AMERICAN WIND WILDLIFE INSTITUTE

TECHNICAL REPORT

A Summary of Bird Fatality Data in a Nationwide Database

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AWWI Technical Report:

A Summary of Bird Fatality Data in a Nationwide Database

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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.

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Introduction

Bird collisions with wind turbines have been observed and monitored at many wind energy facilities. Cumulative assessments of this mortality have relied on data gleaned from publicly available studies of bird collision fatalities at wind energy facilities (Smallwood 2013, Loss et al. 2013, Erickson et al. 2014). In this report we describe and summarize the bird fatality rate and fatality incident data contained in the American Wind Wildlife Information Center (AWWIC), which includes both publicly available and confidential bird collision fatality data from wind energy facilities in the U.S. We evaluate the patterns of bird fatalities across avifaunal biomes, seasons, and species. This preliminary evaluation is intended to focus future research on evaluating questions raised by patterns observed in the data as they relate to variation in collision risk from wind energy development among bird species and biomes.

We summarize bird fatality incidents and adjusted fatality estimates by avifaunal biome (e.g., Erickson et al. 2014). Avifaunal biomes represent aggregations of Bird Conservation Regions (BCRs; Rich et al. 2004, NABCI 2018) that encompass more similar bird fauna than other biomes. The distribution of these biomes is shown in Appendix B. Information about existing wind installation in each region was obtained from the U.S. Wind Turbine Database (https://eerscmap.usgs.gov/uswtdb). Data summarized in this report comes solely from land-based wind energy facilities.

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 predict risk and estimate 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.

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 bird carcasses and bias trials conducted over a specific time period that result in a single, adjusted fatality estimate. The results of a study are usually published in a single report though variants do 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. Although formerly not always the case, all PCM studies now produce fatality estimates based on observed carcasses that are corrected for detection errors (Huso et al. 2016), although the specific protocols followed in specific studies 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-analyses 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, meaning groups of turbines of a similar capacity and manufacturer that are installed within the same time period (e.g., PRJ1234-PH01 for the first phase of project 1234 in the database). 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 parsed into three groups of data: 1) project site description, 2) fatality estimates, and 3) fatality incidents.

Project Site Description

These data contain information about a project's installed capacity (megawatts; MWs), height and rotor swept dimension of wind turbines installed, year of construction, and the geographic region where the project is located.

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 and carcass persistence. Searcher efficiency trials are used to estimate the field biologists' ability to find test carcasses placed within the search area around wind turbines. The proportion of carcasses found of the total 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 biologists 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. Bird carcasses used in trials are obtained from a variety of natural or domestic sources. Carcasses of some groups, such as raptors, can be difficult to obtain, and surrogate birds of similar size, e.g., game birds, may be substituted. Because of assumptions regarding differences in detectability, bias trials are often conducted separately for small birds (< 30 cm total length), large birds (≥ 30 cm total length), and raptors. Separate trials may also be conducted during different seasons.

Fatality Estimates

These data include adjusted fatality estimates and a description of the protocols used to develop these 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 may also be used to adjust fatality estimates, but AWWIC does not contain enough of these data to prepare a summary.

Several different fatality estimators have been developed to calculate an adjusted fatality rate based on the number of carcasses observed and the various sources of detection error (Huso et al. 2016). All estimators incorporate the results of bias trials to quantify searcher efficiency and carcass persistence. How the bias trial results are used, as well as the assumptions about how missed carcasses are treated, are the primary differences among estimators and can lead to differences in the adjusted fatality estimate derived from the raw carcass counts from a survey. Adjusted fatality estimates are most commonly expressed as the number of birds per installed megawatt capacity per year of operation (i.e., birds per MW per year) and are used in comparisons among sites, years, turbine type, and with other covariates.

Fatality Incidents

A third group of AWWIC data contains records of individual fatality incidents reported during scheduled searches and plot-clearing searches, as well as carcass discoveries made incidentally. Scheduled searches occur when plots are searched by trained observers, often along transects established within search plots of defined area, at a pre-determined search interval. Bird carcasses are recorded as fatality incidents as they are encountered during these searches. Some studies recorded carcasses detected when plots are cleared before the first search. Incidental finds are carcasses found at times other than scheduled searches, for example, when observers are traveling from a completed search plot to another plot.

Any evidence of a bird carcass, including whole birds, parts of a bird, or two or more feathers, are considered a collision fatality, or fatality incident. Incidents from all scheduled searches provide the raw counts from which adjusted fatality estimates are calculated. Some studies may also include incidental finds in the calculation of adjusted fatality estimates. Additional data accompany each fatality incident including date of carcass find, species name, carcass condition, and 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 contributed to AWWIC at a level of detail that enables meaningful data analysis while maintaining the anonymity of the individual wind energy project. Most data now are submitted to AWWI directly by the environmental consultant completing the study which reduces the potential for transcription errors in data submission. AWWI reviews data submissions and works directly with the data contributors and consultants to ensure that data are accurate.

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 state wildlife agencies, companies, public utilities commissions, or municipalities. Publicly available studies typically do not contain data for all of the 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. There are cases where the results of some PCM studies have been described in publications but we were unable to access the individual report to extract the data. 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

All PCM studies summarized in this report contained bird fatality incidents and/or estimates and were conducted at sites where turbines had been operating at manufacturer's cut-in speed and without curtailment (when rotor blades have been restricted from spinning at low wind speeds). Of the 230 PCM studies available in AWWIC, 193 studies conducted at 141 phases at 130 wind energy projects between 2002–2017 were used for this report (Table 1). Publicly available studies accounted for 69 of the studies used (35.7%).

Data in this report represents approximately 19.3% of U.S. installed wind capacity based on the amount installed at the end of the fourth quarter of 2016 (AWEA 2016; Table 2). Given that neither wind energy nor AWWIC data are evenly distributed among avifaunal biomes, data representation varied from 7.6% of U.S. installed wind capacity in the Southwest biome to 72.8% in the Pacific biome. Although the Prairie biome had the most data in AWWIC (56 studies from 53 projects totaling 7.5 gigawatts or GW; Table 2), it represented just 13.4% of the 56.03 GW installed in that biome.

The newest facilities for which AWWIC contains PCM data were constructed in 2016; most studies were from projects or phases constructed or repowered between 2001–2016 (Figure 1). We estimate there is a two- to three-year lag between when a project comes online and when PCM study results become available; therefore, most data from 2015–2017 are still in the process of being compiled and have not yet been contributed to AWWIC (Figure 2).

Project Characteristics

Projects represented in AWWIC ranged in size from 2 to 400 MW production capacity and 1 to 200 turbines; median project size was 100 MW and median number of turbines was 60. Turbine hub height was most commonly 80 m (159 out of 194 studies were at towers with hub heights 78 to 82 m). There were 15 studies at towers > 82 m and 20 studies at towers < 78 m.

Search Effort

The studies summarized in this report represent 225,239 searches at 4,340 individual turbines. The number of searches was unevenly distributed among biomes (Figure 3), with the Prairie biome having the most searches and the Southwest biome the least. The percentage of turbines in a project that were reported as searched in a PCM study ranged from 10–100%. All turbines in a project were searched in 55 studies, and < 25% of turbines in a project were searched in 13 studies. Study duration ranged from two months to three years with most studies conducted over 6 to 12 months. The frequency of 12-month studies was lower in the Eastern and Northern Forest biomes (Table 3), perhaps due to harsher weather conditions during winter months in those biomes. Studies that generated only one fatality estimate for searches conducted over multiple years were typically from projects where not enough bird carcasses were found to calculate single-year estimates.

Search interval (the time between visits to each turbine) generally ranged from daily to monthly and was often adjusted throughout the year so that more frequent searches were conducted during periods of presumed high bird 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 interval was sorted into three categories:≤ 7 days, 8–14 days, and > 14 days. Studies with ≤ 7-day search intervals were most common in the Eastern and Northern Forest biomes, whereas > 14-day search intervals were most common in the Northern Rockies, Prairie, and Southwest biomes (Table 4).

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

Fatality Incidents

AWWIC contained bird fatality incidents reported in 193 PCM studies. Discovery dates were available for 87% of incidents (as described above, detailed incident data are not contained in every publicly available report). Carcasses found during scheduled searches at projects meeting our criteria accounted for 6,655 fatality incidents. For the detailed summaries of the incident data below, we did not include fatality

incidents from incidental finds in order to evaluate variation in collision levels among different bird species and groups based on a consistent level of search effort and reduce, although not eliminate, bias due to differences in detection.

Across all studies combined, the most carcasses found at a single turbine over the course of a study was 31. Of a total of 4,340 turbines, 1.7% had ≥ 10 bird carcasses found throughout a study. The maximum number of carcasses found at a single turbine during a single search was 12, and five or more carcasses were found at 13 turbines during a single search. Time since death of a fatality incident was estimated by searchers on some PCM surveys (N = 3,300): 31% occurred the previous day, 32% occurred 2–3 days prior, 19% occurred within 4–7 days, and 18% occurred > 7 days prior.

Using a subset of 48 studies that had search radii ≥ 100 m, the greatest percentage of carcasses of both small and large birds fell in the 26–50 m distance band, and 80% of carcasses fell within 75 m of the turbine (Figure 5). The distance distribution of small and large bird carcasses did not appear to differ (Figure 5).

Searcher Efficiency Trials

The median searcher efficiency for small birds was 56.8% with a range of 17–98.5% (Figure 6a). Large bird searcher efficiency was consistently higher with a median of 85.5% and a range of 48–100% (Figure 6b). In general, small bird searcher efficiency had greater variation within and among avifaunal biomes than large bird searcher efficiency. Searcher efficiency was sometimes estimated by various seasons or visibility classes if deemed to improve fatality estimates, and AWWIC collects that information when available; however, there were not currently enough studies reporting those details to create informative summaries.

Carcass Persistence Trials

A median of 53 small and 38 large bird carcasses were placed during each carcass persistence trial in the 193 studies. Carcasses were often placed in a variety of ground cover and distances from turbines during various seasons. Carcass persistence time reported for small birds had a skewed distribution with a median of 8.45 days and maximum of 40 days (Figure 7a). Small bird carcass persistence times > 22.5 days were plotted as outliers in box plots (defined as > 1.5 times the interquartile range) and occurred in five studies. Large bird carcass persistence times were often much longer with a median of 15 days and a maximum of 116 days (Figure 7b). Most trials did not last beyond 40 days, so reported times may have been influenced by trial length in some cases. Both small and large bird median times were longest in the Northern Rockies biome; however, there was not a large amount of variability between avifaunal biomes.

Part 2. Species Composition of Fatality Incidents

Methods

We aggregated fatality incidents primarily by species and avifaunal biome for all scheduled searches reported in contributed and public data in the AWWIC database. We did not include fatality incidents from studies in which we were able to determine that turbines were operating under a curtailment regime. We aggregated incident data by month to evaluate seasonality of fatality incidents. We present all incident data as unadjusted numbers following the common practice in previously published cumulative assessments of bird fatality rates (Loss et al. 2013, Erickson et al. 2014).

We evaluated the relationship between sampling effort and species richness of the incident data at the level of the BCR (Bird Conservation Region) in a process analogous to building a species-area curve. Our goal was to determine what level of effort would be necessary to detect most of the species that collide

with wind turbines in a BCR. We estimated species richness of a BCR from North American Breeding Bird Survey (BBS) 1966– 2015 trendline data (https://www.mbr-pwrc.usgs.gov/bbs/reglist15.html). Lists of species reported in fatality incidents for each BCR (with migrants and winter residents removed) were compared against the list of breeding birds for the BCR compiled from the BBS data. We calculated the proportion of breeding birds recorded as fatality incidents by dividing the number of breeding species found as fatality incidents by the total number of breeding species in the BCR. We then graphed sampling effort, estimated as the number of turbine searches in a BCR, versus the proportion of breeding birds recorded as incidents, to visually estimate the shape of the curve of species richness versus sampling effort.

Results and Discussion

After applying our study selection criteria, we aggregated data from 193 studies, totaling 6,655 fatality incidents comprising 281 bird species reported as collision fatalities during scheduled searches. A complete list of all species and their percentage of total fatality incidents is in Appendix C. Thirteen additional species were reported only as incidental finds are listed in Appendix D.

