on a shared mission: to facilitate timely and responsible development of wind energy while protecting wildlife and wildlife habitat.

Find this document online at www.awwi.org/resources/awwic-bat-technical-report/

Acknowledgments
We thank the wind companies who voluntarily contributed data to AWWIC, and AWWI's industry and conservation Partners for supporting the development of the AWWIC database. We thank the National Renewable Energy Laboratory for their support of the development of policies and procedures for data contribution and access to AWWIC. We thank Garry George, Amanda Hale, Doug Johnson, Dave Mehlman, Jennie Miller, Leslie New, Dale Strickland, and Katie Umekubo for their review and comment on this report.

Prepared By
Taber Allison, PhD, AWWI Director of Research
Ryan Butryn, AWWIC Program Manager

Suggested Citation Format
American Wind Wildlife Institute (AWWI). 2018. AWWI Technical Report: A Summary of Bat Fatality Data in a Nationwide Database. Washington, DC. Available at www.awwi.org.

Contents

Introduction

Bats collide with wind turbines resulting in fatalities, and much has been learned about the pattern and magnitude of this mortality in the U.S. and Canada (Kunz et al. 2007, Arnett et al. 2008, Arnett and Baerwald 2013, Barclay et al. 2017). Previously, cumulative assessments of this mortality have relied almost entirely on data gleaned from publicly available studies of bat collision fatalities at wind energy facilities (e.g., Arnett and Baerwald 2013). In this report we describe and summarize the bat fatality rate and fatality incident data contained in the American Wind Wildlife Information Center (AWWIC: pronounced "A-wic"), which includes both publicly available and confidential bat collision fatality data from wind energy facilities. We focus on describing the patterns of bat fatalities at wind farms across regions of the U.S. as represented in AWWIC. It is our intention that this report will focus future research evaluating the patterns observed in the data thus furthering our understanding of the variation in risk to bats from wind energy development among species and regions. The current report focuses on data from U.S. wind energy facilities, but we intend to include available data from wind facilities in Canada in future reports. In the process described below, we continue to add data as studies become available and this report will be updated on a regular basis.

AWWIC Description

AWWIC is a cooperative initiative of wind energy companies and the American Wind Wildlife Institute (AWWI) to expand the availability of wind-wildlife data. For more than 20 years, wind energy companies have conducted surveys to assess risk and impacts to wildlife from wind energy projects. Many of the data are publicly available, but other data have remained confidential and have been unavailable for analysis. AWWIC is designed to maintain the confidentiality of wind-wildlife data while making more data available to support research intended to decrease impacts to wildlife.

In this document we describe the database and provide a summary of bat fatality incident data and bat fatality estimates calculated in post-construction fatality surveys. These first analyses represent initial steps to evaluate AWWIC's ability to contribute to the goal of addressing the impacts of wind energy on bats in what we hope will be a positive-feedback loop: as the value of the database becomes apparent, more data will be contributed, further increasing the value of the database.

Description of AWWIC Data

The AWWIC database contains data collected during post-construction fatality monitoring (PCM) studies at individual wind energy projects. We define a study in AWWIC as the set of surveys for bat carcasses and bias trials conducted over a specific time that result in a single, adjusted fatality estimate for bats. The results of a study are published in a single report, although variants exist, i.e., results from multiple studies over multiple years at a wind facility can be published in a single report.

Monitoring studies are usually conducted by environmental consulting firms that employ a team of trained field biologists and statisticians to conduct carcass searches, analyze the results, and prepare a report for the client company. All PCM studies now produce fatality estimates based on observed carcasses that are corrected for detection errors (Huso et al. 2016), although the specific methods used are often tailored to the requirements and conditions at the individual projects. AWWIC captures the data common among all PCM studies to facilitate our ability to aggregate data from different studies and to conduct meta-analysis of post-construction fatality data from multiple wind energy projects.

Each wind energy project in the database is assigned a unique and randomly generated Project ID. A sequential Phase ID modifier is used for wind energy projects that have multiple phases, or groups of turbines of a similar capacity and manufacturer that are installed within the same time period (e.g. PRJ1234-PH01). Often, fatality studies are conducted at each of the phases of a wind facility. Each fatality monitoring study conducted at an individual wind energy project is assigned a unique Protocol ID; a project may have multiple studies and have multiple Protocol IDs attached to it. A detailed listing of data fields contained in AWWIC are provided in Appendix A. For each study the data can be sorted into three main groups – 1) project site description, 2) fatality estimates, and 3) fatality incidents.

Project Site

These data contain information about a project's installed capacity (#MWs), height and rotor swept dimensions of wind turbines installed, year of construction, and the geographic region where the project is located. Geographic regions include U.S. Fish and Wildlife Service Regions (referred to as "USFWS Regions" or "Regions") and EPA Level III Ecoregions (Appendix B and Appendix C, respectively).

In this report, our primary focus is summarizing bat fatality incidents and adjusted fatality estimates by USFWS Region. When sufficient data representation is available, we also aggregate AWWIC data by Ecoregion. Information about existing wind installation in each region was obtained from The U.S. Wind Turbine Database (https://eerscmap.usgs.gov/uswtdb).

Fatality estimation procedures

Modern PCM studies are conducted following established protocols (Strickland et al. 2011). Factors such as observer error in carcass detection and removal of carcasses by scavengers require that raw counts of fatalities be adjusted to more accurately estimate the true number of fatalities. There are two bias trials conducted for every study: searcher efficiency trials and carcass persistence trials. Searcher efficiency trials test the field biologist's ability to find carcasses independently placed in the search area while surveying transects. The proportion of carcasses found versus the number of carcasses placed over the course of the study period is typically expressed as a single percentage but may also be calculated for each season. Carcass persistence trials estimate how long a carcass is available to be detected by the field biologist after the carcass falls into the search area. In most studies provided to AWWIC, the result is expressed as the mean number of days a placed carcass remained available before it decayed or was removed by scavengers. In conducting bias trials, bat carcasses may be used, but often small birds, surrogates such as mice, or a mixture of birds and bats are used.

Fatality Estimates

These data include adjusted fatality estimates and a description of the protocols used to develop those estimates including the search area, search period, search interval, number of turbines searched, and results of searcher efficiency and carcass persistence trials.

The proportion of each plot searched is also used to adjust fatality estimates, but AWWIC only contains these data for studies conducted after 2015.

Several different fatality estimator equations have been developed to estimate an adjusted fatality rate given the number of carcasses observed and the various sources of detection error (Huso et al. 2016). All estimator equations incorporate the results of bias trials that use carcasses placed by researchers and are conducted simultaneously with carcass searches. How the bias trial results are used, as well as the assumptions about how missed carcasses are treated, are the primary differences among estimator equations and can lead to differences in the adjusted fatality estimate derived from the raw carcass counts from a survey. Fatality estimates are most commonly expressed as the number of bats per installed megawatt capacity per year of operation (i.e., # bats $MW^{-1}yr^{-1}$).

Fatality Incidents

A third group of AWWIC data contains information on individual fatality incidents resulting from scheduled searches, incidental finds, and plot-clearing searches. Scheduled searches occur when plots are searched by trained observers, often along transects established within search plots, at a pre-determined search interval, and bat carcasses are recorded as they are encountered. Incidental finds are carcasses found outside of scheduled searches, and some studies record fatalities when plots are cleared of carcasses before the first search. Fatality incidents from scheduled searches are the raw counts from which adjusted fatality estimates are calculated, although some studies also include incidental finds in estimated fatality rates. Additional data accompany each incident including date of carcass find, species name, carcass condition, and carcass distance to the nearest turbine (see Appendix A for a list of all data fields associated with fatality incident data).

Contributed Data

Owners of wind energy projects have worked extensively with AWWI over the past few years to establish a system that allows PCM data to be shared with AWWI at a level of detail that enables meaningful data analysis while maintaining the anonymity of the individual wind energy project. As the program has evolved, most data now are submitted to AWWI directly by the environmental consultant completing the study. This simplified process reduces errors in data submission. AWWI works directly with the data contributors and consultants to review the data and correct errors that may result during data submission.

Public Data

In addition to the contributed data, AWWIC contains PCM data from publicly available reports and publications. Public reports have been obtained by locating references in previously published meta-analyses, searching online databases, and contacting data stewards at companies or municipalities. Data provided in publicly available studies typically do not contain data for all of the data fields provided in contributed data. For example, not all public reports provide detailed data on individual fatality incidents. Public reports, however, add significantly to the amount of data available for certain analyses. The results of some PCM studies have been described in publications, but we have been unable to access the individual report to extract the data from. We have attempted to locate these reports, but we recognize there is a gap between reports that we know exist, and the reports that we have in our database.

Part 1. Data Descriptions and Summaries

Available Data

As of this report, AWWIC contains data from 227 PCM studies conducted at 146 wind energy projects in the U.S. (Table 1). Publicly available studies were most numerous in the Northeast and Pacific USFWS Regions. AWWIC contains contributed data from 41 studies in the Mountain Prairie and Southwest USFWS Regions, which are notably underrepresented in public sources (Table 1).

Based on installed U.S. wind capacity at the end of the fourth quarter of 2016, data in AWWIC represents approximately 21% of the U.S. installed wind capacity (Table 2). The data represent 48% and 50% of installed capacity in the Northeast and Pacific Regions, respectively, and 38% of installed capacity in the Pacific Southwest Region. The Southwest Region has 29 GW of installed capacity, more than any other Region, but AWWIC data represents less than 12% of that capacity (Table 2).

The newest facilities for which AWWIC contains PCM data were constructed in 2015 and most studies are from projects or phases constructed from 2005–2012 (Figure 1). There is a two- to three-year lag between when a project comes online and when PCM study results become available; therefore, most results from 2014-2017 are still in the process of being completed and contributed to AWWIC (Figure 2).

Project Characteristics

Projects represented in AWWIC range in size from 2-400 MW production capacity with 1-200 turbines; median project size is 100 MW and median number of turbines is 60. Turbine hub height is most commonly 80m (173 out of 210 studies were at towers with hub heights 78 to 82m). There are 17 studies at towers >82m and 20 studies at towers <78m.

Search Effort

The AWWIC database contains data from 276,628 searches at 5,108 distinct turbines. The number of searches is unevenly distributed among USFWS Regions (Figure 3). The percentage of turbines in a project that were reported searched in a PCM study range from 10–100%. All turbines in a project were searched at 61 studies, and <25% of turbines in a project were searched in 10 studies (while requirements vary, searching 25% of the turbines is a common recommendation). Study duration ranged from two months to three years with most studies conducted over 6 to 12 months. The frequency of 12-month studies is lower in the Midwest and Northeast Regions (Table 3), perhaps due to harsher weather conditions during winter months in these Regions. Studies that generated only one fatality estimate for searches conducted over multiple years were typically from projects where not enough bat carcasses were found to calculate single-year estimates.

Search intervals -- the time between visits to each turbine -- generally range from daily to monthly and are often adjusted throughout the year so that more frequent searches are conducted during periods of presumed high bat activity. Given these adjustments and the inconsistency of actual search interval reporting, we calculated a mean search interval by first dividing the total number of searches in a study by the number of turbines searched to get the number of searches per turbine, and then dividing the duration of the study by the number of searches per turbine. The mean search intervals were sorted into three categories (≤ 7 days, 8–14 days, and >14 days). Studies with ≤7-day search intervals were most common in the Midwest and Northeast Regions, whereas >14-day search intervals were most common in Mountain Prairie and Pacific Regions (Table 4).

Search plots are either squares or circles centered around a turbine and extend 33–126m from the base of each turbine. For studies that reported plot size (N=193), most plots have a search radius ranging from 50 to 100m (Figure 4).

Fatality Incidents

AWWIC contains 15,786 bat fatality incidents reported in 210 PCM studies. Specific dates are available for 83% of incidents (as described above, detailed incident data are not contained in every publicly available report). Carcasses found during scheduled searches at projects without curtailment accounted for 12,661 fatality incidents. For the detailed description of the incident data below, we do not include fatality incidents from incidental or cleanup finds.

