RELATING PRE-CONSTRUCTION BAT ACTIVITY AND POST-CONSTRUCTION BAT FATALITY TO PREDICT RISK AT WIND ENERGY FACILITIES: A SYNTHESIS

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EXECUTIVE SUMMARY

Bat fatalities have been reported at wind facilities worldwide and expansion of wind energy raises concern over potential cumulative impacts on bat populations, particularly when several species are known or suspected to be in decline. Strategies to avoid or minimize adverse impacts of wind development on bats begins with assessing risk prior to construction of a site, but once a facility is built and operational, mitigation options are currently limited to curtailment of operations during predictable high risk periods when the greatest number of fatalities occur. State and federal agencies, natural resource managers and wind energy developers may benefit from pre-construction assessments of bat presence and activity, but ideally these assessments are most valuable if they also can be used to accurately predict risk of fatalities.

To establish whether pre-construction bat activity relates to post-construction fatality, we synthesized available data from 94 pre-construction bat activity and 75 post-construction bat fatality studies at wind energy facilities across 4 regions in the U.S. and Canada. We present summaries by broad geographic regions of bat activity, measured by acoustic detectors, and fatality rates measured from carcass searches. We also related pre-construction activity and post-construction fatality rates from 12 sites with adequate (i.e., both pre-construction acoustic and post-construction fatality) data to determine whether bat acoustic data gathered prior to construction can be used to predict fatality.

Pre- and post-construction data varied considerably both within and among regions, with the exception of the Great Plains, which showed both low and relatively precise means for activity and fatality. Bat fatality in the Basin-Desert was, on average, the lowest and most precise among, but differed substantially from the higher more variable activity in the Region. We observed a lower mean activity level in the Midwest Region compared to fatality. Although the Midwest had a slightly greater mean fatality rate than the Eastern Forest Region, both regions showed similar high and variable fatality estimates compared to the other regions. Activity in the Eastern Forest Region was, on average, the highest, and the most variable among the regions.

Based on 12 sites with paired data, the regression line was not significantly different from zero, but did suggest a positive relationship ($F_{1,10} = 4.06$; $p = 0.072$). Only a small portion of the variation in fatalities was explained by activity (adj. $R^2 = 21.8\%$). The 95% prediction intervals for this relationship indicate that, given current available data, acoustic data gathered prior to construction cannot accurately predict bat fatality.

Currently, it remains unclear whether pre-construction acoustic data are able to adequately predict post-construction fatality. Given the number of facilities in operation across the U.S. and Canada within the 4 regions presented here, presumably more data exist, but are as of yet unavailable, to aid in this assessment. Considerable resources are being expended in studying bat activity and fatality at wind energy facilities, yet our ability to assess risk of a proposed site remains tenuous, at least based on data available for this synthesis. Regardless, acoustic surveys still provide valuable data useful for understanding the timing and conditions under which bats are more or less active at a site, particularly for regions in which wind development is relatively new. Modeling bat activity or species presence using acoustic detectors as a function of time (i.e., night, season, or year) and meteorological conditions can provide powerful insight to predict when bats are most at risk, and which strategies are best suited to minimize fatalities while maximizing power production.

INTRODUCTION

Wind power is widely regarded as an environmentally sustainable and economically feasible technology for generating electricity (Ledec et al. 2011). The environmental benefits of wind energy accrue through displacement of other energy sources, such as fossil fuels, with known adverse impacts (NRC 2007). Unlike carbon-based fuels, wind energy is an inexhaustible natural resource, which generates near-zero emissions of greenhouse gases and other pollutants once installed and operating (IPCC 2007, NRC 2007, Ledec et al. 2011). Moreover, in contrast to most other power generation, renewable or otherwise, wind power does not require any water in the production process (Ledec et al. 2011). The rapid global expansion of wind power, which reached 270 gigawatts (GW) in 2012 (WWEA 2012), has been driven, in part, by supportive government policies, tax incentives, and increasing economic competitiveness (Ledec et al. 2011). The U.S. has been a world leader, second only to China, in wind generating capacity, and achieved its strongest year ever in 2012, reaching 60,007 megawatts (MW) (AWEA 2013). Today, 45,100 wind turbines from 1,050 projects exist across the U.S. (AWEA 2013).