Species Composition

Similar to Erickson et al. (2014), we aggregated the percentage of reported fatality incidents into 19 bird groups (Table 5). These 19 bird groups correspond reasonably well to the major orders of North American birds potentially exposed to collision risk at wind energy facilities. Of the groups, small passerines constituted the largest percentage of fatalities, followed by diurnal raptors, doves/pigeons, and upland game birds, in that order (Table 5). Percentages for each of these groups varied regionally (Table 5). Notably, small passerines had higher representation in the Northern Forest, diurnal raptors were much higher in the Pacific biome, and the representation of upland game birds was highest in the Northern Rockies and Southwest biomes.

Unidentified birds accounted for 10.7% of all incidents, or more than 700 fatality incidents. Unidentified birds included all carcasses that could not be identified to species. Many studies sub-divided the unidentified bird category further (e.g., unidentified passerine, small bird, large raptor) and we combined all of these carcasses into the single category of unidentified bird to avoid reporting uncertain data in this report. The unidentified bird category could lead to higher fatality numbers for some bird groups. In an unpublished analysis of the unidentified bird category, we determined that approximately 500 fatality incidents were unidentified small birds, including passerines. Therefore, it is likely that the overall percentage of small passerines was higher than what is reported here.

Fatality incidents were disproportionately distributed among a few species. The 15 most reported of the 281 species (5.3% of all species reported) constituted 48.8% of all fatality incidents (Table 6). American kestrel and red-tailed hawk were in the top ten species with the most reported fatality incidents and were the most frequently reported raptor fatalities across almost all avifaunal biomes (Tables 7a, b). One hundred and eight species (38.4% of all species reported) were represented in the database by ≤ 3 fatality incidents and cumulatively accounted for < 3% of all fatality incidents (Appendix C).

Seventeen golden eagles (0.3% of all fatality incidents) were reported in 11 scheduled searches. Most of these (12) were found in the Pacific biome. Fatalities of this species were also reported from the Northern Rockies (3), Prairie (1), and Southwest (1) biomes. Twenty additional golden eagles were reported as incidental finds in the same four biomes. No bald eagles were contained in the AWWIC database. Fatalities of the bald eagles at wind facilities have been reported in the literature (Pagel et al. 2013) and more are known to have occurred since this publication. This lower number of fatalities reported from scheduled searches is consistent with the finding of Pagel et al. (2013) that only 18.8% of the fatalities they reported were found during systematic surveys.

Species Richness

The number of species represented as fatalities in the AWWIC database (281 from 193 studies)is greater than the 246 species reported in 116 publicly available studies by Erickson et al. (2014). We estimate that the 19 bird groups we used in this report comprise 611 species occurring in the continental U.S. Thus, more than half (54.0%) of the species potentially exposed to wind turbines were not reported as fatalities. Some of these unreported species may be explained by the low number of studies from some regions, such as the Southwest biome with only six studies in AWWIC.

The possible breeding bird species are known for BCRs, which allowed for comparison among the species reported in AWWIC and the full list of possible species in each BCR. There was a strong relationship between sampling effort, estimated as the number of turbine searches, and the proportion of species reported as fatalities within a BCR (Figure 8). The proportion increased linearly until 10,000–15,000 searches (approximately 15–20 studies) in a BCR before it began to level off, suggesting that further effort beyond about 15,000 searches or 20 studies per BCR yielded marginal increases in new species reported as fatality incidents in a region.

Absence of evidence for a species as a collision fatality, of course, is not evidence of absence (Huso et al. 2015). In addition, as pointed out by Pagel et al. (2013), for eagles, some species may be missed during scheduled searches yet are reported as fatalities on an incidental basis. However, available data suggest that the majority of bird species are at low risk of collision with wind turbines in comparison to their overall abundance in the North American bird avifauna. The population consequences of this risk are not possible to assess from these data, but we found generally that the proportion of most species found as fatalities was small relative to the proportion the same species comprised in the North American avifauna, as found by Erickson et al. (2014).

Potential Sources of Variation

An unknown, but perhaps substantial, amount of the variation among species groups in fatality incidents reflected differences in detectability. Specifically, the incident numbers for individual species were not adjusted for searcher efficiency and carcass persistence, both of which are higher for large birds (Figures 6, 7). Collectively, these differences resulted in large birds, including raptors, being more likely to be detected than small passerines, and therefore over-represented in this unadjusted sample of bird fatality incidents. Species likely also varied in detectability, but these differences were not evaluated.

The pool of data in AWWIC, although more complete than other previously analyzed fatality datasets, was not fully representative of the distribution of installed wind energy across the U.S. For example, the Pacific biome was substantially over-represented, whereas the Prairie and Southwest biomes were substantially under-represented (Table 2). The overall species compositions we have reported may have been sensitive to changes in regional representation if there were species that were abundant in some regions and not others.

The variation among bird groups and among species in fatality incidents in AWWIC might provide a snapshot of variation in collision risk among the more than 600 bird species that could potentially collide with wind turbines in the continental U.S. Such an analysis is far from simple, however, because the observed variation results from a combination of variation in bird abundance and behavior, differences in detectability, and geograpic representation of studies.

There appears to be variation among bird species in their risk of collision with anthropogenic structures, such as wind turbines (Arnold and Zink 2011). Assessing this variation usually involves comparing representation in fatality databases with abundance of individual species or species groups (Loss et al. 2014). By these criteria, even if all unidentified small birds were counted as small passerines, the overall percentage of small passerine fatalities would be lower than the percentage of these species in North

American birds, estimated at ~90% in North America (PIF 2013;Table 8). Only the Northern Forest biome percentage of small passerines (> 84%, Table 5) approached the relative abundance of these birds in the North American avifauna. On the other hand, diurnal raptors appear over-represented as fatality incidents in AWWIC: diurnal raptors constituted 8.2% of all unadjusted fatality incidents in AWWIC, but < 0.3% of bird abundance in North America (Table 8). Other groups that appear over-represented as fatality incidents in AWWIC in relation to their estimated abundance in North America included doves/pigeons, upland game birds, and vultures (Table 8).

Another potential source of error in the observed patterns of fatality incidents among bird groups was that PCM surveys considered any evidence of bird remains as a collision fatality. Many surveys recorded the condition of the carcass when located on a survey (Table 9a). A substantial proportion of incidents with reported condition – 26% – were categorized as feather spots, defined as two or more feathers. The proportion of feather spots also differed substantially by bird group (Table 9b). Feather spots constituted more than 40% of reported fatalities for upland game birds, doves/pigeons, shorebirds, and waterfowl. Feather spots constituted a much smaller, but still substantial, percentage of small passerine and diurnal raptor fatality incidents. Feather spots could have represented a collision fatality scavenged *in situ*. However, it is possible that many feather spots did not represent collision fatalities, but were molted or lost feathers or evidence of depredation. Very few PCM surveys attempted to determine background (non-collision) fatality levels, but if feather spots, or a large proportion of them, were the result of events other than collisions, it could substantially change the percentage of fatalities among bird groups and our assumptions about collision risk for different bird groups and species.

Variation in fatality incidents could be evaluated within bird groups and all of the above factors apply to some degree in explaining that variation. Bird abundance might also be an obvious predictor of the variation in fatality incidents, but this is not always supported by the data. For example, American robin is the most abundant landbird in the U.S. and Canada (~300 million individuals, or ~5% of all landbirds; PIF 2013), but this widespread species comprised only 0.4% of all incidents in AWWIC. American kestrel and red-tailed hawk are the most abundant diurnal raptors in the U.S. and Canada at 2.2 and 2 million individuals respectively (PIF 2013), and they constituted the largest percentage of diurnal raptor fatalities. However, the number of broad-winged hawks is ~1.7 million individuals (~14% of diurnal raptors in the U.S. and Canada; PIF 2013), but they comprise < 1% of raptor fatality incidents. Numerous other components of avian biology presumably influence fatality risk including behavior, migration routes and timing, breeding ecology, and the proximity of wind turbines to areas of specific habitat requirements.

Fatality Timing

We examined the seasonality of fatality incidents for passerines and raptors using a reduced dataset of 52 studies that searched for at least 11 months and had search intervals ≤ 14 days. These criteria were used in order to account for shorter studies giving greater search effort during certain parts of the year that could bias fatality timing summaries. Passerine fatality incidents displayed distinct seasonal patterns with peaks during spring and fall migration seasons (Figure 9a). We further evaluated seasonal variation in fatality incidents for seven species of passerines that represented ≥ 1% of observed incidents (see Table 6). These species could be further grouped into those that showed a distinct pattern of collision risk during the migration seasons (golden- and ruby-crowned kinglet, magnolia warbler, and red-eyed vireo; Figure 9b, Group A) and species that had a more even distribution of fatality incidents (western meadowlark, horned lark, and red-winged blackbird; Figure 9b, Group B).

Seasonality in raptor fatalities is subtler, but a peak in incidents in the fall was evident (Figure 9a), presumably coincident with the fall migration season. We examined the monthly distribution of fatality incidents for the two diurnal raptors with the most fatality incidents: American kestrel and red-tailed hawk. Both species showed fall peaks, but spring peaks were less obvious (Figure 9c). By restricting our sample to only those studies that surveyed 11 months or more, we provided evidence of some bias against projects in the eastern U.S. and upper Midwest where shorter studies were more common.

However, it is also true that at these more northern latitudes with harsher winter weather many landbird species are no longer present in the winter, at least partially accounting for the lack of monitoring during these time periods. Fatality timing provides valuable information for informing fatality avoidance and minimization efforts as well as for focusing future monitoring studies. Therefore, we will be continuing research on correcting timing summaries for search effort for inclusion in future reports.

Part 3. Bird Fatality Estimates

Methods

Bird fatality estimates from studies included in this report were calculated after cumulative raw carcass counts were adjusted for detection biases as described earlier 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. 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 to make cumulative assessments have varied substantially and are a topic of ongoing research (Johnson et al. 2016). We assumed that each study contained in AWWIC 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 the database, we included studies in our summaries if they met the following criteria:

1. Studies reported species found during scheduled fatality searches
2. Turbines operated according to the manufacturer's specifications (e.g., studies conducted while turbines were operating under a curtailment regime were not included)
3. Fatality surveys lasted at least six months and included both spring and fall to capture peak bird migration 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

Thirty-five 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

Bird fatality estimates were plotted to observe their distribution and variability among biomes for all birds, small birds (< 30 cm total length), large birds (≥ 30 cm total length), and raptors. Not all studies provided estimates for these categories, so a minimum of five studies was required to include a biome in the summary for each group. In addition to fatality estimates by avifaunal biomes, we analyzed all bird fatality estimates by USFWS Region to provide insight into variability among political/regulatory regions.

Estimates for two years of study were available for 25 phases and for three years at eight phases. There were also studies with a single annual estimate derived from carcasses found over more than one year of searching. Further, some studies provided estimates for searches conducted at multiple phases. These

special cases would have been needed to be addressed for a detailed analysis that directly compared projects. However, for this report, we have included all estimates that met our criteria for study inclusion (see above). Estimates are presented as fatalities per 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, 167 studies from 126 phases at 115 projects with estimates were available to use. The pool of studies available for analysis of fatality rates was less than the pool for summarizing fatality incidents because of the selection criteria used. Shoenfeld (Shoenfeld 2004), Huso (Huso 2011), and Jain (e.g., Jain et al. 2007) were the estimators most frequently used for studies contained in AWWIC (Figure 10). Examples of other estimators used include Erickson (Erickson et al. 2000) and customized approaches (e.g., Ventus Environmental Solutions 2016). Bird fatality estimates were often accompanied by further groupings: small birds (91 studies), large birds (87 studies), and raptors (76 studies).

All bird fatality estimates for the U.S. had a skewed distribution with 75% of studies reporting < 3.1 birds per MW per year (Figure 11, All Birds). The median fatality estimate for all studies was 1.8 birds per MW per year. Forty-five studies (26.9%) estimated < 1 bird fatality per MW per year. Estimates > 6.79 birds per MW per year were plotted as outliers in the box plot for the U.S. (> 1.5 times the interquartile range) (N = 7; Figure 11, All Birds). Median fatality rates for the avifaunal biomes ranged from 2.7 birds per MW per year in the Eastern biome to 1.37 birds per MW per year in the Southwest biome.