When all studies in AWWIC are considered, the most carcasses found at a single turbine over the course of a study was 59. 8% of turbines had ≥10 carcasses found throughout a study. The maximum number of carcasses found at a single turbine during a single search was 17, and 10 or more carcasses were found at 11 turbines during a single search. For incidents that had time since death recorded (N=7,600), 44% occurred the previous day, 27% occurred 2-3 days prior, 19% occurred within 4-7 days, and 10% occurred >7 days prior. Using a subset of 23 studies that had search radii ≥100m, the greatest percentage of carcasses fall in the 26-50m distance band, and 80% of carcasses fall within 50m of the turbine (Figure 5).

Collectively, AWWIC bat fatality incident data show distinct seasonal patterns; peaks of incidents occur in late summer or early fall and are assumed to correspond to the fall migration period (Kunz et al. 2007) (Figure 6). In northern Regions, reported fatality incidents peak for all bats in August, with the exception of the Pacific Region where reported incidents peak in September. In the Southwest and Pacific Southwest Regions, fatality incidents peak in September (Figure 7).

Searcher Efficiency Trials

The median searcher efficiency reported by studies in AWWIC is 54% and most searcher efficiency estimates range from 40-80% (Figure 8). Of the 188 studies reporting searcher efficiency, 95 used carcass types other than bat carcasses, e.g., small birds or mice, for the searcher efficiency trials (Figure 9).

Carcass Persistence Trials

A median of 30 carcasses were placed during carcass persistence trials. Carcasses were often placed in a variety of ground cover and distances from turbines during various seasons. Carcass persistence times reported for bats in AWWIC have a skewed distribution with a median of 7.7 days and maximum of >30 days (Figure 10). For the 180 studies reporting carcass persistence times, 96 used carcasses other than bats to estimate persistence of bat carcasses. Surrogates, most often house mice, had similar median carcass persistence times as bats at 6.7 and 7 days respectively (Figure 11).

Part 2. Species Composition of Fatality Incidents

Methods

We aggregated fatality incidents by species and region from all contributed and public data in the AWWIC database. Our summary does not include fatality incidents from studies where we were able to determine that turbines were operating under a curtailment regime, i.e., rotor blades were restricted from spinning at low wind speeds. We wanted to avoid including results from fatality monitoring of curtailed turbines that might bias the species composition of fatality incidents towards species that are less capable of flying at higher wind speeds. We aggregated incident data across all projects by species and USFWS Region and EPA Level III Ecoregion when relevant. Incident data are typically reported as unadjusted numbers. Thus, the data we report do not reflect detection errors that are used to adjust fatality estimates (see below), and the data don’t reflect adjustments for possible, but as yet unmeasured, variation in detectability among bat species.

Results and Discussion

After applying our study selection criteria, we aggregated data from 190 studies, totaling 12,661 fatality incidents comprising 22 bat species. We are aware of 24 species found as fatalities at wind facilities in the U.S. and Canada. Two species, Eastern small-footed myotis (*Myotis leibii*) and long-eared myotis (*Myotis evotis*) have been found as fatalities at Canadian wind facilities, but not at the U.S. wind facilities contained in AWWIC. Both species occur in the U.S. and Canada.

Overall, hoary bat (*Lasiurus cinereus*) had the highest percentage of incidents (32%; Table 5) and the highest frequency of occurrences in PCM studies (95%; 180 of 190; Table 6). The three migratory tree bats -- hoary bat, eastern red bat (*Lasiurus borealis*), and silver-haired bat (*Lasionycteris noctivagans*) -- collectively accounted for 72% of all fatality incidents contained in AWWIC. The top eight bat species by number of fatalities accounted for 96% of all fatality incidents, while the bottom 14 species accounted for 0.8% of all incidents. The remaining incidents were bats where species was unable to be identified. A full species list of fatality incidents and frequency of occurrences contained in AWWIC is presented in Appendix D.

Hoary bat fatalities have been found at almost all the wind facilities included in the AWWIC database (95%). Silver-haired bat and big brown bat (*Eptesicus fuscus*) are the only other bat species with incidents at wind facilities within every USFWS Region, although both species show relatively large variation among regions. Eastern red bat fatality incidents, while constituting the 2nd highest overall percentage in AWWIC, are most prevalent in the Midwest Region and absent from the Pacific and Pacific Southwest Regions, which are outside the known range of this species.

Species' fatality incidents show substantial regional variation (Table 5 and Table 6) in total number of incidents and relative abundance by species, thus illustrating how geographic representation can skew a cumulative assessment of wind energy's impacts on bats. Previous cumulative assessments of bat fatalities included a preponderance of studies from the northern regions of the U.S. AWWIC, however, includes a substantial number of studies from USFWS Regions within the range of Mexican free-tailed bat (*Tadarida brasiliensis*), one of the most numerous bat species in North America (Harvey et al. 2011). AWWIC data indicate that this species can constitute the majority of fatalities at wind facilities within this species' range. With additional data from these previously under-represented regions, the percentage of Mexican free-tailed bat fatalities increased from ~3% in assessments based on public data to 9.8% of all fatality incidents in AWWIC.

The increase in Mexican free-tailed bat fatality incidents is reflected in the proportion of the three tree bat species that have dominated previous cumulative assessments of bat fatalities at wind energy facilities. Assessments based on publicly available data described migratory tree bat incidents accounting for 78-80% of all fatality incidents, and hoary bat accounted for 38% of all incidents (e.g., Arnett and Baerwald 2013). In studies contained in AWWIC, the proportion of incidents for these three species declined to ~72% of all fatality incidents, and to ~32% of all incidents for hoary bat. We note that regions where fatalities of Mexican free-tailed bat predominate remain underrepresented in AWWIC. If representation of Mexican free-tailed bat fatalities is similar at other facilities in those Regions, the overall percentage of fatalities of this species will be higher, resulting in a lower percentage of tree bat fatalities as a proportion of total fatalities. Tree bat fatality incidents remain prevalent in most parts of the country, but particularly in the Midwest and Northeast Regions, where they account for 86% and 78% of the fatality incidents in AWWIC, respectively.

Table 8 shows the alpha diversity[1] of bat fatality incidents relative to the species pool. The latter was determined by overlap of range maps with USFWS Regions.[2] The Pacific Region has the lowest species diversity of fatality incidents, but the Northeast has the lowest number of bat species of any Region. The Southwest Region has the highest diversity of bat species overall, and the highest number of species represented as fatalities in AWWIC. However, there are 29 species presumed to occur in this Region that do not show up as fatalities. Data from the Southeast Region does not meet AWWIC standards for data inclusion as there are only two installed wind projects in the Region and only one project has produced fatality studies.

There is also substantial variation in representation of the eight most frequently recorded species within USFWS Regions. To explore this variation, we subdivided USFWS Regions by identifying Level III EPA Ecoregions that are entirely or nearly encompassed within the USFWS Region, and that had ~250 or more bat fatality incidents. Hoary bat and silver-haired bat show limited variation within USFWS Regions, but other species have substantial variation. For example, tri-colored bat (*Perimyotis subflavus*) constitutes ~5% of the fatalities in the Northeast Region, but within that region, fatality incidents range from 0.4% in

[1] Alpha diversity is the mean species diversity in sites or habitats at a more local scale.
[2] Data layers for range maps for all bat species were downloaded from the USGS Gap Analysis Program Species Viewer website at https://gis1.usgs.gov/csas/gap/viewer/species/Map.aspx.

the Northern Allegheny Plateau Ecoregion to 11.4% in the Ridge and Valley Ecoregion – the latter is immediately to the south of the former (Table 7a). In the Midwest Region, little brown myotis (*Myotis lucifugus*) fatality incidents are slightly less than 5% of all incidents within the Region, but at the Ecoregion level, fatalities within the Midwest range from 0.04% to 18.7% (Table 7b). Big brown bat incidents also vary by an order of magnitude among Ecoregions within the Midwest Region.

In addition to eastern red bat and hoary bat, five other species of *Lasiurus* in the U.S. have fatality incidents in AWWIC. Three of these species, northern yellow bat (*L. intermedius*), southern yellow bat (*L. ega*), and western yellow bat (*L. xanthinus*) reach the northern limits of their range in southernmost U.S. Some projects occur in areas where there are multiple species of *Lasiurus*. Where these species overlap with hoary bat, incident data typically show a preponderance of hoary bats, while the other *Lasiurus* species are less numerous. In these studies, unidentified bats included unknown yellow bats and unidentified *Lasiurus* species. Further, in the lower Midwest Region, the ranges of eastern red bat and Seminole bat (*L. seminolus*) overlap. Although recognized as separate species based on genetic information, it may be very difficult to separate these two species in the field based on morphological characters alone (Laerm et al. 1999). Thus, it is possible that fatality incidents of the 'southern' *Lasiurus* species are underestimated in some studies due to misidentification.

Part 3. Bat Fatality Estimates

Methods

Bat fatality estimates used in this report are all adjusted for detection biases as described in Section 1 and are "as reported." We did not make any additional adjustments to correct for among-study variation in sampling period, plot size, or estimator used in the adjustments made to raw counts. Some standardization of fatality estimates is desirable for efforts such as making comparisons between studies and generating cumulative fatality estimates. However, methods for standardizing fatality estimates across studies have been inconsistently applied and are a topic of ongoing research (Johnson et al. 2016). In this report, we describe the contents of AWWIC and observed patterns. We assume that each study employed protocols that were tailored to the conditions at each wind facility. To maintain a basic level of standardization in our review of fatality estimates in AWWIC, we included studies if they met the following criteria:

1. All species found during scheduled fatality searches were recorded
2. Turbines operated at normal procedures (e.g., studies conducted while turbines were operating under a curtailment regime were not included)
3. Fatality surveys included seasons of peak bat activity
4. Reported fatality estimates adjusted raw carcass counts for searcher efficiency, carcass persistence, and incomplete space and time coverage
5. Adjusted fatality estimates were greater than the number of observed carcasses

Forty-two studies reported multiple adjusted fatality estimates, which often occurs when estimates were calculated using multiple fatality estimators. We used the following criteria when multiple estimates were provided in a study following criteria adapted from Thompson et al. 2017. We chose the adjusted estimate that was based on the following criteria:

1. Largest plot size
2. Longest survey duration
3. Greatest number of turbines sampled
4. Greatest number of total searches
5. If more than one estimator was used to calculate adjusted fatality estimates, the estimates were selected in the following sequence - Huso ----> Shoenfeld ----> Others

6. All else being equal, we chose the highest adjusted estimate

Bat fatality estimates were plotted to observe their distribution and variability among USFWS regions and selected EPA Ecoregions. Given a reasonable subsample of studies using the Shoenfeld and Huso estimators (see Part 1), we also summarized regional variation using only studies whose adjusted estimates were based on a single estimator under the assumption that some variation among studies may be due to the estimator used. To support interpretation of the regional fatality estimates, we also examined regional variability in search intervals, searcher efficiency, and carcass persistence.

We have included estimates from each year of study available for each project phase. Multiple years of study are available for 44 phases. Estimates are presented as fatalities per megawatt (MW) per year (or study period) where MW is based on the rated power production capacity of the turbine, not the actual power produced.

Results and Discussion

After applying our selection criteria, AWWIC contains 137 projects and 202 studies with estimates available to use. The pool of studies available for analysis of fatality rates is greater than the pool for fatality incidents because estimates are reported more frequently than incidents. Shoenfeld, Huso, and Jain are the estimators most frequently used for studies contained in AWWIC (Figure 12). Bat fatality estimates for the entire U.S. have a skewed distribution with 75% of studies reporting fewer than five bats per MW per year (Figure 13). The median fatality estimate for all studies is 2.66 bats per MW per year. 44 studies estimated less than one bat fatality per MW. Studies considered outliers (N=16; Figure 13) ranged from 11.6 – 49.7 bats per MW.

The Midwest Region has fatality estimates from 36 studies ranging from 0.4–32.0 bats per MW; this Region has the highest median fatality rate of 6.2 bats per MW per year. The Mountain Prairie Region has 27 studies with adjusted fatality estimates ranging between 0.2 and 19 bats per MW per year and a median of 2.4. The Northeast Region has 52 studies and the greatest range of reported estimates, 0.1–49.7 bats per MW per year, and the second-highest median of 3.5. The Pacific Region has 35 studies and the lowest range -- 0–4.2 – and median -- 0.7 bats per MW per year. The Pacific Southwest Region has 30 studies with fatality estimates that ranged from 0–5.2 bats per MW per year and a median of 1.4. The Southwest region has 22 studies with a fatality estimate range of 0.1–36.9 and a median of 3.3 bats per MW per year. Regional variation in fatality estimates is apparent whether studies used the Shoenfeld estimator (N=91; Figure 14a) or the Huso estimator (N=69; Figure 14b).