Despite the positive features, erecting and operating wind-powered turbines has the potential for both direct and indirect impacts on wildlife, especially if turbine placement is done without adequate consideration for local populations (Arnett et al. 2007, Kuvlesky et al. 2007). For example, bat fatalities have been reported at wind facilities worldwide (Hall and Richards 1972, Durr and Bach 2004, Barclay et al.2007, Arnett et al. 2008, Rydell et al. 2010). Recent expansion of wind energy has raised concerns over the potential cumulative impact on bat populations, particularly when several species are known or suspected to be in decline (Pierson 1998, Racey and Entwistle 2003, Winhold and Kurta 2006, Jones et al. 2009, Frick et al. 2010). Turbine-related bat fatalities have consistently occurred among these facilities and a recent synthesis estimates that between approximately 650,000 to more than 1,300,000 bats have been killed from 2000–2011 in the U.S. and Canada (Arnett and Baerwald 2013). Because bats have low reproductive potential (i.e., reproducing once per year and typically only having a single pup) and require high adult survivorship to avoid population declines (Barclay and Harder 2003, Podlutsky et al. 2005), they are unable to recover quickly and large-scale impacts may place populations at risk (Findley 1993, Henderson et al. 2008). Bats provide numerous ecosystem services, including insect suppression, plant pollination and seed dispersal (Boyles et al, 2011), and adverse impacts from wind development, in conjunction with other natural and anthropogenic factors, on local bat populations could disrupt the ecological health and stability of a region (Kunz et al. 2011). Thus, as the U.S. moves to expand wind energy production, high environmental standards must be consistently employed to maintain and protect the nation’s wildlife resources (Strickland 2011, USFWS 2012).

Strategies to minimize direct adverse impacts of wind development on bats (e.g., operational mitigation and acoustic deterrents) have shown promise (Baerwald and Barclay 2009, Arnett et al. 2011, Good et al. 2011, 2012, Arnett et al. 2012, Young et al. 2011, 2012), but can only be implemented once the facility is operating. State and federal agencies, natural resource managers and wind energy developers may benefit from pre-construction assessments of bat presence and activity patterns (i.e., when and under what conditions bats are most active), but ideally these assessments and metrics also could be used for potential siting purposes and to accurately predict risk of fatalities. Unfortunately, past and current efforts to acoustically monitor bat activity prior to construction of turbines have suffered from flaws in study design, including small sample sizes and poor temporal and spatial replication (Hayes 1997, 2000), pseudoreplication (Hurlbert 1984), and inappropriate inference because limitations and assumptions were not understood or clearly articulated (Hayes 2000, Sherwin et al. 2000, Gannon et al. 2003). Also, there has been a lack of information and lack of agreement among stakeholders, biologists, and scientists regarding what constitute different levels of risk in relation to bat activity and potential fatality of bats at wind facilities.

High pre-construction bat activity may or may not equal high post-construction bat fatality, and the converse (i.e., low activity equals low fatality) may not be true, particularly if collisions are not random and bats are indeed attracted to wind turbines or wind energy facilities (Kunz et al. 2007a, Horn et al. 2008, Cryan and Barclay 2009). Moreover, several factors, such as inter-annual variation in bat activity patterns, changes in habitat conditions (i.e., clearing of forest habitat for roads and pads), and the introduction of wind turbines potentially confound our ability to generate reliable risk assessments (Reynolds 2006, Cryan and Brown 2007). Although a direct relationship between bat activity and fatality has not yet been demonstrated empirically, there is strong postulation that such a positive and predictive relationship may exist. The assumption of a direct relationship underlies many agency policies and management decisions (e.g., PGC 2007). However, if this relationship is weak or non-existent, then basing site selection and risk assessment on pre-construction acoustic data may be not only be unfounded, but potentially counterproductive to conservation goals, especially as we currently are unaware of any study that has correlated a fundamental link necessary for understanding potential risk of wind facilities to bats.

To examine the relationship between pre-construction acoustic data with post-construction fatality, we synthesized data from existing and available pre-construction bat activity and post-construction bat fatality studies at wind energy facilities across the U.S. and Canada. Our objectives were to: 1) present summaries by broad geographic regions of bat activity, measured by acoustic detectors, and fatality rates measured by collecting carcasses; 2) compare activity, and fatality rates within and among regions; 3) assess whether there are sufficient data to establish a relationship between bat acoustic activity and bat fatality; and, 4) discuss key lessons learned and offer suggestions for future research.