Seventy-five percent of studies with small bird estimates reported < 2.0 small birds per MW per year (Figure 11, Small Birds). The median fatality estimate for all studies was 1.2 small birds per MW per year. Thirty-four studies (20.4%) estimated < 1 small bird fatality per MW per year. Estimates plotted as outliers in the box plot for U.S. small birds ranged from 4.79–6.02 small birds per MW per year (N = 2; Figure 11, Small Birds). Median fatality rates for the avifaunal biomes ranged from 2.3 birds per MW per year in the Northern Forest biome to 0.91 birds per MW per year in the Southwest biome.

Large bird fatality estimates for the U.S. had a skewed distribution with 75% of studies reporting < 0.46 large birds per MW per year (Figure 11, Large Birds). The median fatality estimate for all studies was 0.22 large birds per MW per year. Eighty-one studies (48.5%) estimated < 1 large bird fatality per MW per year. Estimates plotted as outliers in the box plot for U.S. large birds ranged from 1.1–2.8 large birds per MW per year (N = 6; Figure 11, Large Birds). Large bird fatality estimates > 1 large bird per MW per year were reported in the Prairie and Eastern biomes.

Seventy-five percent of studies with raptor fatality estimates reported < 0.23 raptors per MW per year (Figure 11, Raptors). The median fatality estimate for all studies was 0.06 raptors per MW per year. Seventy-four studies (44.3%) estimated < 1 raptor fatality per MW per year. Estimates plotted as outliers in the box plot for U.S. raptors ranged from 0.69–1.01 raptors per MW per year (N = 4; Figure 11, Raptors). The Pacific biome reported the highest raptor fatality rates with a median of 0.74 raptors per MW per year.

Median bird fatality estimates for each USFWS Region with data in AWWIC are shown in Figure 12. Median bird fatality estimates were highest in the Midwest and Northeast Regions (2.63 birds per MW per year and 2.49 birds per MW per year, respectively). Median bird fatality estimates were lowest in the Mountain-Prairie Region with 1.36 birds per MW per year. The smallest range of all bird fatality estimates was in the Pacific Region where the maximum was 3.55 and the minimum 0.173 birds per MW per year.

Conclusions and Next Steps

Results presented in this report are consistent with conclusions from previous comprehensive assessment of publicly available data (Loss et al. 2013, Erickson et al. 2014). Although containing more data than previous assessments of publicly available data, AWWIC is a non-random dataset, where representation varied among defined geographic regions and with differences in protocols among studies that influenced detectability. Thus, any conclusions about patterns should be considered tentative or as potential hypotheses about variation in regional and species-specific collision risk among bird species given the issues concerning detection and representation described earlier. The primary findings were:

- AWWIC has sufficient data, with enough geographic coverage, for us to pose reasonable hypotheses about the impacts of wind energy on birds in the U.S. These hypotheses can be evaluated with data from additional PCM studies.
- A total of 281 of more than 600 North American bird species were recorded as collision fatalities in scheduled searches reported in studies contained in AWWIC. One hundred and eight (38%) of the reported species had three or fewer collision fatalities reported in all scheduled searches contained in AWWIC.
- Fifteen species account for nearly half of the fatality incidents in AWWIC. Whether these collision fatalities pose a population-level threat to these species is unknown.
- Because of their life history attributes, diurnal raptors are a group of concern. Collision risk appears to vary considerably within this group, and this variation will be evaluated with additional data and further analysis.
- Increased investment in fatality monitoring may lead to diminishing returns in finding new species.

This report is a companion to the summary of bat fatality data contained in AWWIC (AWWI 2018). We will continue to add data to AWWIC and anticipate regular updates to the information contained in this report. We will also continue evaluation of existing data, including detailed Bayesian hierarchical analyses, with the goal of distinguishing the importance of methodological and ecological factors to the variation observed. In particular, we will be evaluating the following topics:

1) A few independent studies (e.g., Johnson et al. 2000) and this report suggest the potential for a significant level of background mortality, i.e., avian mortality from sources other than collisions that would be occurring whether or not the turbines were present, to be recorded as collision fatalities, and that there is systematic bias in the amount of background mortality among bird groups. Further evaluation of background mortality would be useful to increase the accuracy of bird collision fatality estimates.
2) A new “generalized estimator” has been released (Dalthorp et al. 2018) that is intended to provide less biased adjusted fatality estimates and improve comparability among studies. We will investigate recalculating fatality estimates in AWWIC using this new estimator.
3) Recalculated fatality estimates will enable more reliable evaluation of temporal and regional trends in bird fatalities and the number of studies needed to accurately and reliably estimate bird collision fatalities within a region.
4) We will further evaluate inter-group and interspecific variation in fatality risk, focusing on diurnal raptors, by adjusting fatality incidents for differences in detection and representation.

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Tables

Table 1. Number of wind energy projects, phases, and post-construction fatality monitoring studies for U.S. avifaunal biomes in AWWIC that contain bird fatality incidents and/or estimates. Studies were made available by data contributors or acquired from publicly available reports.

	Contributed		Public Reports		Combined	
Avifaunal Biome	Projects /Phases	Studies	Projects /Phases	Studies	Projects /Phases	Studies
Eastern	11/11	21	9/9	14	20/20	35
Northern Forest	10/10	15	7/7	8	17/17	23
Northern Rockies	14/17	25	10/14	16	24/31	41
Pacific	3/3	6	7/8	11	10/11	17
Prairie	39/41	53	14/15	17	53/56	70
Southwest	4/4	5	2/2	2	6/6	7
Total U.S.	81/86	125	49/55	69	130/141	193

Table 2. Amount of U.S. installed wind energy capacity in gigawatts (GW) as of the fourth quarter 2016 (AWEA 2016) by avifaunal biome analyzed in this report. Percent representation for each biome is in the far-right column.

	Installed Capacity in U.S. or avifaunal biome (Q4 2016)		Installed Capacity Represented in AWWIC Database		
Avifaunal Biome	Projects/Phases	GW	Projects/Phases	GW	% GW
Eastern	75/80	5.17	20/20	2.01	38.9%
Northern Forest	53/60	3.55	17/17	1.13	31.8%
Northern Rockies	82/124	9.02	24/31	3.60	39.9%
Pacific	24/27	1.51	10/11	1.10	72.8%
Prairie	455/538	56.03	53/56	7.50	13.4%
Southwest	69/92	6.86	6/6	0.52	7.58%
Total U.S.[1]	758/921	82.15	130/141	15.86	19.3%

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

Table 3. Frequency of survey duration of post-construction fatality monitoring studies by avifaunal biome. Reported for a subset of 193 studies used in this report.

Avifaunal Biome	≤ 6 months	6–11 months	full year	> 1 year
Eastern	6	21	8	0
Northern Forest	11	12	0	0
Northern Rockies	0	7	29	5
Pacific	0	1	12	4
Prairie	10	28	25	7
Southwest	0	0	6	1
Total U.S.	27	69	80	17

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

Avifaunal Biome	≤ 7 days	8–14 days	> 14 days
Eastern	30	5	0
Northern Forest	18	5	0
Northern Rockies	1	11	29
Pacific	5	8	4
Prairie	21	23	26
Southwest	0	2	5
Total U.S.	75	54	64

Table 5. Percent composition of unadjusted bird fatality incidents for 19 bird groups by avifaunal biome reported in scheduled carcass searches at wind facilities in the U.S. Bird group is sorted in descending order of percentage for the U.S. Number of studies for each biome is listed in parentheses and '# incidents' is the number of incidents reported in scheduled searches in AWWIC studies in each biome and the U.S.

Bird Group	U.S. (193)	Eastern (34)	Northern Forest (23)	Northern Rockies (41)	Pacific (17)	Prairie (71)	Southwest (7)
small passerines	56.5%	54.3%	85.4%	62.0%	51.3%	51.5%	51.4%
diurnal raptors	8.2%	3.5%	1.4%	5.3%	22.3%	4.6%	2.8%
doves/pigeons	6.1%	6.4%	0.8%	4.7%	8.2%	6.5%	7.5%
upland game birds	4.3%	2.2%	2.6%	8.7%	1.3%	4.6%	12.7%
vultures	2.4%	2.6%	0.4%	0.1%	1.5%	5.2%	0.5%
shorebirds	2.1%	2.1%	0.4%	0.3%	0.5%	5.2%	0.5%
waterfowl	2.0%	1.1%	0.8%	4.0%	1.5%	2.0%	0.5%
rails/coots	1.4%	0.5%	0.0%	1.0%	3.2%	1.1%	0.9%
owls	1.2%	0.3%	0.0%	1.4%	2.7%	0.8%	0.9%
large cuckoos	1.1%	3.0%	0.6%	0.0%	0.0%	1.4%	0.9%
woodpeckers	0.9%	0.6%	2.8%	1.4%	0.6%	0.5%	2.4%
gulls/terns	0.8%	2.8%	0.0%	0.0%	1.0%	0.0%	0.0%
swifts/hummingbirds	0.6%	0.8%	0.8%	0.4%	0.5%	0.6%	2.4%
goatsuckers	0.5%	0.3%	0.0%	0.8%	0.1%	0.8%	0.9%
large corvids	0.4%	0.2%	0.6%	0.8%	0.3%	0.2%	2.4%
loons/grebes	0.4%	0.1%	0.0%	0.8%	0.2%	0.6%	0.0%
waterbirds	0.3%	0.8%	0.2%	0.1%	0.3%	0.2%	0.0%
kingfishers	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
unidentified birds	10.7%	18.4%	3.0%	8.2%	4.2%	14.1%	13.2%
# of Incidents	6,655	1,312	499	1,248	1,492	1,893	212

Table 6. Unadjusted percentages of fatality incidents for the 25 most reported species and the unidentified birds group from scheduled searches at U.S. wind facilities. N is the number of studies reporting a species out of a total of 193 studies in the database. Total refers to the number of incidents on which percentages are based and the number of studies.

Species	%	N
horned lark	12.6%	83
mourning dove	4.7%	71
red-eyed vireo	4.6%	58
western meadowlark	4.2%	40
golden-crowned kinglet	4.0%	69
American kestrel	3.1%	44
red-tailed hawk	2.9%	63
turkey vulture	2.3%	44
red-winged blackbird	2.1%	25
killdeer	1.6%	26
ring-necked pheasant	1.4%	29
European starling	1.4%	45
ruby-crowned kinglet	1.2%	52
rock pigeon	1.2%	38
magnolia warbler	1.0%	30
gray partridge	0.9%	21
American coot	0.8%	24
yellow-rumped warbler	0.8%	31
savannah sparrow	0.8%	31
tree swallow	0.7%	27
yellow-billed cuckoo	0.7%	16
barn owl	0.6%	22
Wilson's warbler	0.6%	23
brewer's blackbird	0.6%	12
dark-eyed junco	0.6%	25
unidentified birds	15.2%	154
Total	6,655	193

Table 7. Unadjusted percentages of fatality incidents for the 25 most reported species and the unidentified birds group from scheduled searches by avifaunal biome. N is the number of studies reporting a species. Total refers to the number of incidents on which percentages are based.