Search intervals and mean carcass persistence times vary regionally. Search intervals in AWWIC studies are longer in the Pacific Region (Table 4; see Part 1). Mean carcass persistence time is also longer in this Region (Figure 10), but shorter than the typical search interval. Such variation may result in systematic bias in Regional fatality estimates. We are currently undertaking a detailed evaluation of this potential bias and other factors that underly the patterns that we are seeing in the data.

Small bird carcasses were used in bias trials to estimate carcass persistence times instead of bats in 23 out of 29 studies reporting from the Pacific Region. Mean carcass persistence time for small birds is often longer than for bats (Figure 11; see Part 1). Taken together, we hypothesize that systematic methodological differences may bias bat fatality estimates low in the Pacific Region. The Mountain Prairie and Pacific Southwest Regions also have more studies with longer search intervals, and fatality estimates could be biased low if carcass persistence times are less than the search interval. The greater number of searches (Figure 3) and the typically shorter search intervals (Table 4) conducted in Midwest and Northeast regions represent a substantially greater amount of effort put into carcass searches in these Regions.

While the politically determined boundaries of USFWS Regions comprise a useful aggregation from a regulatory perspective, there can be a wide range of ecosystem types within USFWS Regions contributing to the variation we observed in fatality estimates. Finer-scale assessment can be useful in evaluating variation in fatality risk within these coarser-scale regulatory regions. Examining Level III EPA Ecoregions within the Northeast and Midwest USFWS Regions indicates that there is substantial within- and among-region variation in bat fatality estimates. For example, all studies from the Acadian Plains and Hills Ecoregion showed fatality estimates below the Northeast USFWS Region median of 3.5 bats/MW. Conversely, nearly all estimates from Central Appalachians and Ridge and Valley Ecoregions were above the Northeast Region median (Figure 15 left panel). Studies in Eastern Great Lakes Lowlands, Northeastern Highlands, and Northern Allegheny Plateau Ecoregions had similar variability in estimates centered on the Northeast Region median.

In the Midwest Region, AWWIC studies from the Western Corn Belt Plains Ecoregion show fatality estimates mostly below the Region median of 6.2 bats/MW, whereas the Southeastern Wisconsin Till Plains and Central Corn Belt Plains Ecoregions have much greater variation in estimates, and they all fall above the Midwest Region median (Figure 15 right panel).

Conclusions

In this report, we describe the patterns of fatality incident data, fatality estimates, and related information of confidential and publicly available studies contained in AWWIC. Although this collection of data is more comprehensive and regionally representative than presented in previous publications, we recognize that the data represent a non-random sample of operating wind facilities in the U.S. and there appear to be systemic differences in study protocols and detectability, for example, across USFWS Regions, that may influence the patterns we observe.

Although the inferences of our data summaries are limited to the data universe of AWWIC, the amount and coverage of the data enable us to pose reasonable hypotheses about the impacts of wind energy on bat species in the U.S. that can be evaluated with data from additional PCM studies. For example, AWWIC data indicate that most bat species are rarely detected as fatality incidents. Additional studies, especially from Regions not well represented in AWWIC as well as a finer-scale evaluation of the overlap of bat species' distribution with wind energy, could help to determine whether this lack of fatalities reflects differences in collision risk or is an artifact of data representation in AWWIC and/or the lack of overlap of wind energy development and the presence of these species. The USGS GAP program has produced maps based on Species Distribution Models for most bat species occurring in the U.S., and in combination with the mapped locations of wind energy facilities, a more detailed assessment of overlap of bat species with wind energy may be possible.[3]

The substantial variation in fatality incidents in AWWIC among bat species does suggest the hypothesis that there is variation in fatality risk among bat species, and that this variation could reflect differences among bat species in activity levels in the rotor swept zone. Korner-Nievergelt et al. 2013 suggested bat species that spend more time in the rotor swept zone are at higher collision risk. Differences in fatality incidents among species within Regions also could reflect differences in abundance of these species. Or, it could be some combination of these and other factors. We lack data to effectively evaluate differences in abundance as a factor, and the substantial decline of some cave-hibernating bat species due to white-nose syndrome that occurred over the time period of studies, included in our summaries (Frick et al. 2010, 2015), potentially confounds the effects of abundance on the patterns we have observed.

[3] See https://gis1.usgs.gov/csas/gap/viewer/species/Map.aspx and https://eerscmap.usgs.gov/uswtdb/viewer/#3/39.51/-96.74

A discussion of hypotheses to explain variation in collision risk among bat species is beyond the scope of this technical report and is covered in detail elsewhere (Barclay et al. 2017). What we show with this summary of AWWIC data is that for creating an accurate picture of the risk of wind energy to bats, representation across geographic regions matters, and cumulative assessments at the national level obscure important regional and species-specific variation.

Future Steps

This report represents the first summary of fatality data collected in AWWIC. We will continue to acquire data and anticipate regular updates to the information contained in this report. We will also continue evaluation of existing data, including detailed Bayesian hierarchical analysis with the goal of distinguishing the importance of methodological and ecological factors in the variation we observe in the data. We will also be evaluating the following topics:

1. There are hypotheses that numbers of migratory tree bat species are declining, and we are evaluating this with current data in AWWIC.
2. A new “generalized estimator” is expected to be released by a team of USGS scientists that is intended to provide more accurate adjusted fatality estimates. We will investigate recalculating fatality estimates in AWWIC using this new estimator.
3. We are analyzing the variability of fatality estimates described in this report to estimate the number of studies needed to accurately and reliably estimate bat collision fatalities within a region.
4. We will be preparing a Bird Technical Report similar in scope and content to this Report.

Literature Cited

Arnett, E. B., and E. F. Baerwald. 2013. Impacts of wind energy development on bats: implications for conservation. Pages 435–456 *in* R. A. Adams and S. C. Pedersen, editors. Bat Evolution, Ecology, and Conservation. Springer New York, New York, NY.

Arnett, E. B., W. K. Brown, W. P. Erickson, J. K. Fiedler, B. L. Hamilton, T. H. Henry, A. Jain, G. D. Johnson, J. Kerns, R. R. Koford, C. P. Nicholson, T. J. O'Connell, M. D. Piorkowski, and R. D. Tankersley JR. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management 72:61–78.

Barclay, R. M. R., E. F. Baerwald, and J. Rydell. 2017. Bats. Pages 191–221 *in* M. R. Perrow, editor. Wildlife and Wind Farms, Conflicts and Solutions. Volume 1 Onshore: Potential Effects. Pelagic Publishing.

Frick, W. F., J. F. Pollock, A. C. Hicks, K. E. Langwig, D. S. Reynolds, G. G. Turner, C. M. Butchkoski, and T. H. Kunz. 2010. An emerging disease causes regional population collapse of a common North American bat species. Science 329:679–682.

Frick, W. F., S. J. Puechmaille, J. R. Hoyt, B. A. Nickel, K. E. Langwig, J. T. Foster, K. E. Barlow, T. Bartonička, D. Feller, A. J. Haarsma, C. Herzog, I. Horáček, J. van der Kooij, B. Mulkens, B. Petrov, R. Reynolds, L. Rodrigues, C. W. Stihler, G. G. Turner, and A. M. Kilpatrick. 2015. Disease alters macroecological patterns of North American bats. Global Ecology and Biogeography 24:741–749.

Harvey, M. J., J. S. Altenbach, and Best. Troy L. 2011. Bats of the United States and Canada. The Johns Hopkins University Press, Baltimore, MD.

Huso, M., D. Dalthorp, T. J. Miller, and D. Bruns. 2016. Wind energy development: methods to assess bird and bat fatality rates post- construction. Human–Wildlife Interactions 10.

Johnson, D. H., S. R. Loss, K. S. Smallwood, and W. P. Erickson. 2016. Avian fatalities at wind energy facilities in North America: a comparison of recent approaches. Human-Wildlife Interactions 10:7–18.

Korner-Nievergelt, F., R. Brinkmann, I. Niermann, and O. Behr. 2013. Estimating Bat and Bird Mortality Occurring at Wind Energy Turbines from Covariates and Carcass Searches Using Mixture Models. PLoS ONE 8:e67997.

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. M. Tuttle. 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Frontiers in Ecology and the Environment 5:315–324.

Laerm, J., M. A. Menzel, D. M. Krishon, and J. L. Boone. 1999. Morphological discrimination between the eastern red bat, Lasiurus borealis, and Seminole bat, Lasiurus seminolus (Chiroptera: Verspertilionidae), in the southeastern United States. The Journal of the Elisha Mitchell Scientific Society 115:131–139.

Norberg, A. U. M., and J. M. V Rayner. 1987. Ecological Morphology and Flight in Bats (Mammalia ; Chiroptera): Wing Adaptations , Flight Performance , Foraging Strategy and Echolocation Source : Philosophical Transactions of the Royal Society of London . Series B , Biological Sciences , Published. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 316:335–427.

Strickland, M. D., E. B. Arnett, W. P. Erickson, D. H. Johnson, M. L. Morrison, J. A. Shaffer, and W. Warren-Hicks. 2011. Comprehensive Guide to Studying Wind Energy/Wildlife Interactions. Washington DC USA.

Thompson, M., J. A. Beston, M. Etterson, J. E. Diffendorfer, and S. R. Loss. 2017. Factors associated with bat mortality at wind energy facilities in the United States. Biological Conservation 215:241–245.

Tables

Table 1. Number of wind energy projects and post-construction fatality monitoring studies for the U.S. and USFWS Regions contained in AWWIC. Studies are made available by data contributors or acquired from publicly available reports. Some wind energy projects have multiple turbine groups called phases, which often receive separate fatality monitoring studies.

	Contributed		Public Reports		Combined Total	
Regions	Projects/ Phases	Studies	Projects/ Phases	Studies	Projects/ Phases	Studies
Midwest	17/18	28	12/12	17	29/30	45
Mountain Prairie	14/15	22	5/5	6	19/20	28
Northeast	15/15	28	22/22	35	37/37	63
Pacific	9/11	13	15/19	23	24/30	36
Pacific Southwest	8/8	16	11/12	15	19/20	31
Southwest	14/15	19	4/5	5	18/20	24
U.S.	77/82	126	69/75	101	146/157	227

Table 2. AWWIC database representation of U.S. installed wind energy capacity (gigawatts [GW]) and USFWS Regions. Percent representation for each region is in the far-right column. Some wind energy projects have multiple turbine groups called phases, which often receive separate fatality monitoring studies.

	Installed Capacity in U.S. or USFWS Region (Q4 2016)		Installed Capacity Represented in AWWIC Database		
Regions	Projects/Phases	GW	Projects/Phases	GW	% GW
Midwest	213/237	19.90	29/30	3.75	18.8%
Mountain Prairie	132/163	15.60	19/20	2.10	13.5%
Northeast	97/103	5.33	37/37	2.54	47.7%
Pacific	64/102	7.26	24/30	3.60	49.6%
Pacific Southwest	87/107	5.66	19/20	2.12	37.5%
Southwest	186/231	29.42	18/20	3.41	11.6%
U.S.[1]	779/943	83.17	146/157	17.5	21.0%

[1] U.S. total does not include Southeast Region, Puerto Rico, Alaska, or Hawaii

Table 3. Frequency of survey duration of post-construction fatality monitoring studies by USFWS Region. Reported for a subset of 207 studies for which start and end dates are known.

Regions	≤6 months	6-12 months	full year	>1 year
Midwest	10	24	8	3
Mountain Prairie	2	11	10	3
Northeast	19	36	1	1
Pacific	0	11	15	5
Pacific Southwest	0	9	15	4
Southwest	0	11	7	2
U.S.	31	102	56	18

Table 4. Frequency of search intervals for scheduled carcass searches by USFWS regions. Reported for a subset of 193 studies. When studies used variable search intervals in different seasons, a mean interval value for the entire study duration was used.