a) Eastern, Northern Forest, and Northern Rockies

Eastern	%	N	Northern Forest	%	N	Northern Rockies	%	N
red-eyed vireo	14.4%	28	red-eyed vireo	18.6%	21	horned lark	29.3%	34
mourning dove	5.7%	8	golden-crowned kinglet	18.4%	13	golden-crowned kinglet	4.6%	19
golden-crowned kinglet	3.4%	17	magnolia warbler	5.6%	11	gray partridge	4.4%	18
turkey vulture	2.4%	8	common yellowthroat	2.2%	8	mourning dove	3.4%	14
magnolia warbler	2.1%	12	black-and-white warbler	2.0%	7	ring-necked pheasant	2.6%	9
yellow-billed cuckoo	2.1%	6	ovenbird	2.0%	6	ruby-crowned kinglet	2.2%	19
blackpoll warbler	1.9%	2	northern parula	1.6%	5	European starling	2.0%	14
yellow-breasted chat	1.9%	4	ruby-crowned kinglet	1.6%	6	western meadowlark	2.0%	12
wood thrush	1.4%	6	ruffed grouse	1.6%	7	American kestrel	1.9%	13
yellow-rumped warbler	1.4%	7	bay-breasted warbler	1.4%	5	dark-eyed junco	1.7%	12
black-throated blue warbler	1.2%	9	yellow-bellied sapsucker	1.4%	5	Townsend's warbler	1.5%	10
laughing gull	1.1%	4	American redstart	1.2%	6	chukar	1.4%	8
ruby-crowned kinglet	1.1%	10	Blackburnian warbler	1.2%	6	yellow-rumped warbler	1.4%	12
black-throated green warbler	1.1%	5	blackpoll warbler	1.2%	4	red-tailed hawk	1.3%	12
blue-headed vireo	1.0%	8	pine warbler	1.2%	2	rock pigeon	1.3%	10
European starling	1.0%	4	tree swallow	1.2%	5	American coot	1.0%	6
red-tailed hawk	0.8%	10	black-throated blue warbler	1.0%	5	American robin	1.0%	9
wild turkey	0.8%	4	black-throated green warbler	1.0%	5	northern flicker	0.9%	10
black-billed cuckoo	0.8%	7	blue-headed vireo	1.0%	5	red-breasted nuthatch	0.8%	6
Blackburnian warbler	0.8%	8	wild turkey	1.0%	3	snow goose	0.8%	2
bobolink	0.8%	5	eastern kingbird	0.8%	3	savannah sparrow	0.7%	6
ruffed grouse	0.8%	6	eastern wood-pewee	0.8%	4	Swainson's hawk	0.7%	6
Tennessee warbler	0.8%	7	hermit thrush	0.8%	4	white-crowned sparrow	0.7%	6
Cape May warbler	0.7%	1	red-breasted nuthatch	0.8%	3	common nighthawk	0.6%	5
northern parula	0.7%	5	red-tailed hawk	0.8%	4	house wren	0.6%	5
unidentified birds	23.8%	25	unidentified birds	10.6%	15	unidentified birds	13.8%	34
Total	1,312			499			1,248	

b) Pacific, Prairie, and Southwest

Pacific	%	N	Prairie	%	N	Southwest	%	N
western meadowlark	14.9%	16	horned lark	19.34%	31	California scrub-jay	5.6%	1
American kestrel	10.2%	15	turkey vulture	5.2%	22	Wilson's warbler	5.1%	5
red-tailed hawk	8.8%	16	mourning dove	5.0%	27	chukar	4.7%	2
red-winged blackbird	8.4%	13	killdeer	4.8%	17	mourning dove	4.7%	4
horned lark	6.8%	14	golden-crowned kinglet	3.6%	17	California quail	3.7%	1
mourning dove	5.8%	15	ring-necked pheasant	2.4%	14	mountain quail	3.7%	1
Brewer's blackbird	2.5%	10	northern bobwhite	1.5%	5	yellow-rumped warbler	3.7%	2
rock pigeon	2.3%	11	red-tailed hawk	1.5%	19	black-headed grosbeak	3.3%	3
European starling	2.1%	12	American kestrel	1.2%	9	golden-crowned sparrow	2.8%	1
barn owl	2.0%	13	western meadowlark	1.2%	10	western meadowlark	2.8%	1
American coot	1.7%	7	red-eyed vireo	1.1%	9	common raven	2.3%	2
turkey vulture	1.5%	10	ruby-crowned kinglet	1.1%	10	rock pigeon	2.3%	2
tree swallow	1.4%	10	European starling	1.0%	13	house finch	1.9%	3
American pipit	1.3%	5	rock pigeon	1.0%	11	northern flicker	1.9%	2
savannah sparrow	1.3%	6	yellow-billed cuckoo	1.0%	8	rock wren	1.9%	2
Wilson's warbler	1.1%	9	American redstart	1.0%	5	savannah sparrow	1.9%	2
mallard	1.0%	5	American coot	0.8%	10	Townsend's warbler	1.9%	2
yellow warbler	1.0%	10	grasshopper sparrow	0.8%	5	white-throated swift	1.9%	2
ring-necked pheasant	0.9%	6	tree swallow	0.8%	7	American kestrel	1.4%	3
northern harrier	0.9%	8	house wren	0.8%	13	black-throated gray warbler	1.4%	1
golden eagle	0.8%	6	vesper sparrow	0.8%	8	black-throated sparrow	0.9%	2
ruby-crowned kinglet	0.6%	7	common nighthawk	0.7%	4	Bullock's oriole	0.9%	1
Virginia rail	0.6%	6	Swainson's hawk	0.7%	6	common poorwill	0.9%	2
black-throated gray warbler	0.5%	5	brown creeper	0.6%	6	greater roadrunner	0.9%	2
house finch	0.5%	5	dark-eyed junco	0.6%	7	horned lark	0.9%	2
unidentified birds	7.8%	12	unidentified birds	17.1%	58	unidentified birds	16.8%	6
Total	1,492			1,893			212	

Table 8. Comparison of estimated percent abundance in North America for each of the 19 bird groups and their representation in the AWWIC database. Estimates of abundance were compiled from Kushlan et al. (2002), Wetlands International (2012), PIF (2013), and USFWS (2017).

Bird Group	Percent Composition of AWWIC Fatality Incidents (N = 6,655)	Estimated Percent Abundance in North America (N = $6X10^9$)
small passerines	56.5%	89.9%
diurnal raptors	8.2%	0.3%
doves/pigeons	6.1%	2.0%
upland game birds	4.3%	1.5%
vultures	2.4%	0.1%
shorebirds	2.1%	0.5%
waterfowl	2.0%	0.9%
rails/coots	1.4%	0.1%
owls	1.2%	0.2%
large cuckoos	1.1%	0.2%
woodpeckers	0.9%	1.1%
gulls/terns	0.8%	0.3%
swifts/hummingbirds	0.6%	1.0%
goatsuckers	0.5%	0.5%
large corvids	0.4%	0.7%
loons/grebes	0.4%	0.1%
waterbirds	0.3%	0.2%
kingfishers	0.0%	0.4%

Table 9. a) Condition of bird carcasses found during fatality searches at wind energy facilities. Percentages are based on the total of incidents for which condition was reported; blank and not specified are included in the total. b) Percentage of carcasses that are feather spots by bird group where condition of the fatality incident was reported.

a)

Condition	#	%
Dismembered	273	5.0%
Feather spot(s)	1418	26.0%
Intact	1495	27.4%
Other	1243	22.8%
Partial	1009	18.5%
Scavenged	5	0.1%
Unknown	15	0.3%
Total	5,458	

b)

Bird Group	# Incidents	% Total Incidents
diurnal raptors	82	21.7%
doves/pigeons	172	48.7%
goatsuckers	10	30.3%
gulls/terns	15	28.8%
large corvids	11	42.3%
large cuckoos	14	23.0%
loons/grebes	3	13.6%
owls	19	30.2%
rails/coots	9	17.0%
shorebirds	64	48.1%
small passerines	494	16.3%
swifts/hummingbirds	2	5.4%
unidentified birds	301	38.4%
upland gamebirds	136	53.3%
vultures	16	11.0%
waterbirds	2	11.1%
waterfowl	48	42.1%
woodpeckers	20	37.7%

Figures

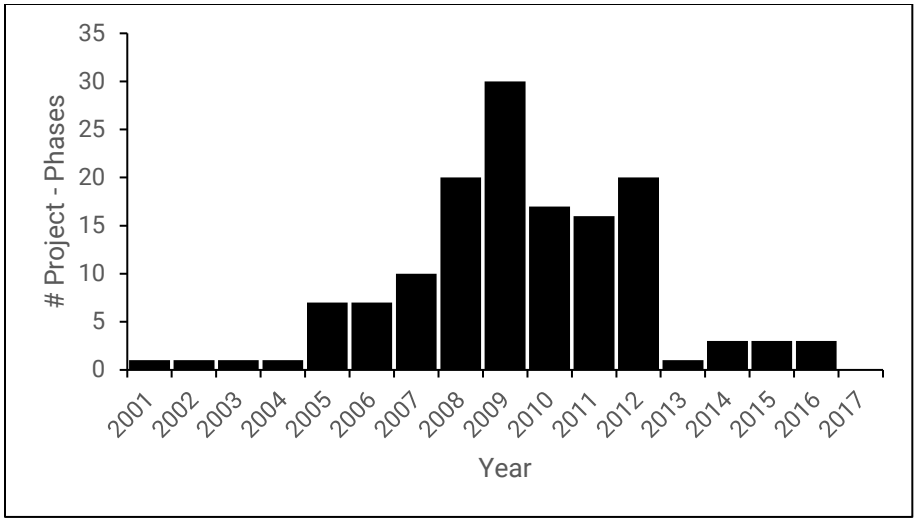


Figure 1. Number of wind energy projects represented in AWWIC (N = 141) that became operational or repowered by year.

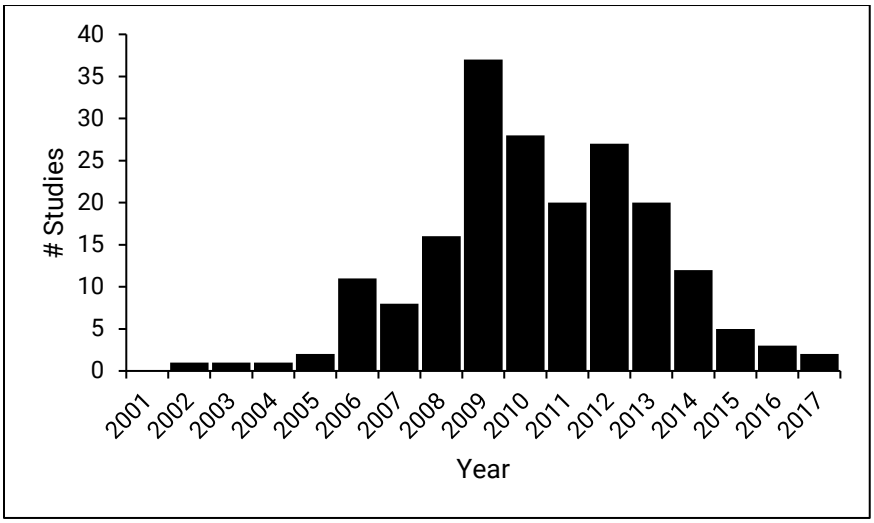


Figure 2. Number of post-construction monitoring studies contained in AWWIC (N = 194) by year.

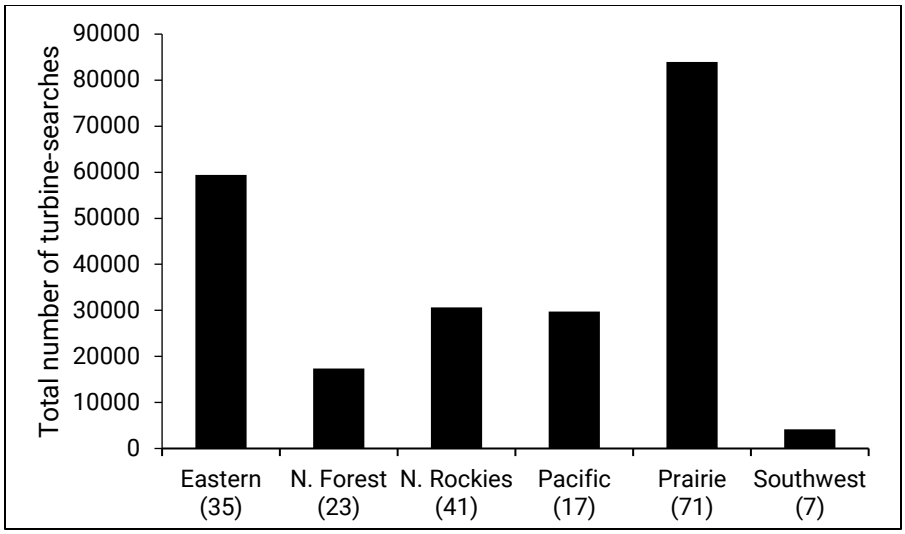


Figure 3. Total number of turbine searches conducted during post-construction monitoring studies by avifaunal biome with bird fatality data available. The number of studies for each biome is indicated by the number in parentheses.

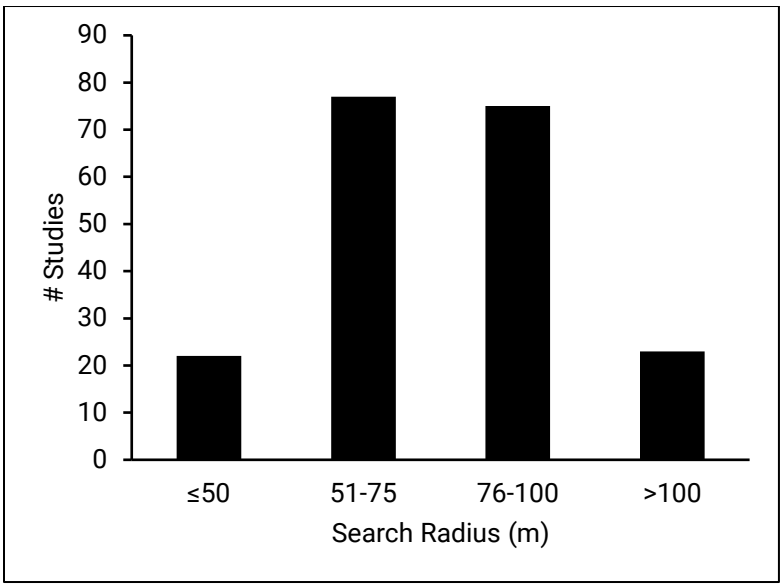


Figure 4. Distribution of plot radius around turbines searched during post-construction fatality monitoring (N = 194 studies).

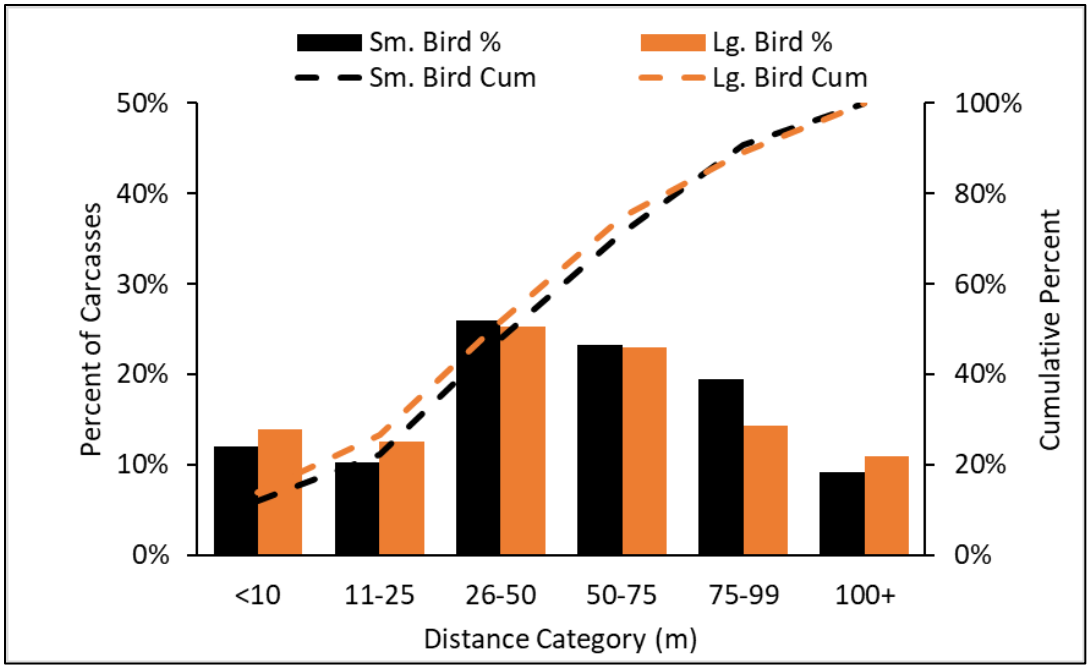


Figure 5. Distance category (m) from the turbine tower at which small (Sm. Bird) and large (Lg. Bird) bird carcasses (N = 1,364 small bird; 840 large bird) were found during scheduled carcass searches. Only studies with search radius ≥ 100m (N = 48 studies) were included. Dashed lines show cumulative percentage (right axis) of carcasses found as distance from the turbine increases.

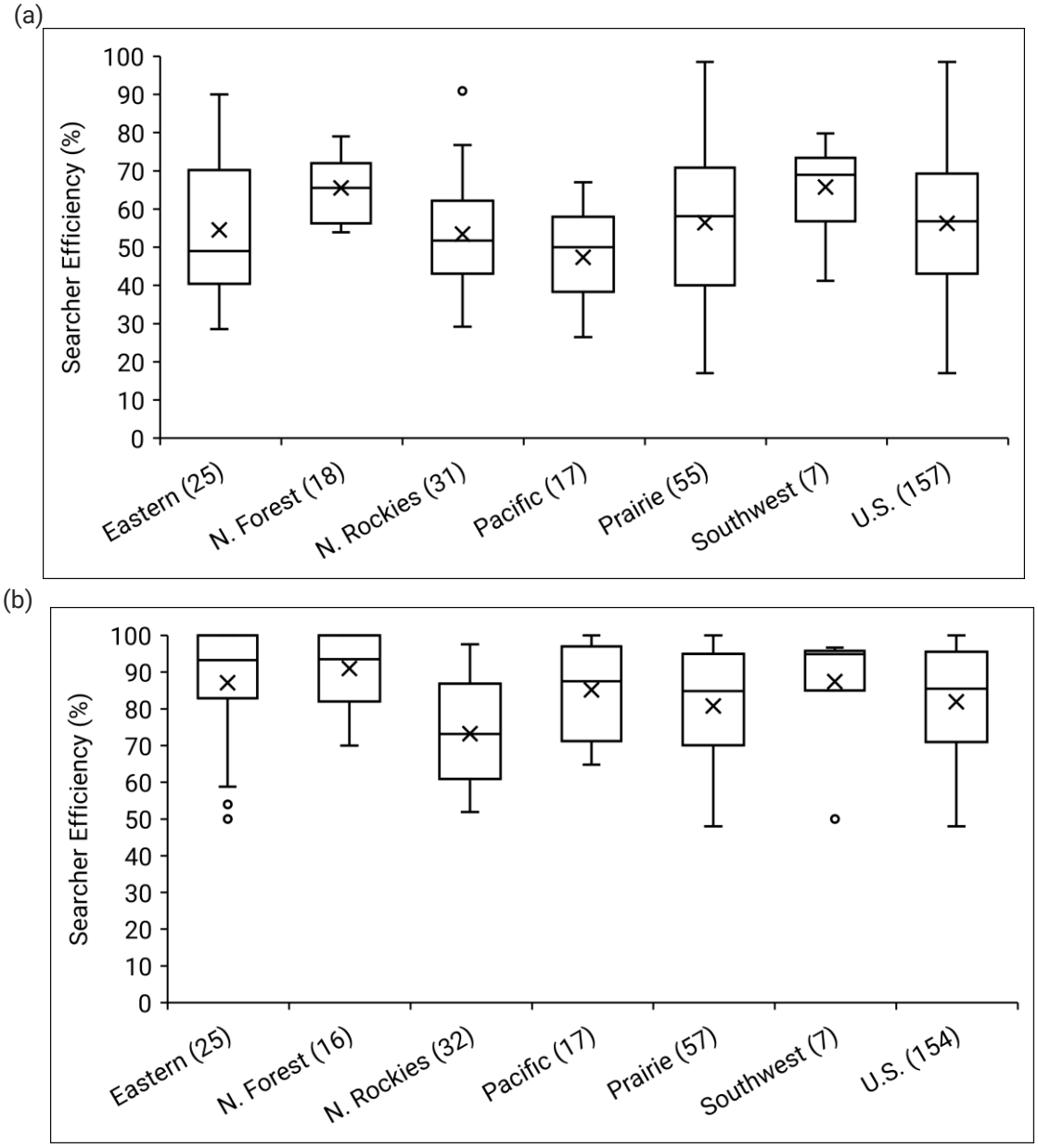


Figure 6. Searcher efficiency by avifaunal biome and for the entire U.S. as percent of placed carcasses found by search personnel in post-construction monitoring studies contained in AWWIC: (a) Small birds and (b) Large birds. Number of studies available in each biome is contained in parentheses. Box plots show median and first and third quartile values; "X" indicates mean value.

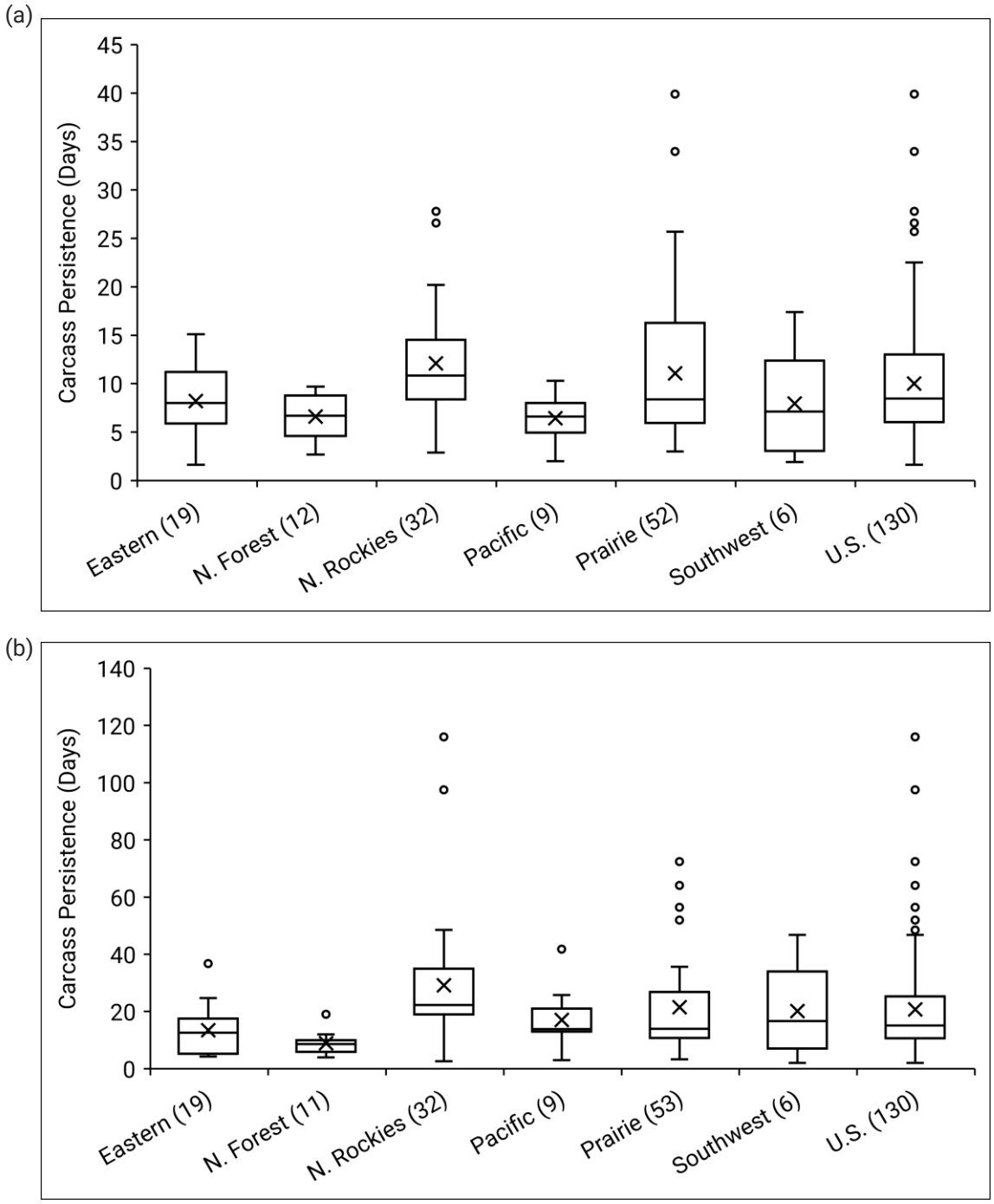


Figure 7. Distribution of mean carcass persistence time by avifaunal biome and for the entire U.S. for carcasses used in removal trials in post-construction monitoring studies contained in AWWIC: (a) Small birds and (b) Large birds. Number of studies available in each biome is contained in parentheses. Box plots show median and first and third quartile values; "X" indicates mean value. Note the different scales in the y axis between (a) and (b).