Regions	≤ 7 days	8-14 days	>14 days
Midwest	22	12	8
Mountain Prairie	2	9	12
Northeast	44	13	0
Pacific	0	4	21
Pacific Southwest	0	17	10
Southwest	6	9	4
U.S.	74	64	55

Table 5. Percent composition of unadjusted bat fatality incidents for the most commonly detected species by USFWS Region from studies conducted at wind facilities in the U.S. and contained in AWWIC. Number of studies for each region is listed in parentheses and '# incidents' is the total unadjusted number of incidents for all AWWIC studies in the region. See Appendix D for complete list of species reported as fatalities.

	USFWS Region						
Species	Midwest (36)	Mountain Prairie (26)	Northeast (51)	Pacific (28)	Pacific Southwest (27)	Southwest (22)	U.S. (190)
hoary bat	25.8%	41.2%	36.6%	48.4%	34.8%	26.1%	31.9%
eastern red bat	39.0%	13.6%	25.3%	0.0%	0.0%	3.1%	24.0%
silver-haired bat	20.8%	15.0%	16.1%	42.7%	4.7%	0.8%	16.1%
Mexican free-tailed bat	0.0%	11.5%	0.0%	0.0%	53.2%	43.7%	10.0%
little brown myotis	4.9%	1.6%	9.6%	3.1%	0.0%	0.0%	5.1%
big brown bat	7.8%	2.1%	5.8%	1.1%	0.2%	0.3%	5.0%
tri-colored bat	0.1%	0.0%	5.2%	0.0%	0.0%	0.4%	1.7%
evening bat	0.3%	5.7%	0.0%	0.0%	0.0%	9.0%	1.7%
other species	0.2%	0.4%	1.3%	0.0%	4.2%	3.0%	0.8%
unidentified bat	1.2%	8.9%	0.2%	4.8%	2.8%	13.7%	3.7%
# incidents	4775	906	3987	525	848	1620	12661

Table 6. Percent occurrence by USFWS Region for most commonly detected bat species in AWWIC studies. If species is reported by all studies in a Region, percent occurrence = 100%. Number of species is the number of species with fatality incidents in AWWIC in each Region. Numbers in parentheses are the number of studies in each Region. Zeroes indicate that species was not observed in that Region, possibly due to restricted geographic range of species. Species are sorted in order of overall U.S. percent occurrence.

	USFWS Region						
Species	Midwest (36)	Mountain Prairie (26)	Northeast (51)	Pacific (28)	Pacific Southwest (27)	Southwest (22)	U.S. (190)
hoary bat	97.2%	88.5%	98.0%	100%	88.9%	90.9%	95.0%
silver-haired bat	97.2%	61.5%	86.3%	92.9%	33.3%	22.7%	71.1%
eastern red bat	91.7%	34.6%	86.3%	0	0	40.9%	50%
big brown bat	75.0%	38.5%	64.7%	21.4%	7.4%	13.6%	42.6%
little brown myotis	61.1%	15.4%	56.9%	17.9%	0	0	31.6%
Mexican free-tailed bat	0	23.1%	0	0	96.3%	86.4%	26.8%
tri-colored bat	8.3%	0	37.3%	0	0	9.1%	12.6%
evening bat	16.7%	11.5%	0	0	0	27.3%	7.9%
# species	10	9	9	4	12	14	22

Table 7. Percent composition of bat fatalities of most commonly detected species within EPA Level III Ecoregions in the Northeast (a) and Midwest (b) USFWS Regions. Northeast and Midwest Regions have the highest number of reported bat fatalities allowing for sufficient representation of finer-scale ecoregions. Ecoregion number and name is followed by the number of studies reporting fatalities in parenthesis. See Appendix C for map and list of ecoregions.

a) Region 5: Northeast

	EPA Level III Ecoregion				
Species	69–Central Appalachians (7)	83–Eastern Great Lakes Lowlands (11)	58–Northeastern Highlands (12)	60–Northern Allegheny Plateau (5)	67–Ridge and Valley (4)
hoary bat	34.0%	40.0%	47.8%	40.6%	32.4%
eastern red bat	32.6%	17.6%	10.0%	14.3%	28.3%
silver-haired bat	16.1%	19.4%	18.7%	20.1%	11.5%
big brown bat	4.9%	5.3%	6.1%	*2.5%*	8.2%
little brown myotis	5.2%	14.5%	14.2%	19.3%	7.9%
tri-colored bat	6.3%	0.9%	0.6%	0.4%	11.4%
unidentified bat	0.6%	2.1%	2.7%	2.5%	0.3%
# bat fatalities	1463	567	622	244	924

b) Region 3: Midwest

	EPA Level III Ecoregion			
Species	54–Central Corn Belt Plains (6)	57–Huron/Erie Lake Plains (8)	53–Southeastern Wisconsin Till Plains (5)	47–Western Corn Belt Plains (14)
hoary bat	28.9%	23.7%	23.6%	29.8%
eastern red bat	49.6%	42.6%	15.6%	33.7%
silver-haired bat	18.4%	22.7%	23.0%	13.5%
big brown bat	1.6%	10.0%	14.5%	4.6%
little brown myotis	0.4%	0.0%	18.7%	15.8%
unidentified bat	0.4%	0.3%	4.7%	2.0%
# bat fatalities	1129	2287	636	594

Table 8: Number of bat species and number of bat species for which fatality incidents have been reported by USFWS Region. Species ranges were based on data layers provided by the USGS Gap Program (gis1.usgs.gov/csas/gap/viewer/species/Map.aspx) and the IUCN Red List database (http://iucnredlist.org/). See Appendix D for complete list of species reported in AWWIC.

Regions	# Species in Region	# Species in AWWIC
Midwest	16	10
Mountain Prairie	26	9
Northeast	14	9
Pacific	17	4
Pacific Southwest	25	12
Southwest	43	14
U.S.	47	22

Figures

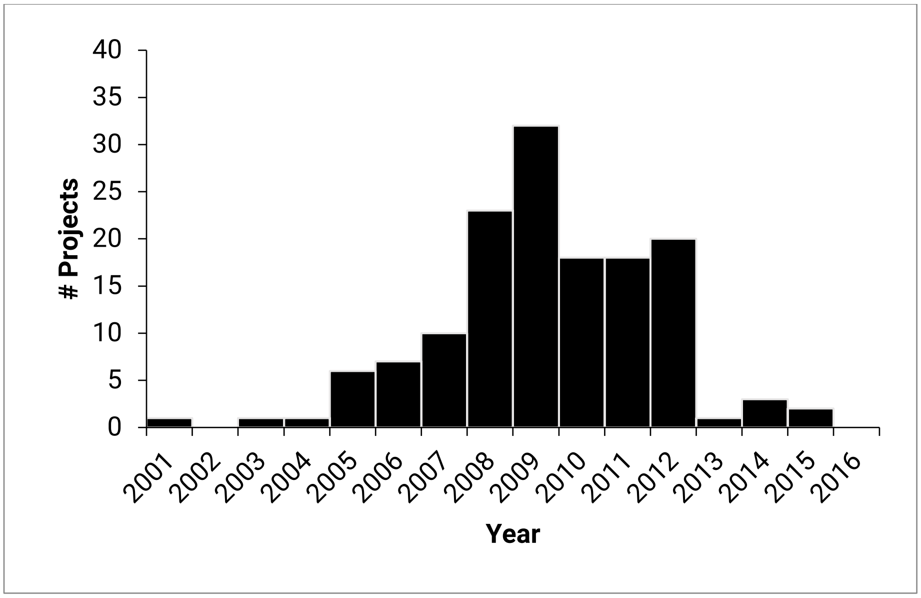


Figure 1. Number of wind energy projects represented in AWWIC (N=146) that became operational or repowered each year.

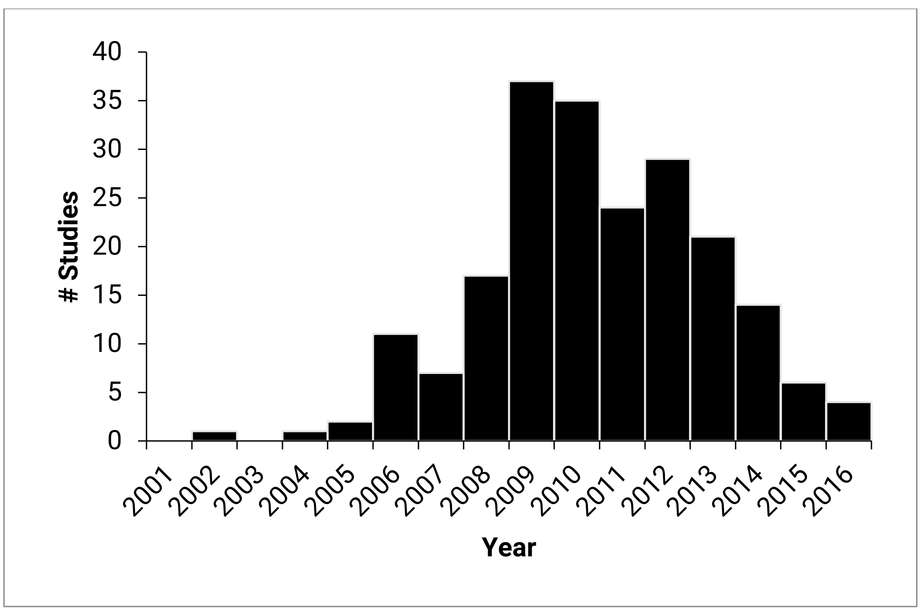


Figure 2. Distribution of monitoring years for post-construction monitoring studies contained in AWWIC.

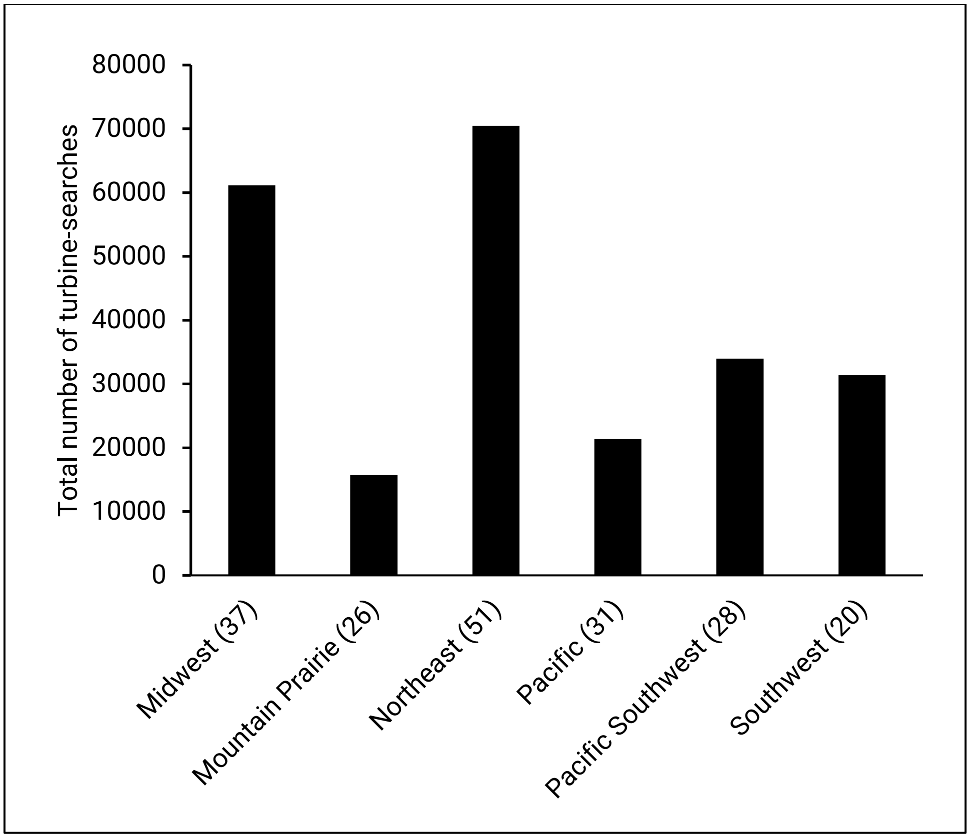


Figure 3. Total number of turbine searches conducted during post-construction monitoring studies by USFWS Region currently contained in AWWIC. The number of studies reporting for each Region is indicated by the number in parentheses.