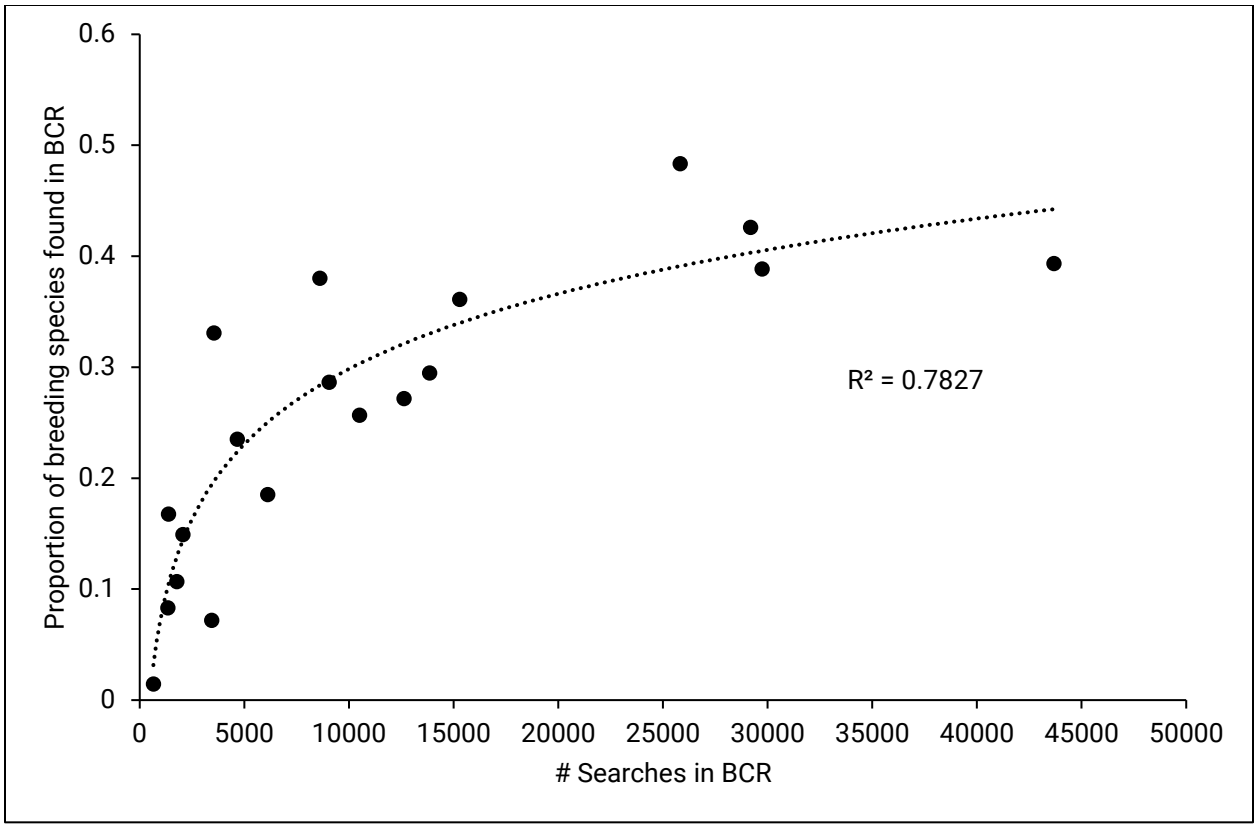


Figure 8. Relationship between the proportion of breeding bird species found and the sum of scheduled searches conducted in all studies within a Bird Conservation Region (BCR). Each point corresponds to the result calculated for a BCR, e.g., BCR 28 (x = 29,184 scheduled searches, y = 0.426 proportion of breeding species found across all scheduled searches). R^2 is the correlation coefficient of the fitted logarithmic trendline. Species richness in each BCR estimated from North American Breeding Bird Survey 1966–2015 trendline data (https://www.mbr-pwrc.usgs.gov/bbs/reglist15.html).

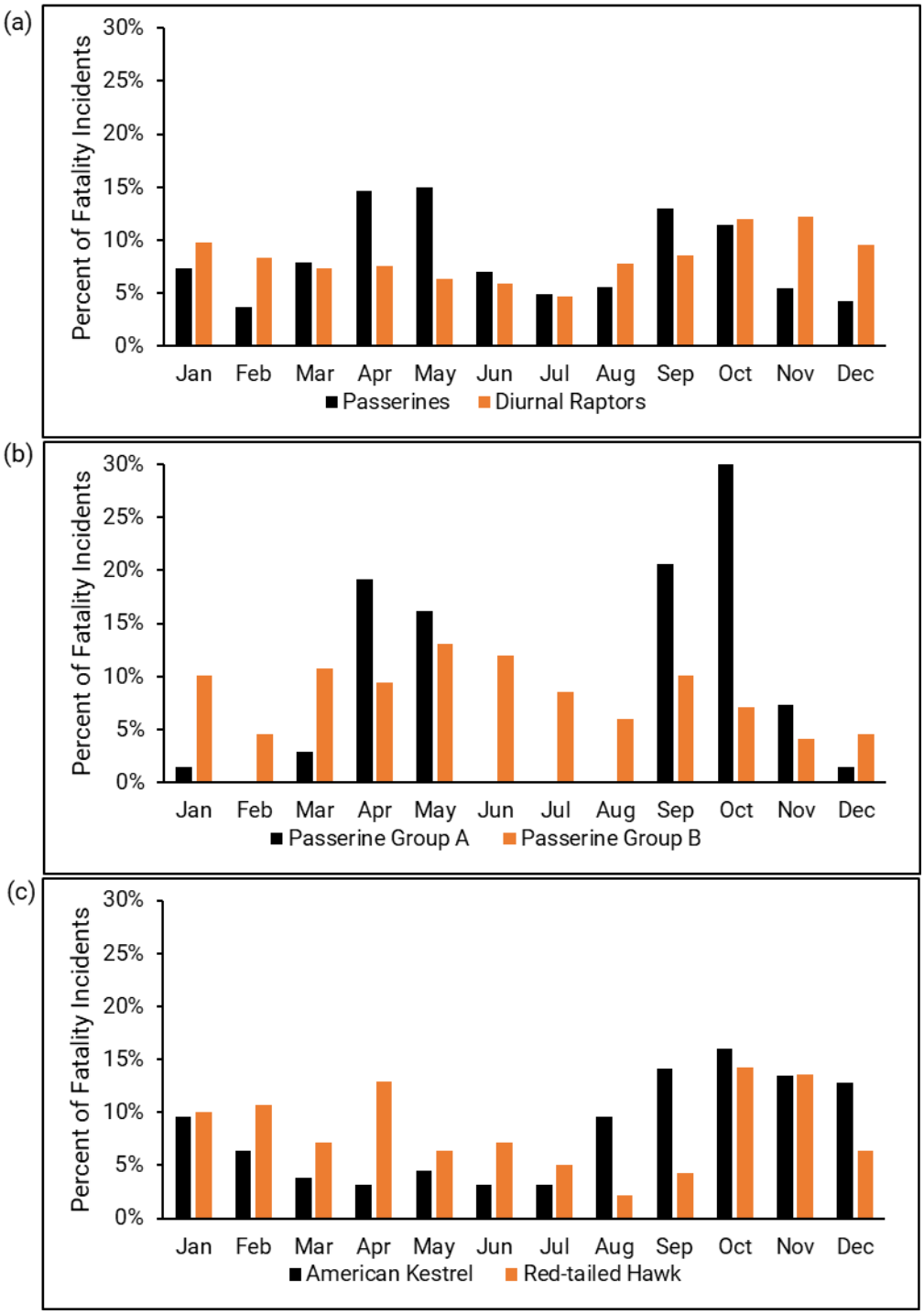


Figure 9. Distribution of bird fatality incidents by month found during scheduled searches by post-construction monitoring studies that searched ≥ 11 months with search interval ≤ 14 days (N = 52) at U.S. wind energy projects where date of carcass discovery was known: (a) All passerine (N = 1,360) and raptor (N = 409) incidents, (b) Passerine Group A (Golden-crowned Kinglet, Ruby-crowned Kinglet, Red-eyed Vireo, and Magnolia Warbler; N = 68); Group B (Horned Lark, Western Meadowlark, and Red-winged Blackbird; N = 467); (c) Most frequently observed diurnal raptors (American Kestrel [N = 156] and Red-tailed Hawk [N = 140]).

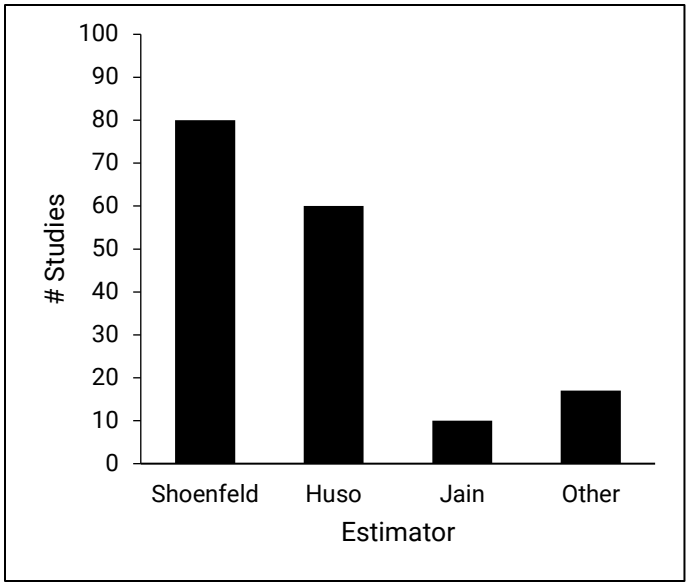


Figure 10. Frequency of fatality estimator used to adjust fatality estimates of post-construction studies contained in AWWIC. See text for estimator references.

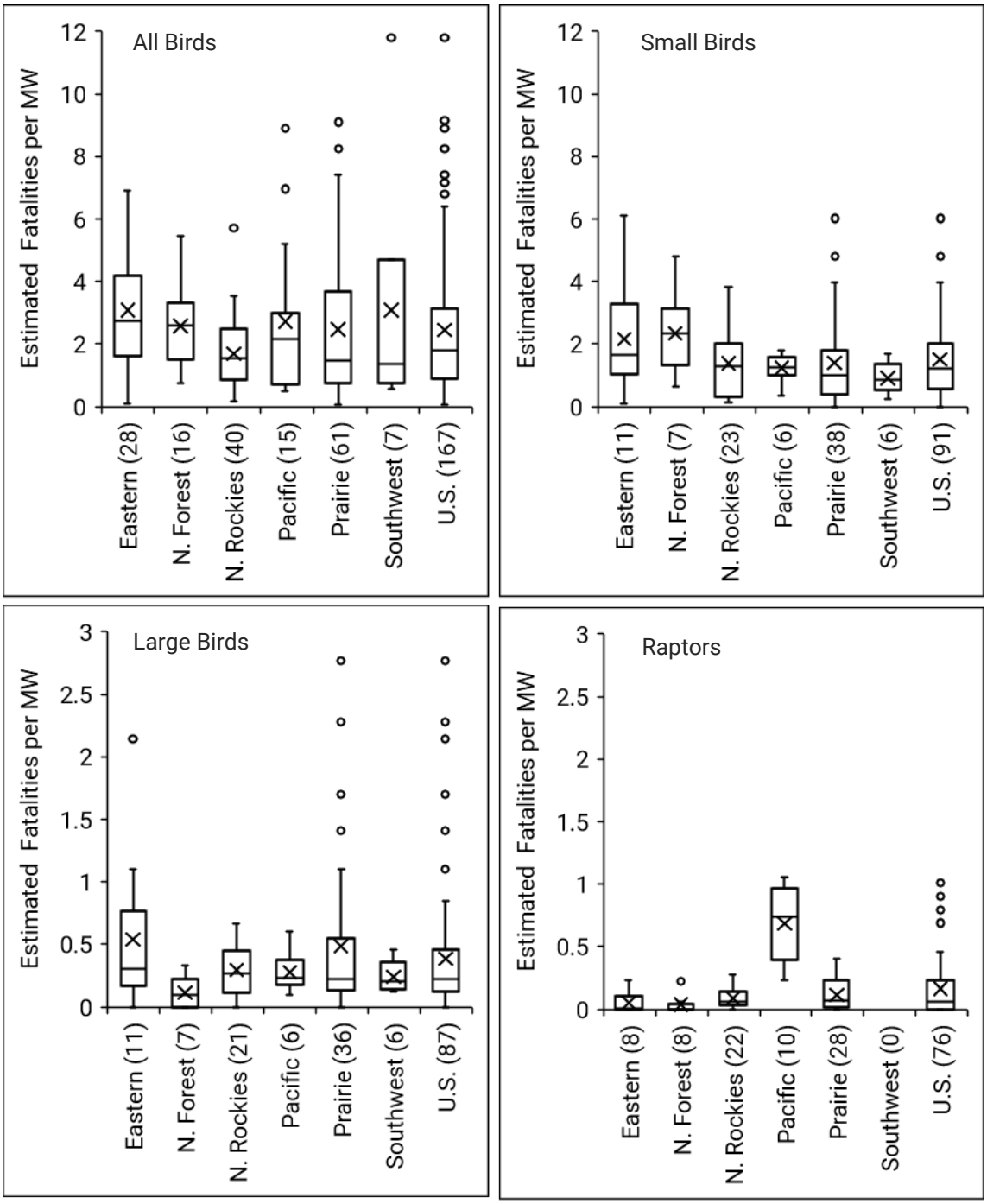


Figure 11. Adjusted bird fatality estimates by avifaunal biome from post-construction monitoring studies contained in AWWIC. Estimates are presented as reported and not standardized for differences in study methodology. Number of studies available in each biome is contained in parentheses. Note difference in y-axis scale between upper and lower panels; there were too few raptor estimates in the southwest biome for inclusion in the Raptors panel. Box plots display median and first and third quartile values with outliers indicated by open circles and mean value indicated by "X".

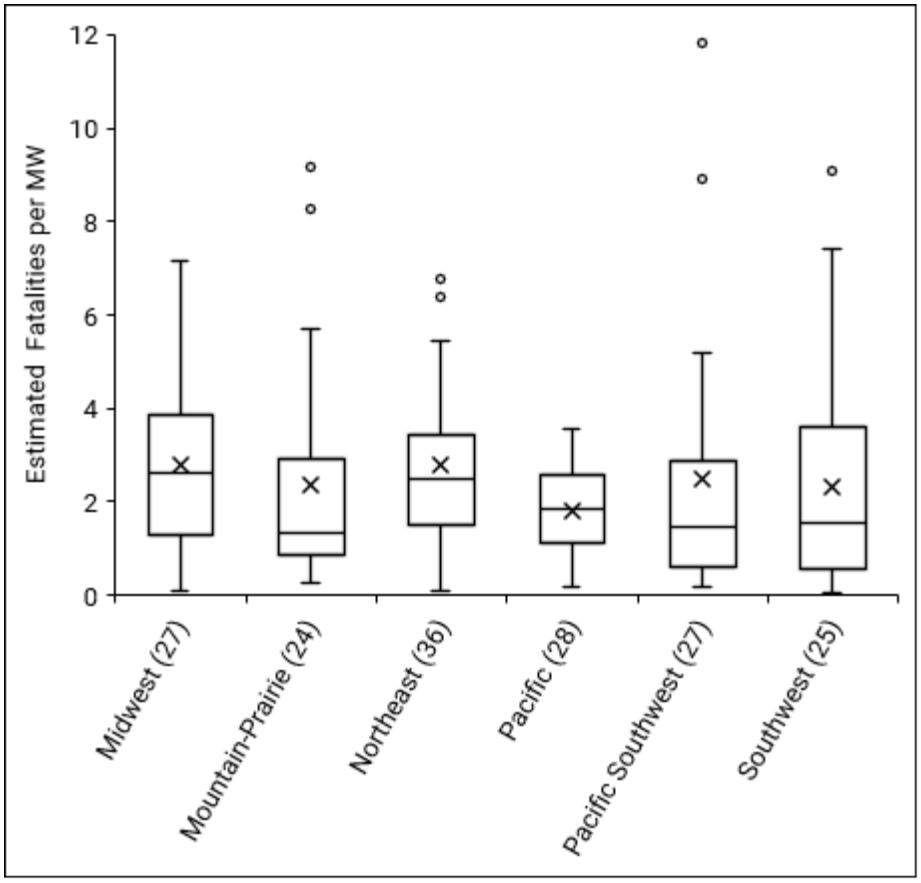


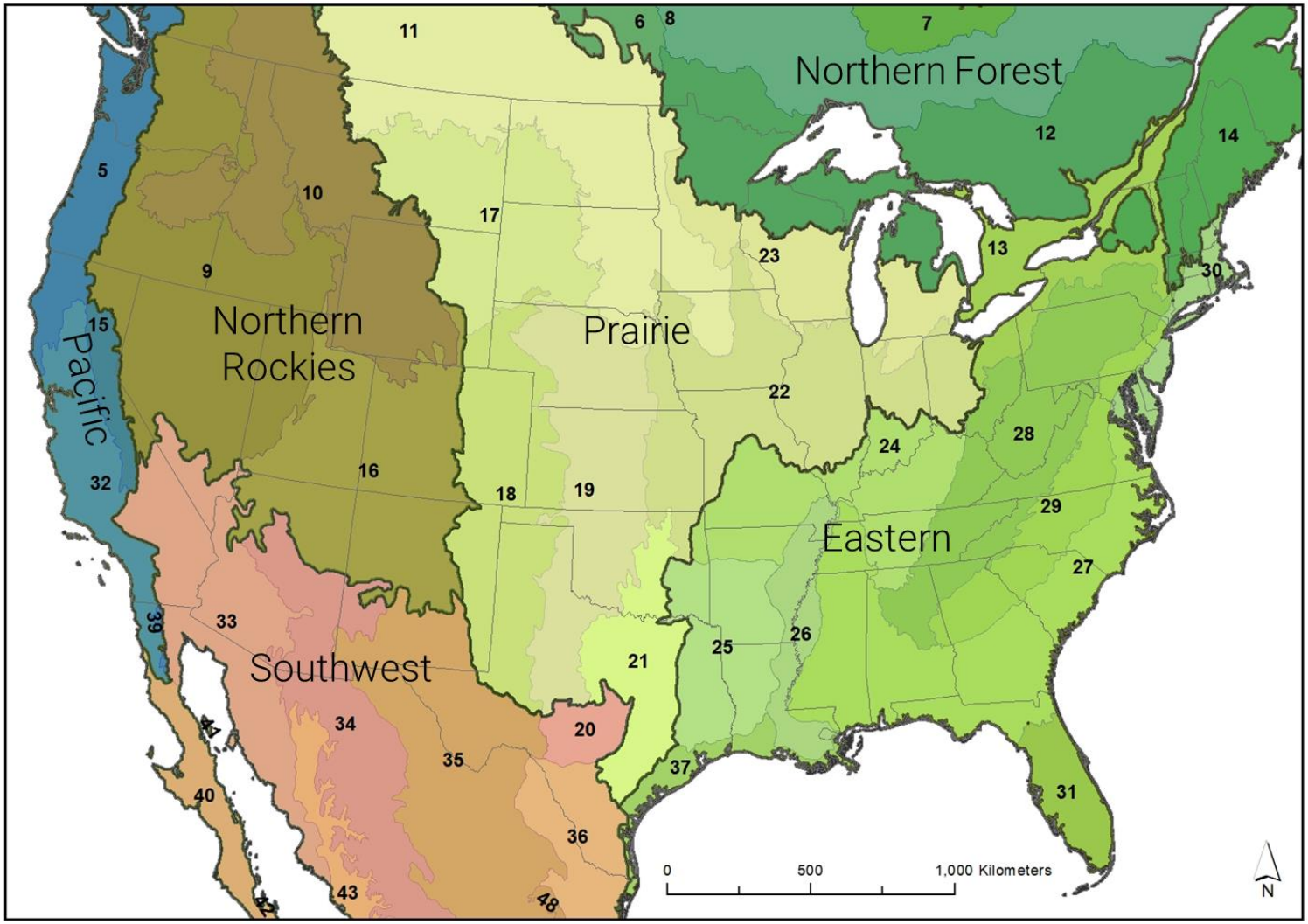
Figure 12. Adjusted all bird fatality estimates by USFWS Region from post-construction monitoring studies contained in AWWIC. There were no data in AWWIC for the Southeast and Alaska Regions. Estimates are presented as reported and not standardized for differences in study methodology. Number of studies available in each Region is contained in parentheses. Box plot of bird fatality estimates displays median and first and third 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 (acres)
	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 (meters, degrees)
	Nearest Turbine
	Find Type (Large Bird, Small Bird, Bat, Other)
	Sex (Male, Female, Unknown)
	Age (Adult, Juvenile, Unknown)
	Condition (Intact, Partial, Dismembered, Feather Spots, Other)
	Scavenged By (None, Carnivores, Corvids, Insects, Other, Unknown)
	Decomposition
	Est. Time Since Death (Last night, 2-3 days, 4-7 days, >7 days)
	Possible Cause (Turbine Collision, Non-turbine Collision, Unknown)

Appendix B. Map of avifaunal biome boundaries used in this report. Avifaunal biomes represent aggregations of Bird Conservation Regions (Rich et al. 2004, NABCI 2018). The Bird Conservation Regions that make up each avifaunal biome are shaded and numbered and listed in the legend.



Legend

Eastern

13	Lower Great Lakes/St. Lawrence Plain
24	Central Hardwoods
25	West Gulf Coastal Plain/Ouachitas
26	Mississippi Alluvial Valley
27	Southeastern Coastal Plain
28	Appalachian Mountains
29	Piedmont
30	New England/Mid-Atlantic Coast
31	Peninsular Florida
37	Gulf Coastal Prairie

Northern Forest

12	Boreal Hardwood Transition
14	Atlantic Northern Forest

Northern Rockies

9	Great Basin
10	Northern Rockies
16	Southern Rockies/Colorado Plateau

Pacific

5	Northern Pacific Rainforest
15	Sierra Nevada
32	Coastal California

Prairie

11	Prairie Potholes
17	Badlands and Prairies
18	Shortgrass Prairie
19	Central Mixed Grass Prairie
21	Oaks and Prairies
22	Eastern Tallgrass Prairie
23	Prairie Hardwood Transition

Southwest

20	Edwards Plateau
33	Sonoran and Mojave Deserts
34	Sierra Madre Occidental
35	Chihuahuan Desert
36	Tamaulipan Brushlands

Appendix C. Number and percentage of unadjusted bird fatality incidents found during scheduled searches from all studies included in this report. Species are sorted in order of descending percent fatality incidents. Frequency is the number of studies containing fatality incidents of each species. No fatality incidents from incidental finds or projects using curtailment at low wind speeds were included in this table. Bolded text indicates species not previously reported in Loss et al. (2013) or Erickson et al. (2014). No species federally listed under the U.S. Endangered Species Act are contained in this list.