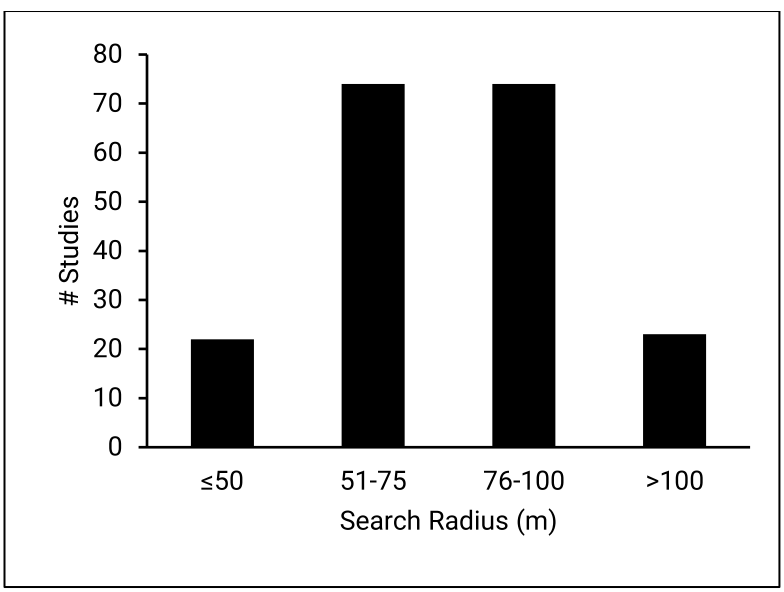


Figure 4. Distribution of plot radius around turbines searched during post-construction fatality monitoring (N=193 Studies).

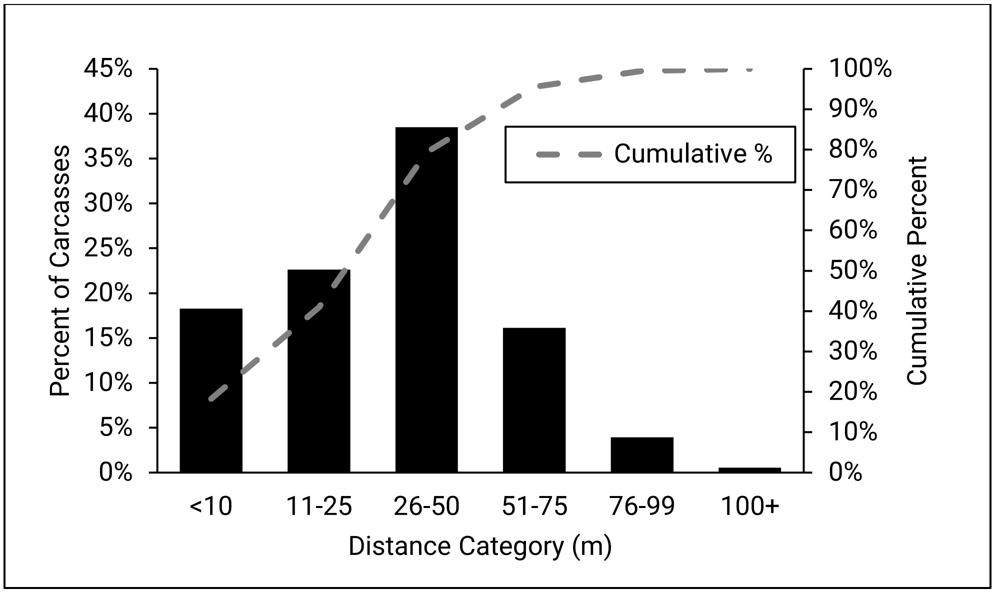


Figure 5. For the 23 studies with search radius ≥100m, distance in meters from the turbine tower of bat carcasses (N=3,540) found during scheduled carcass searches. Distance bins are commonly reported categories. Dashed line shows cumulative percentage (right axis) of carcasses found as distance from the turbine increases.

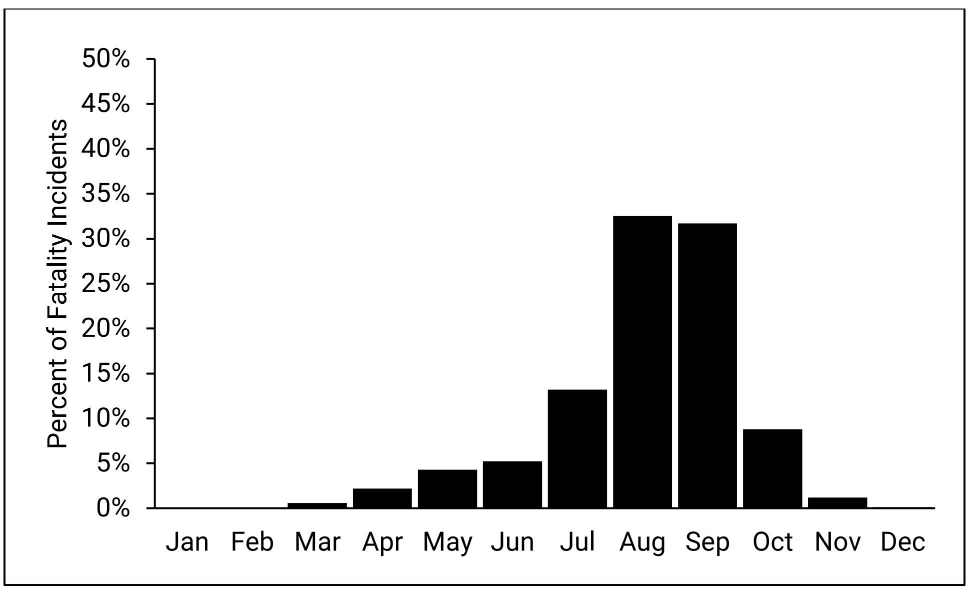


Figure 6. Distribution of bat fatality incidents by month for all U.S. wind energy projects where date of carcass discovery is known (N=10,183). Fatality incidents are recorded during scheduled searches of post-construction studies contained in AWWIC.

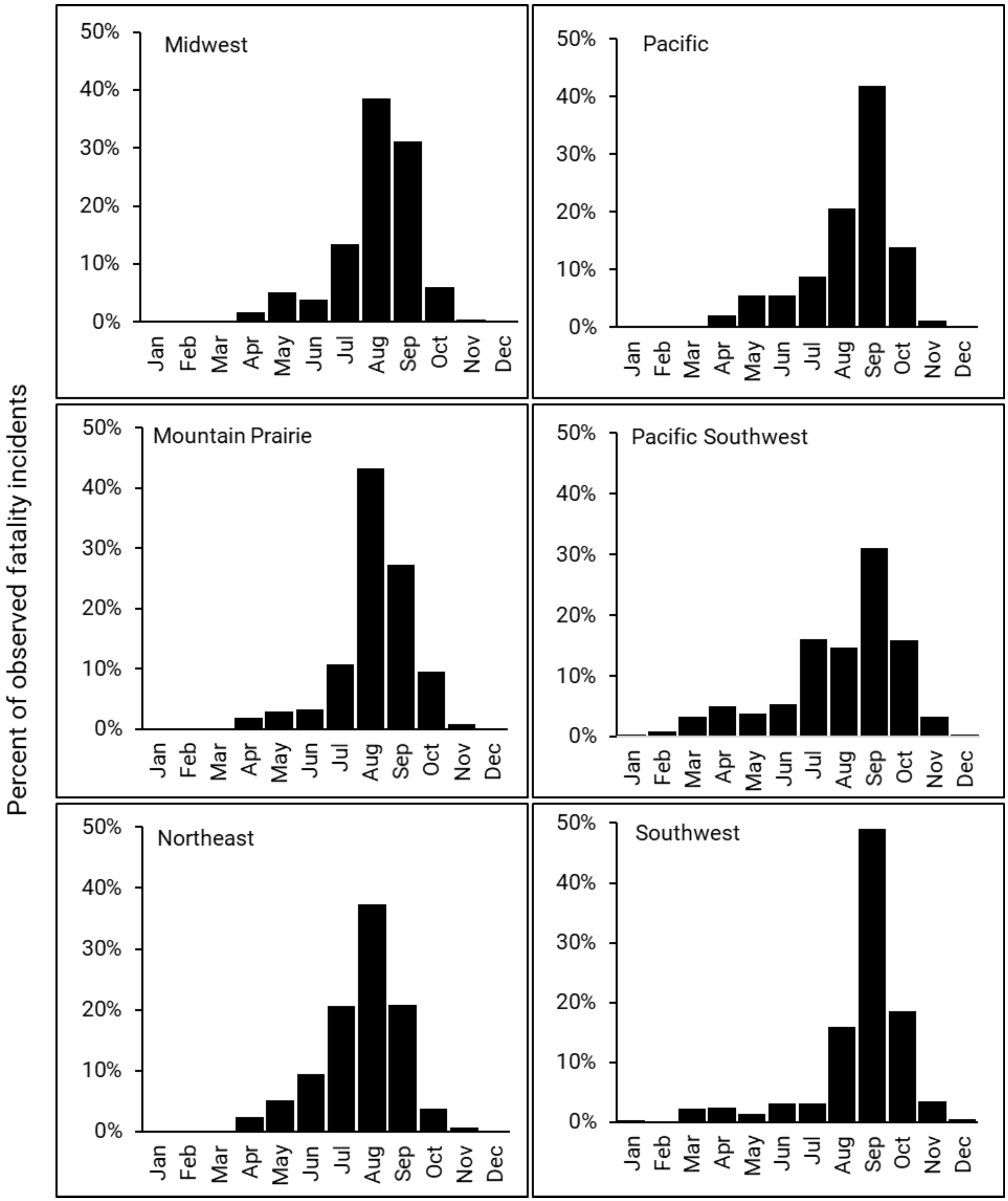


Figure 7. Distribution of bat fatality incidents by month for each USFWS Region. Fatality incidents are recorded during scheduled searches of post-construction studies contained in AWWIC. Not all studies search every month, see table 3 for summary of survey duration.

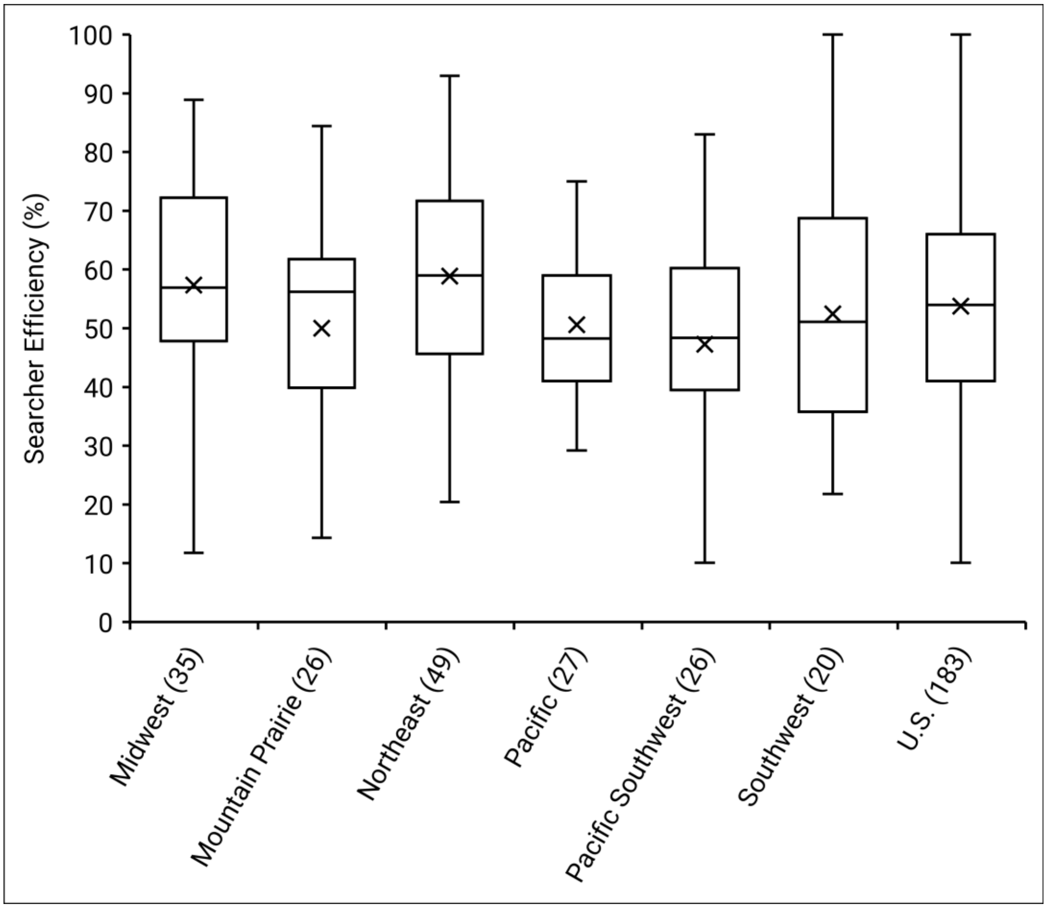


Figure 8. Searcher efficiency by USFWS Region as percent of placed carcasses found by search personnel for adjustment of raw carcass counts in post-construction monitoring studies contained in AWWIC. Number of studies available in each Region is contained in parentheses. Boxplots show median and quartile values; “x” indicates mean value.

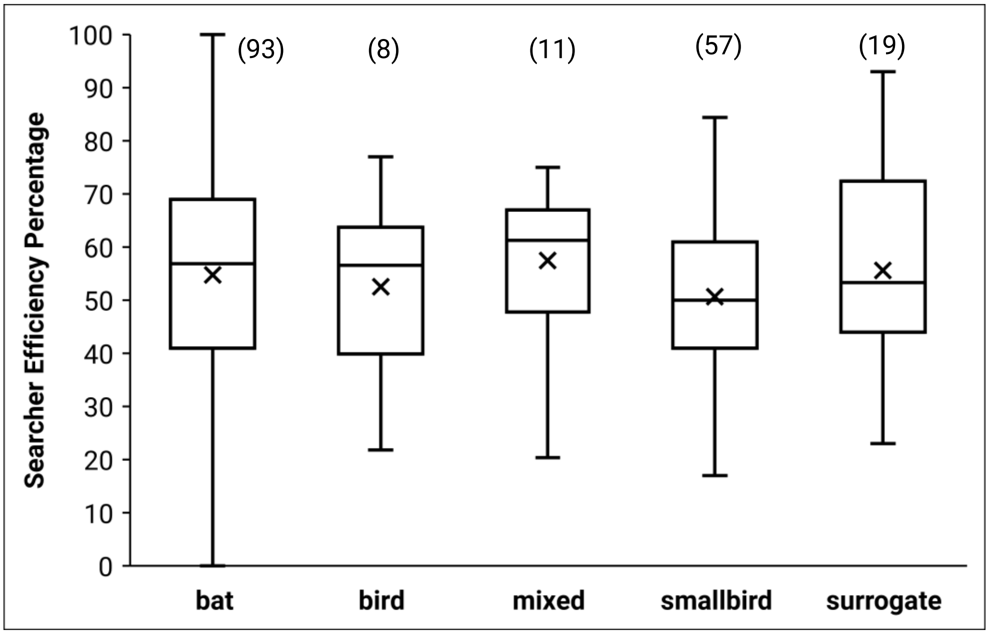


Figure 9. Searcher efficiency percentage for each carcass type used to estimate bat searcher efficiency for adjustment of raw carcass counts in post-construction monitoring studies contained in AWWIC. Number of studies using each carcass type is contained in parentheses above respective plots. Boxplots show median and quartile values; “x” indicates mean value.

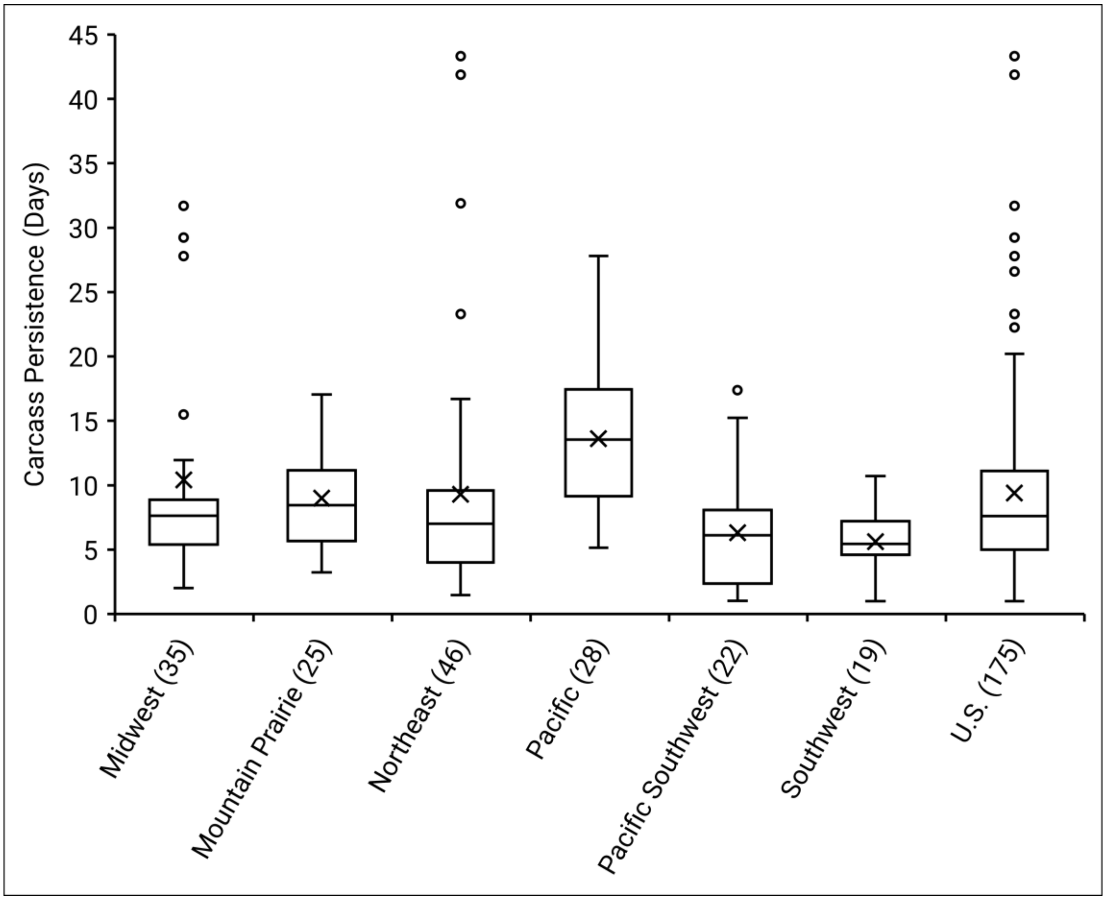


Figure 10. Distribution of mean carcass persistence time by USFWS Region for carcasses used in removal trials for adjustment of raw carcass counts in post-construction studies contained in AWWIC. Number of studies available in each Region is contained in parentheses. Boxplots show median and quartile values; "x" indicates mean value.

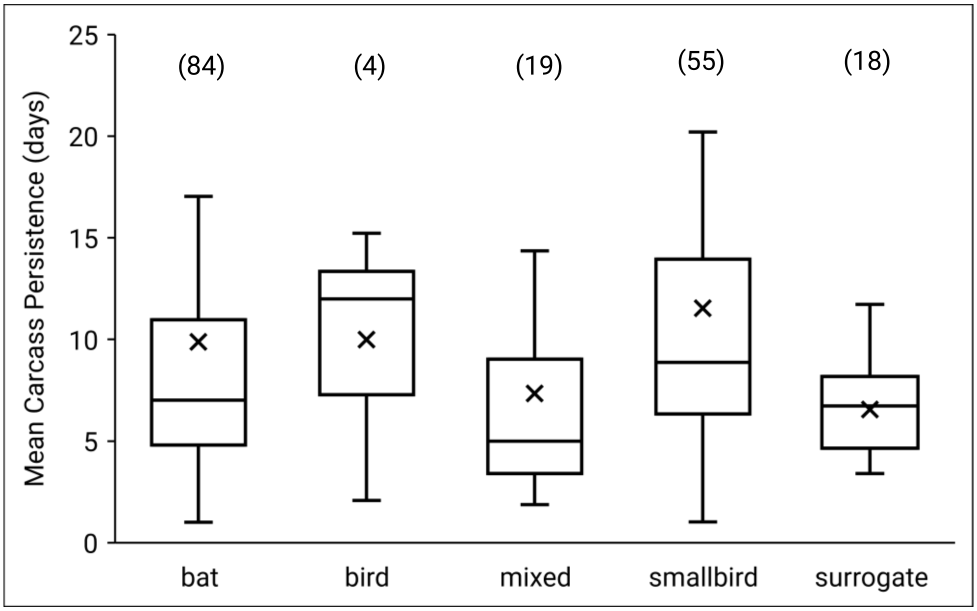


Figure 11. Mean carcass persistence time of carcass types used in carcass persistence trials to adjust raw carcass counts in post-construction studies contained in AWWIC. Number of studies using each carcass type is contained in parentheses above respective plots. Boxplots show median and quartile values; "x" indicates mean value.

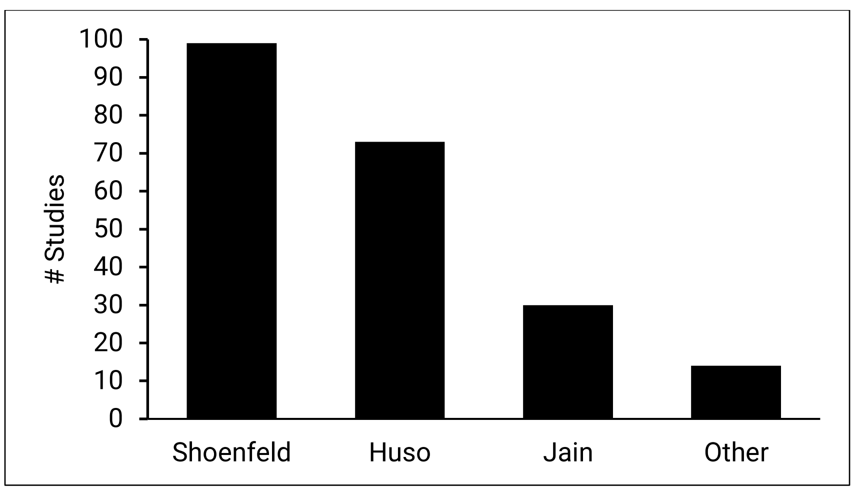


Figure 12. Frequency of fatality estimator equation used to adjust fatality estimates of post-construction studies contained in AWWIC