Species	Incidents	%	Frequency
horned lark	840	12.8%	83
mourning dove	312	4.7%	71
red-eyed vireo	303	4.6%	58
western meadowlark	277	4.2%	40
golden-crowned kinglet	267	4.1%	69
American kestrel	209	3.2%	44
red-tailed hawk	193	2.9%	63
turkey vulture	156	2.4%	44
red-winged blackbird	140	2.1%	25
killdeer	106	1.6%	26
ring-necked pheasant	92	1.4%	29
European starling	91	1.4%	45
ruby-crowned kinglet	80	1.2%	52
rock pigeon	79	1.2%	38
magnolia warbler	64	1.0%	30
gray partridge	58	0.9%	21
American coot	54	0.8%	24
yellow-rumped warbler	53	0.8%	31
savannah sparrow	51	0.8%	31
tree swallow	48	0.7%	27
yellow-billed cuckoo	48	0.7%	16
barn owl	42	0.6%	22
Wilson's warbler	42	0.6%	23
Brewer's blackbird	39	0.6%	12
dark-eyed junco	39	0.6%	25
northern bobwhite	37	0.6%	8
mallard	35	0.5%	20
yellow warbler	33	0.5%	25
blackpoll warbler	32	0.5%	7
chukar	32	0.5%	12
northern flicker	32	0.5%	27
Swainson's hawk	31	0.5%	16
Townsend's warbler	31	0.5%	16
American redstart	30	0.5%	16
common yellowthroat	28	0.4%	23
yellow-breasted chat	27	0.4%	6
American robin	26	0.4%	20

Species	Incidents	%	Frequency
house wren	24	0.4%	20
black-throated blue warbler	23	0.3%	16
black-throated green warbler	23	0.3%	13
common nighthawk	23	0.3%	11
house sparrow	21	0.3%	15
ovenbird	21	0.3%	12
American pipit	20	0.3%	6
blue-headed vireo	20	0.3%	15
Tennessee warbler	20	0.3%	14
vesper sparrow	20	0.3%	13
wild turkey	20	0.3%	11
northern harrier	19	0.3%	13
sora	19	0.3%	15
chipping sparrow	18	0.3%	16
cliff swallow	18	0.3%	11
grasshopper sparrow	18	0.3%	7
northern parula	18	0.3%	11
ruffed grouse	18	0.3%	13
white-crowned sparrow	18	0.3%	13
wood thrush	18	0.3%	6
Blackburnian warbler	17	0.3%	15
golden eagle	17	0.3%	11
Swainson's thrush	17	0.3%	10
brown creeper	16	0.2%	11
red-breasted nuthatch	16	0.2%	11
yellow-bellied sapsucker	16	0.2%	13
black-and-white warbler	15	0.2%	12
black-throated gray warbler	15	0.2%	8
house finch	15	0.2%	11
laughing gull	15	0.2%	4
warbling vireo	15	0.2%	10
brown-headed cowbird	14	0.2%	12
common raven	14	0.2%	11
great horned owl	14	0.2%	10
black-billed cuckoo	13	0.2%	10
short-eared owl	13	0.2%	9
western tanager	13	0.2%	11
bay-breasted warbler	12	0.2%	7
California scrub-jay	**12**	**0.2%**	**1**
cooper's hawk	12	0.2%	9
eared grebe	12	0.2%	7
pine warbler	12	0.2%	7
Virginia rail	12	0.2%	9

Species	Incidents	%	Frequency
white-throated swift	12	0.2%	8
barn swallow	11	0.2%	10
bobolink	11	0.2%	6
Canada goose	11	0.2%	9
chimney swift	11	0.2%	9
ferruginous hawk	11	0.2%	8
golden-crowned sparrow	11	0.2%	6
Lincoln's sparrow	11	0.2%	10
rock wren	11	0.2%	7
song sparrow	11	0.2%	11
veery	11	0.2%	6
American goldfinch	10	0.2%	10
black-headed grosbeak	10	0.2%	6
Cape May warbler	10	0.2%	2
gray catbird	10	0.2%	9
hermit thrush	10	0.2%	10
lark bunting	10	0.2%	7
loggerhead shrike	10	0.2%	9
long-billed curlew	10	0.2%	5
mountain quail	**10**	**0.2%**	**2**
northern mockingbird	10	0.2%	10
orange-crowned warbler	10	0.2%	9
snow goose	**10**	**0.2%**	**2**
American crow	9	0.1%	9
Brewer's sparrow	9	0.1%	8
California quail	**9**	**0.1%**	**2**
eastern kingbird	9	0.1%	8
greater roadrunner	**9**	**0.1%**	**5**
indigo bunting	9	0.1%	7
purple martin	9	0.1%	7
ruby-throated hummingbird	9	0.1%	8
white-eyed vireo	9	0.1%	7
winter wren	9	0.1%	7
Baltimore oriole	8	0.1%	6
blue-winged teal	8	0.1%	6
chestnut-sided warbler	8	0.1%	4
common poorwill	8	0.1%	6
field sparrow	8	0.1%	5
lark sparrow	8	0.1%	4
least flycatcher	8	0.1%	5
ring-billed gull	8	0.1%	3
sharp-shinned hawk	8	0.1%	8
spotted towhee	8	0.1%	8

Species	Incidents	%	Frequency
western grebe	8	0.1%	6
yellow-bellied flycatcher	8	0.1%	5
American white pelican	**7**	**0.1%**	**3**
cedar waxwing	7	0.1%	7
common grackle	7	0.1%	7
green-winged teal	**7**	**0.1%**	**5**
Lapland longspur	7	0.1%	6
northern shoveler	**7**	**0.1%**	**3**
Philadelphia vireo	7	0.1%	4
sedge wren	7	0.1%	6
swamp sparrow	7	0.1%	6
blue jay	6	0.1%	6
burrowing owl	6	0.1%	3
downy woodpecker	6	0.1%	6
eastern meadowlark	6	0.1%	5
osprey	6	0.1%	4
pacific-slope flycatcher	6	0.1%	4
upland sandpiper	6	0.1%	4
white-winged dove	**6**	**0.1%**	**1**
American tree sparrow	5	0.1%	4
American woodcock	5	0.1%	3
black-billed magpie	5	0.1%	5
broad-winged hawk	5	0.1%	5
Bullock's oriole	5	0.1%	4
Cassin's sparrow	**5**	**0.1%**	**2**
common ground-dove	**5**	**0.1%**	**2**
dickcissel	5	0.1%	5
eastern wood-pewee	5	0.1%	5
gray-cheeked thrush	5	0.1%	3
hooded warbler	5	0.1%	3
northern pintail	5	0.1%	5
northern rough-winged swallow	**5**	**0.1%**	**4**
sage thrasher	5	0.1%	5
Vaux's swift	5	0.1%	5
black-throated sparrow	4	0.1%	4
Cassin's vireo	4	0.1%	3
dunlin	4	0.1%	3
Eurasian collared-dove	**4**	**0.1%**	**4**
great blue heron	4	0.1%	4
greater sage-grouse	**4**	**0.1%**	**3**
Hammond's flycatcher	4	0.1%	4
Kentucky warbler	4	0.1%	3
northern waterthrush	4	0.1%	4

Species	Incidents	%	Frequency
palm warbler	4	0.1%	4
peregrine falcon	4	0.1%	4
rose-breasted grosbeak	4	0.1%	4
rough-legged hawk	4	0.1%	4
scarlet tanager	4	0.1%	3
varied thrush	4	0.1%	4
yellow-throated vireo	4	0.1%	4
black rail	3	<0.1%	2
black vulture	**3**	**<0.1%**	**2**
Canada warbler	3	<0.1%	3
eastern towhee	3	<0.1%	3
gadwall	3	<0.1%	2
hairy woodpecker	3	<0.1%	3
long-eared owl	3	<0.1%	3
Macgillivray's warbler	3	<0.1%	2
marsh wren	3	<0.1%	3
mountain bluebird	3	<0.1%	3
Nashville warbler	3	<0.1%	3
prairie falcon	3	<0.1%	3
red-naped sapsucker	**3**	**<0.1%**	**3**
ruddy duck	3	<0.1%	3
scissor-tailed flycatcher	3	<0.1%	3
semipalmated sandpiper	**3**	**<0.1%**	**3**
snow bunting	3	<0.1%	2
Steller's jay	3	<0.1%	1
tricolored blackbird	3	<0.1%	2
western kingbird	3	<0.1%	3
white-tailed hawk	**3**	**<0.1%**	**2**
white-tailed kite	3	<0.1%	1
yellow-throated warbler	3	<0.1%	3
Acadian flycatcher	2	<0.1%	2
bank swallow	2	<0.1%	2
blue-gray gnatcatcher	2	<0.1%	2
blue-winged warbler	2	<0.1%	2
bushtit	2	<0.1%	1
California gull	**2**	**<0.1%**	**2**
Carolina wren	**2**	**<0.1%**	**1**
cattle egret	2	<0.1%	2
chuck-will's-widow	2	<0.1%	2
cinnamon teal	**2**	**<0.1%**	**2**
clay-colored sparrow	**2**	**<0.1%**	**1**
common gallinule	2	<0.1%	2
crested caracara	**2**	**<0.1%**	**1**

Species	Incidents	%	Frequency
double-crested cormorant	2	<0.1%	2
eastern bluebird	2	<0.1%	2
eastern phoebe	2	<0.1%	2
green heron	2	<0.1%	2
green-tailed towhee	2	<0.1%	2
lesser goldfinch	2	<0.1%	2
Lewis's woodpecker	2	<0.1%	2
merlin	2	<0.1%	2
pied-billed grebe	2	<0.1%	2
purple finch	2	<0.1%	2
scaled quail	**2**	**<0.1%**	**1**
sharp-tailed grouse	2	<0.1%	2
white-breasted nuthatch	2	<0.1%	2
white-throated sparrow	2	<0.1%	2
American wigeon	**1**	**<0.1%**	**1**
ash-throated flycatcher	1	<0.1%	1
belted kingfisher	1	<0.1%	1
Bewick's wren	1	<0.1%	1
black-bellied whistling-duck	**1**	**<0.1%**	**1**
black-crowned night-heron	1	<0.1%	1
black-tailed gnatcatcher	1	<0.1%	1
brown thrasher	1	<0.1%	1
calliope hummingbird	**1**	**<0.1%**	**1**
canvasback	1	<0.1%	1
Cassin's finch	**1**	**<0.1%**	**1**
cerulean warbler	1	<0.1%	1
chestnut-collared longspur	1	<0.1%	1
common merganser	1	<0.1%	1
Connecticut warbler	**1**	**<0.1%**	**1**
costa's hummingbird	**1**	**<0.1%**	**1**
eastern whip-poor-will	**1**	**<0.1%**	**1**
European goldfinch	**1**	**<0.1%**	**1**
evening grosbeak	1	<0.1%	1
flammulated owl	**1**	**<0.1%**	**1**
fox sparrow	1	<0.1%	1
Gambel's quail	**1**	**<0.1%**	**1**
glaucous-winged gull	**1**	**<0.1%**	**1**
golden-winged warbler	**1**	**<0.1%**	**1**
gray-crowned rosy-finch	**1**	**<0.1%**	**1**
great black-backed gull	1	<0.1%	1
great egret	**1**	**<0.1%**	**1**
greater white-fronted goose	**1**	**<0.1%**	**1**
gull-billed tern	1	<0.1%	1

Species	Incidents	%	Frequency
herring gull	1	<0.1%	1
lazuli bunting	1	<0.1%	1
lesser scaup	1	<0.1%	1
long-billed dowitcher	**1**	**<0.1%**	**1**
mourning warbler	1	<0.1%	1
northern cardinal	**1**	**<0.1%**	**1**
oak titmouse	1	<0.1%	1
olive-sided flycatcher	**1**	**<0.1%**	**1**
pine siskin	1	<0.1%	1
prairie warbler	1	<0.1%	1
prothonotary warbler	1	<0.1%	1
red crossbill	1	<0.1%	1
red-bellied woodpecker	**1**	**<0.1%**	**1**
redhead	**1**	**<0.1%**	**1**
ring-necked duck	1	<0.1%	1
Ross's goose	**1**	**<0.1%**	**1**
sagebrush sparrow	**1**	**<0.1%**	**1**
short-billed dowitcher	1	<0.1%	1
spotted sandpiper	1	<0.1%	1
Townsend's solitaire	1	<0.1%	1
tufted titmouse	1	<0.1%	1
western bluebird	1	<0.1%	1
western gull	**1**	**<0.1%**	**1**
western wood-pewee	1	<0.1%	1
willow flycatcher	**1**	**<0.1%**	**1**
Wilson's phalarope	1	<0.1%	1
wood duck	1	<0.1%	1
yellow-headed blackbird	1	<0.1%	1
unidentified bird	1,014	15.4%	138
domestic chicken	3	0.0%	2

Appendix D. Additional bird species reported in post-construction fatality studies only as incidental finds. Species were not included in report summaries. Species are listed alphabetically. Frequency is the number of studies in which the species was found, and incidents are the number of carcasses reported as incidental finds. Bolded text indicates species not previously reported in Loss et al. (2013) or Erickson et al. (2014). No species federally listed under the U.S. Endangered Species Act are contained in this list.

Species	Frequency	# Incidents
barred owl	1	1
black-chinned hummingbird	1	1
brown pelican	1	1
bufflehead	1	1
gray vireo	1	1
greater prairie-chicken	1	1
hermit warbler	1	1
hooded merganser	1	1
Leconte's sparrow	2	2
northern saw-whet owl	1	1
pacific wren	1	1
violet-green swallow	1	1
Williamson's sapsucker	1	1