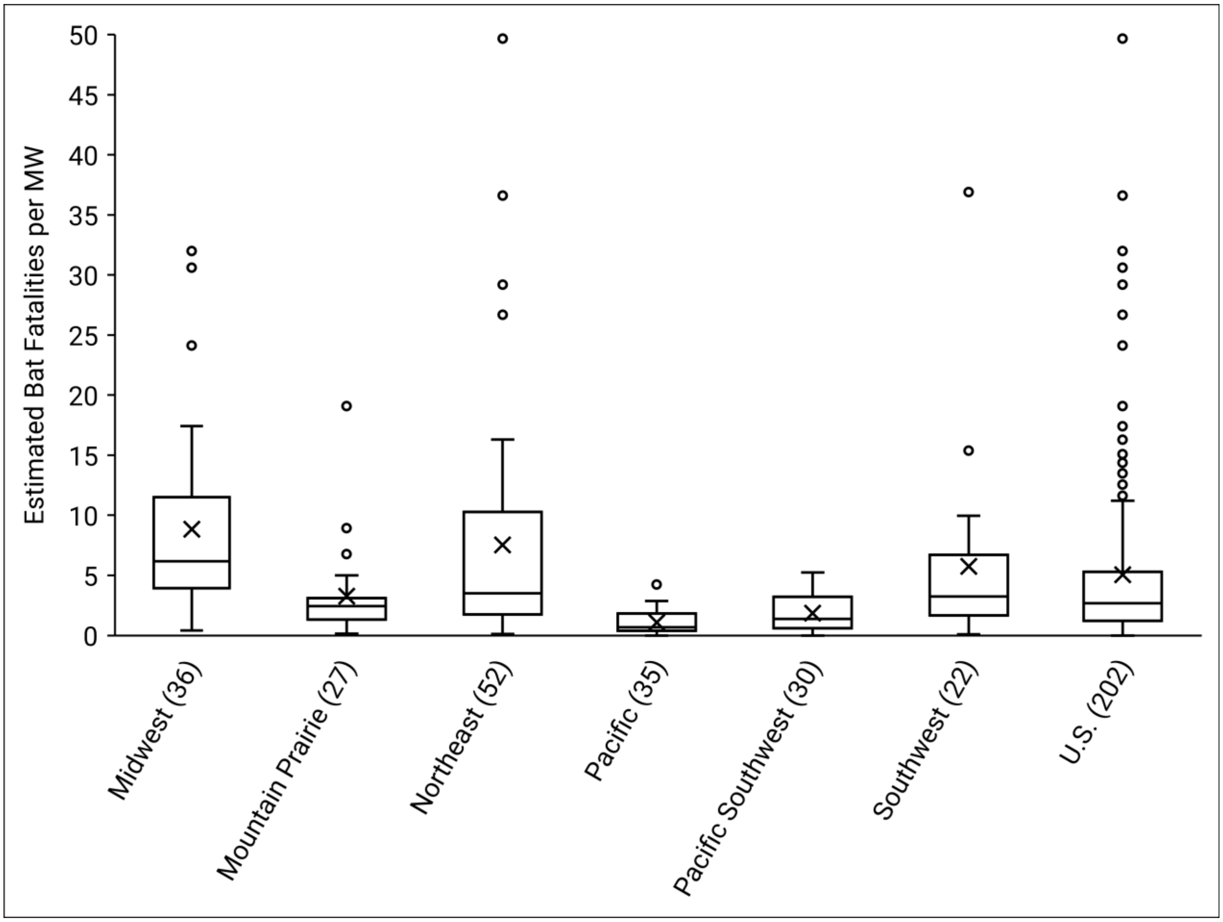


Figure 13. Adjusted bat fatality estimates by USFWS Region from post-construction studies contained in AWWIC. Estimates are presented as reported and not standardized for differences in study methodology. Number of studies available in each Region is contained in parentheses. Box plot of bat fatality estimates displays median and quartile values with outliers indicated by open circles and mean value indicated by “x”.

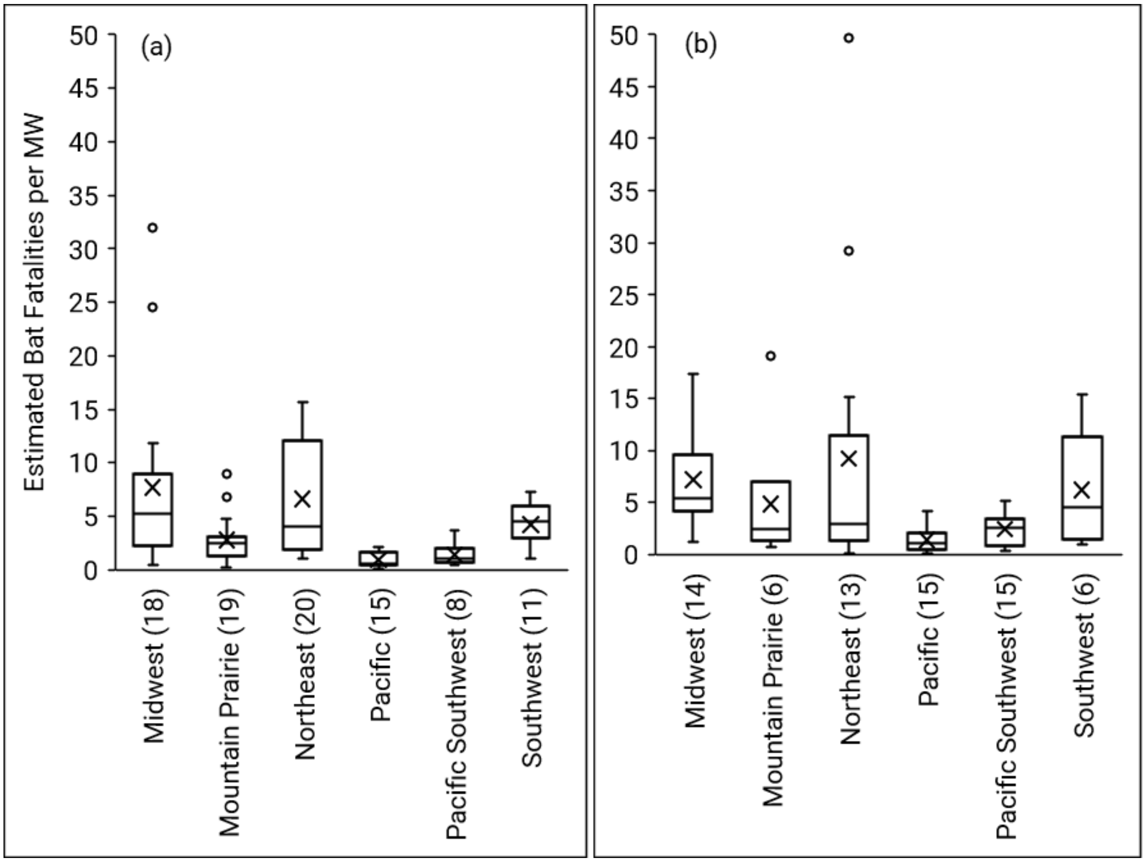


Figure 14. Adjusted bat fatality estimates by USFWS Region for studies using different estimators to adjust estimates. Estimates are from post-construction studies contained in AWWIC and the different panels are non-overlapping datasets: a) Shoenfeld estimator; b) Huso estimator. Number of studies available in each Region is contained in parentheses. Box plot of bat fatality estimates displays median and quartile values with outliers indicated by open circles and mean value indicated by "x".

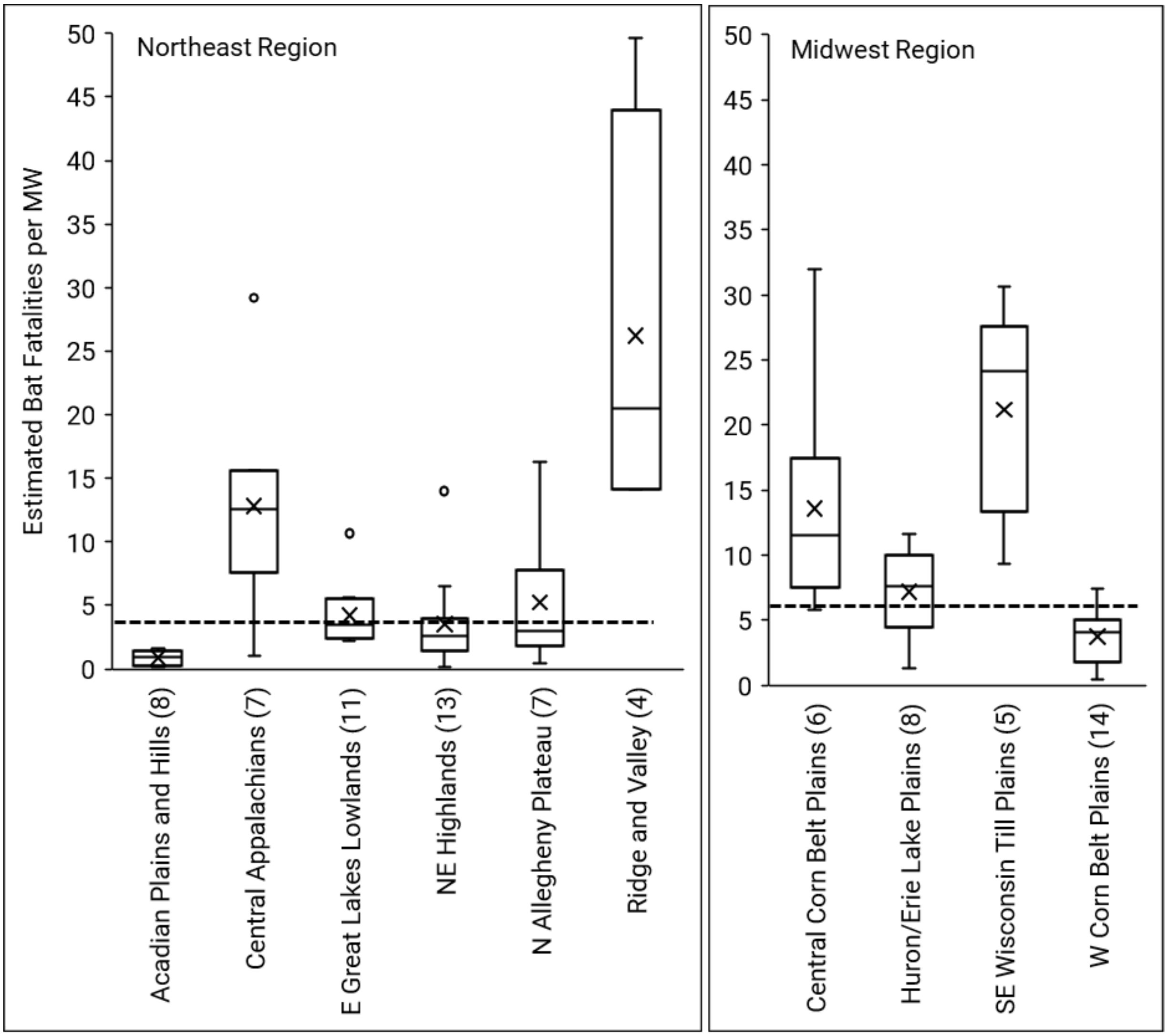


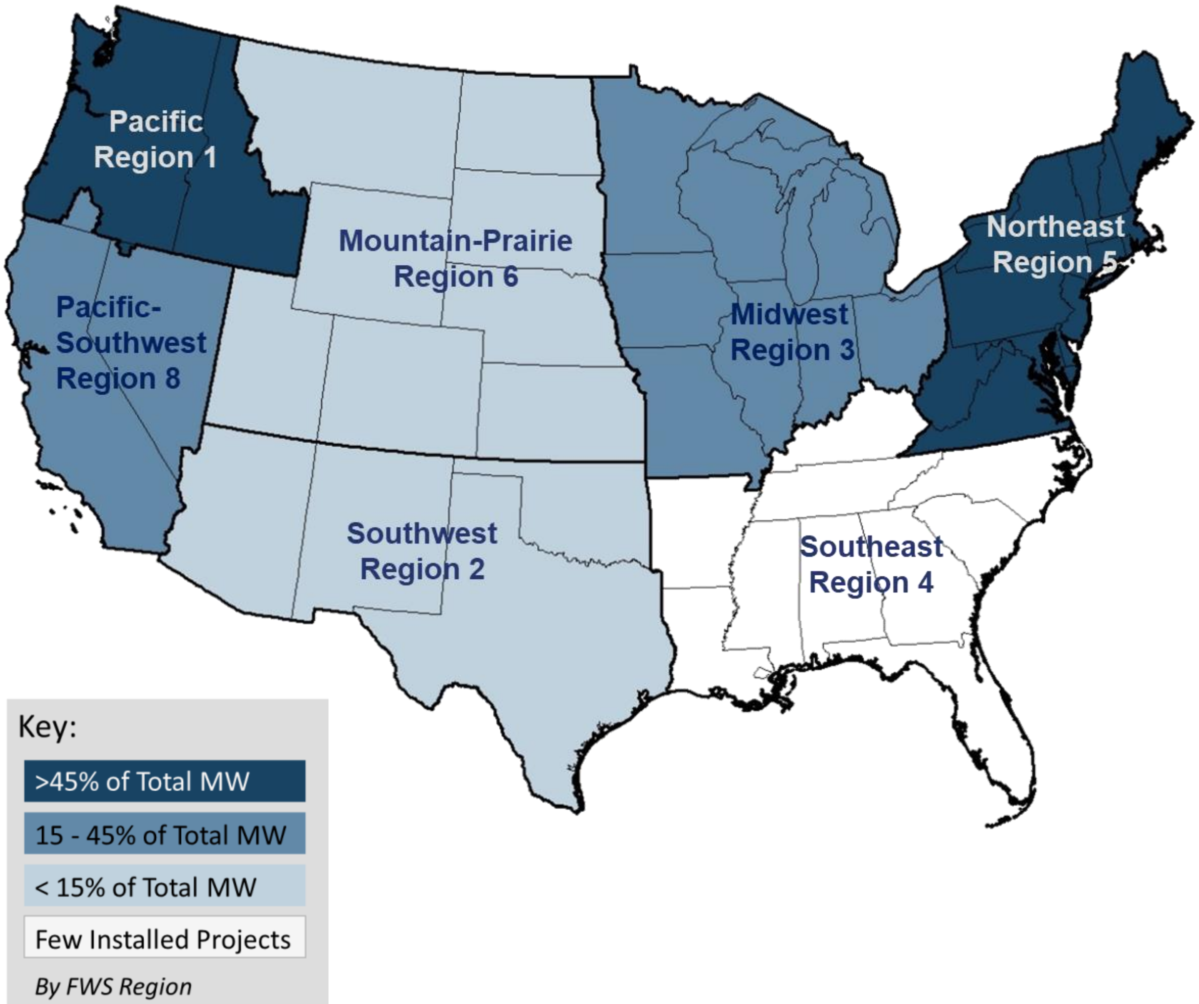
Figure 15. Adjusted bat fatality estimates by EPA Level III Ecoregions located within the Northeast (left panel) and Midwest (right panel) USFWS Regions. Estimates are presented as reported from post-construction studies contained in AWWIC and not standardized for differences in study methodology. Dashed lines represent median bat fatality rate for each Region. Number of studies available in each Region is contained in parentheses. Box plot of bat fatality estimates displays median and quartile values with outliers indicated by open circles and mean value indicated by "x".

Appendices

Appendix A. Data fields contained in AWWIC

Project Site Information	
	Site Size
	USFWS Region
	EPA Level III Ecoregion
	Bird Conservation Region
	Landscape Types (e.g. row crop, forested, grassland)
	Year Operations Started
	Turbine Details (e.g. make, model, size)
	# Turbines
Fatality Estimates	
Study Protocols	**Study Start/End Date**
	Search Interval (weekly, monthly, etc.)
	# Turbines searched
	Plot Dimensions
Fatality Estimates	**Fatality Estimate Group** (e.g. Bird, Bat, Large Bird)
	Estimator used (e.g. Shoenfeld, Empirical Pi, Huso)
	Estimated Fatalities per MW & per Turbine
	Fatality Estimate Confidence Intervals
Bias Trials	**Searcher Efficiency Specimen Type**
	SE: # placed, # available, # found, %found
	Carcass Removal Trial Specimen Type
	CR: # trials, # specimens placed, mean removal time, % remaining
Fatality Incidents	
	Species
	How Found (Scheduled Search, Cleanup Find, Incidental Find, Other)
	Action Taken (Collected, Released, Euthanized, Transported, None)
	Date Found
	Location Type (Turbine, Power Line, Met Tower, Other, n/a)
	Distance and Bearing from Turbine
	Nearest Turbine
	Find Type (Large Bird, Small Bird, Bat, Other)
	Sex
	Age (Adult, Juvenile, Unknown)
	Condition (Intact, Partial, Dismembered, Feather Spots, Other)
	Scavenged By (None, Carnivores, Corvids, Insects, Other, Unknown)
	Decomposition
	Est. Time Since Death
	Possible Cause (Turbine Collision, Non-turbine Collision, Unknown)

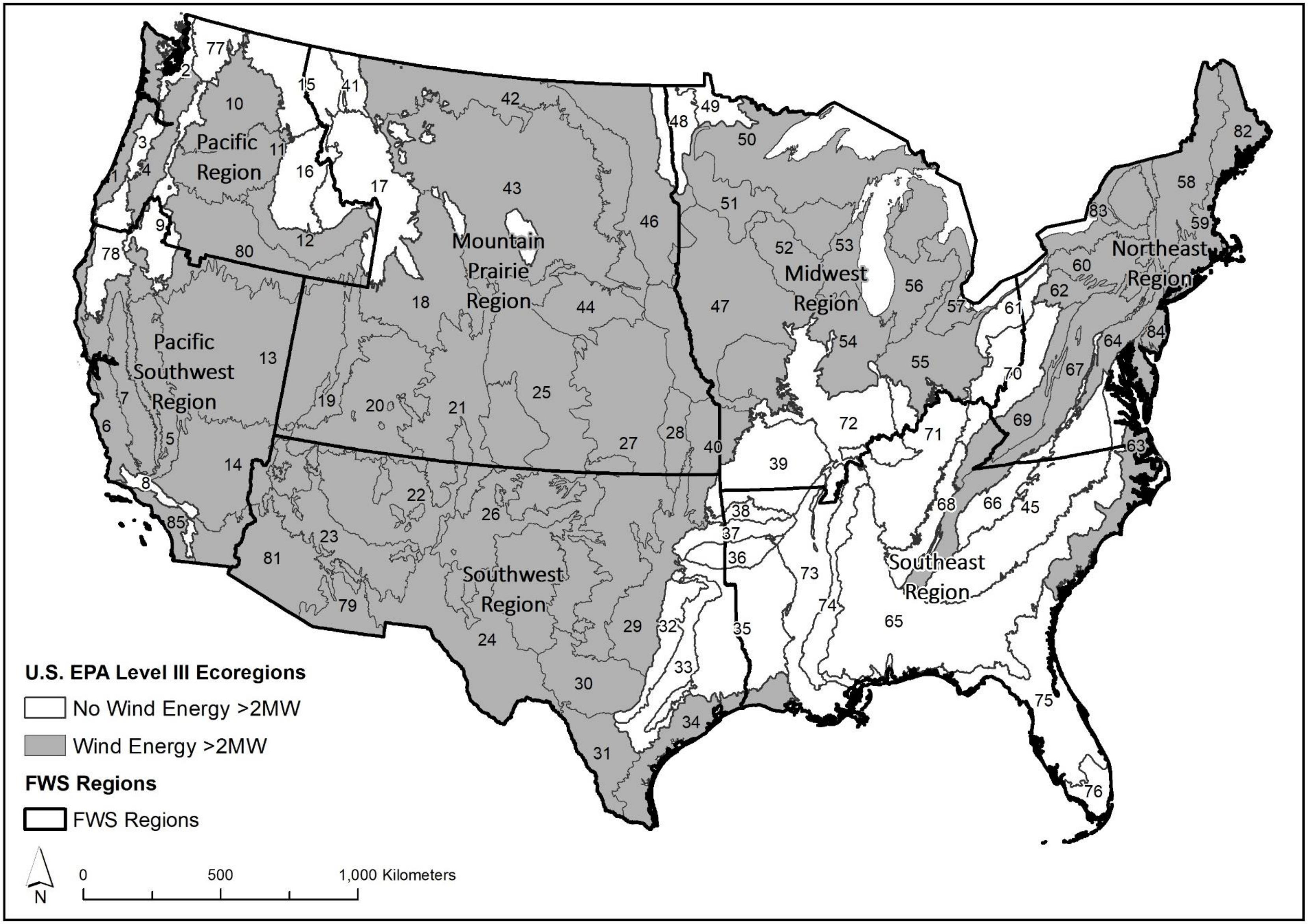
Appendix B. Map of AWWIC data representation of installed wind energy in USFWS Regions



Alaska (Region 7), Hawaii (Region 1), and Puerto Rico (Region 4) have wind energy projects installed, however there are no data in AWWIC from those areas.

Region information available online: https://www.fws.gov/where/

Appendix C. Map of Level III EPA Ecoregions in the coterminous U.S.



Ecoregion Number	Ecoregion Name	Ecoregion Number	Ecoregion Name
1	Coast Range	44	Nebraska Sand Hills
2	Puget Lowland	45	Piedmont
3	Willamette Valley	46	Northern Glaciated Plains
4	Cascades	47	Western Corn Belt Plains
5	Sierra Nevada	48	Lake Agassiz Plain
6	Central California Foothills and Coastal Mountains	49	Northern Minnesota Wetlands
7	Central California Valley	50	Northern Lakes and Forests
8	Southern California Mountains	51	North Central Hardwood Forests
9	Eastern Cascades Slopes and Foothills	52	Driftless Area
10	Columbia Plateau	53	Southeastern Wisconsin Till Plains
11	Blue Mountains	54	Central Corn Belt Plains
12	Snake River Plain	55	Eastern Corn Belt Plains
13	Central Basin and Range	56	Southern Michigan/Northern Indiana Drift Plains
14	Mojave Basin and Range	57	Huron/Erie Lake Plains
15	Northern Rockies	58	Northeastern Highlands
16	Idaho Batholith	59	Northeastern Coastal Zone
17	Middle Rockies	60	Northern Allegheny Plateau
18	Wyoming Basin	61	Erie Drift Plain
19	Wasatch and Uinta Mountains	62	North Central Appalachians
20	Colorado Plateaus	63	Middle Atlantic Coastal Plain
21	Southern Rockies	64	Northern Piedmont
22	Arizona/New Mexico Plateau	65	Southeastern Plains
23	Arizona/New Mexico Mountains	66	Blue Ridge
24	Chihuahuan Deserts	67	Ridge and Valley
25	High Plains	68	Southwestern Appalachians
26	Southwestern Tablelands	69	Central Appalachians
27	Central Great Plains	70	Western Allegheny Plateau
28	Flint Hills	71	Interior Plateau
29	Cross Timbers	72	Interior River Valleys and Hills
30	Edwards Plateau	73	Mississippi Alluvial Plain
31	Southern Texas Plains	74	Mississippi Valley Loess Plains
32	Texas Blackland Prairies	75	Southern Coastal Plain
33	East Central Texas Plains	76	Southern Florida Coastal Plain
34	Western Gulf Coastal Plain	77	North Cascades
35	South Central Plains	78	Klamath Mountains/California High North Coast Range
36	Ouachita Mountains	79	Madrean Archipelago
37	Arkansas Valley	80	Northern Basin and Range

38	Boston Mountains	81	Sonoran Basin and Range
39	Ozark Highlands	82	Acadian Plains and Hills
40	Central Irregular Plains	83	Eastern Great Lakes Lowlands
41	Canadian Rockies	84	Atlantic Coastal Pine Barrens
42	Northwestern Glaciated Plains	85	Southern California/Northern Baja Coast
43	Northwestern Great Plains		

Regions Available Online: https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states

Wind Energy Data: https://eerscmap.usgs.gov/uswtdb/viewer/#3/37.25/-96.25

Appendix D: Number and percentage of bat fatality incidents from all studies contained in the AWWIC database. Frequency is the number of studies containing fatality incidents of each species found during carcass searches in post-construction studies contained in AWWIC. No incidents from projects using curtailment at low wind speeds was included in this table. Wing loading for each species, if available, is as defined and calculated in (Norberg and Rayner 1987).

Species	# Incidents	Percent Incidents	Frequency	Wing Loading (g/m^2)[4]
hoary bat	4033	31.85%	180	16.5
eastern red bat	3042	24.03%	95	14.0
silver-haired bat	2044	16.14%	135	8.2
Mexican free-tailed bat	1263	9.98%	51	11.5
little brown myotis	647	5.11%	60	7.5
big brown bat	636	5.02%	81	9.4
tri-colored bat	217	1.71%	24	5.6
evening bat	211	1.67%	15	10.7
northern yellow bat	22	0.17%	3	-
western red bat	16	0.13%	8	-
southern yellow bat	14	0.11%	4	-
Seminole bat	9	0.07%	6	-
big free-tailed bat	8	0.06%	5	-
western yellow bat	7	0.06%	3	-
canyon bat	6	0.05%	4	6.9
northern long-eared myotis	6	0.05%	5	6.8[5]

[4] Source: Norberg, U.M. and Rayner, J.M.V. 1987. Ecological morphology and flight in bats (Mammalia; Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. Philosophical Transactions of the royal society of London B 316: 335-427.
[5] Used the value for *Myotis keenii*

pocketed free-tailed bat	5	0.04%	3	-
Indiana myotis	4	0.03%	4	6.5
cave myotis	3	0.02%	3	6.3
greater bonneted bat	3	0.02%	1	25.1
California myotis	2	0.02%	2	4.8
long-legged myotis	1	0.01%	1	8.3
unidentified bat	462	3.65%	93	-
Total	12,661	100.00%		