METHODS

We compiled data from available pre-construction bat acoustic and post-construction bat fatality studies from across the U.S. and Canada. Many of these studies are publicly available, but for those that are not, we received permission from project owners to use the data presented herein. Our dataset is not exhaustive, as many reports remain unavailable. We present summaries of data and did not attempt to conduct a meta-analysis and develop our own activity rates or estimates of fatality from compiled data. We caution that studies had varying levels of effort (e.g., study duration and sampling intensity), and used varying methods to quantify activity (e.g., definition of a bat pass) and fatality (e.g., accounting for bias associated with carcass searches). We used mean activity or fatality for sites that had more than one year of pre-construction and/or post-construction data. We included studies regardless of duration of the study season (i.e., spring–fall and fall-only studies).

For pre-construction bat acoustic surveys, we included only those reporting zero-crossing analysis data. We included data from studies using ≥2 detectors, positioned either near the ground (i.e. within 2 m above ground level [agl], herein referred to as ground-based detectors), or at some elevation above the ground, generally >30 m agl. Although many studies differentiated between phonic groups (i.e., high- and low-frequency bats), criteria used to define these groups differed, thus we focused on total bat activity. For our metric of activity, we used bat passes/detector-night. For post-construction fatality monitoring studies, we used only those that incorporated bias trials (i.e., carcass removal and searcher efficiency; Strickland et al. 2011) in their estimates of fatality, but included studies that reported different estimators. We report estimates of total bat fatality and did not differentiate fatality by species. We used the reported number of bats/MW as our metric of fatality.

We grouped sites where activity and fatality data were collected into distinct geographic regions (Table 1). We categorized regions based on those reported in peer-reviewed journals and book chapters (Johnson 2005, Kunz et al. 2007a, Arnett et al. 2008, Arnett and Baerwald 2013). Classifications incorporated broad habitat characterizations (e.g., forest, shrub-steppe habitats) that potentially influence how bats may generally utilize an area, features that would serve as migration corridors (i.e., topography, geographic landscape, riparian corridors), behavior of different bat species, and the amount of installed wind capacity. These consisted of the Great Basin-Southwest Open Range and Desert Region (Basin-Desert), the Central Great Plains Region (Great Plains), the Deciduous Forest and Agricultural Region (Midwest) and Northeastern Deciduous Forest Region (Eastern Forest). We were unable to present data from other regions (e.g., Gulf Coast, Southeastern Mixed Forest) because publically available studies were not yet available or no wind energy facilities have been constructed there to date.

We calculated means for both pre-construction activity and post-construction fatality studies by including the estimates for each type of study across all regions. We used paired studies (i.e., those possessing both acoustic and fatality data from the same project) to investigate the predictive relationship between bat activity recorded prior to construction and bat fatality reported after operation of turbines. We used linear regression to assess this relationship. We also created 95% prediction intervals around the regression line to predict the distribution of future observations, given the existing data. All summaries and analyses were generated using Minitab 14 (Minitab, Inc., State College, Pennsylvania, USA).

RESULTS

We compiled a total of 94 pre-construction bat acoustic studies. Of these, 15 were projects with multiple years of data. These studies were relatively evenly distributed among the 4 geographic regions, ranging from n = 15 in the Eastern Forest to n = 31 in the Midwest (Table 1). The lowest (0.02 passes/detector-night) and highest (141.70 passes/detector-night) activity rates occurred in the Basin-Desert and Eastern Forest Regions, respectively (Table 2). Overall mean activity was 10.52 bat passes/detector-night (95% CI: 5.98–15.07), but most studies reported activity rates below this mean (Fig. 1). However, a few projects in the Basin-Desert, Eastern Forest, and Midwest Regions reported activity rates well above the overall mean, in some cases exceeding 50 bat passes/detector-night.

We acquired a total of 75 post-construction bat fatality studies. Of these, 37 were projects with multiple years of data. As with the pre-construction data, studies were relatively evenly distributed among the 4 geographic regions. The Basin-Desert region had the most data (n = 28) and the Midwest had the fewest (n = 13; Table 1). Overall mean bat fatality/MW was 5.71 (95% CI: 3.91–7.52). The lowest fatality rate reported (0.12 bats/MW) occurred at two sites, one in the Basin-Desert and one in the Great Plains Regions (Table 2). The highest fatality rate (35.62 bats/MW) was observed in the Eastern Forest Region. Most studies in the Basin-Desert and Great Plains Regions reported lower fatality estimates, with no project exceeding 15 bats/MW (Fig. 2). The distribution of fatality was more varied among sites in the Eastern Forest and Midwest Regions, and several projects had fatalities >15 bats/MW.

Activity and fatality data varied dramatically both within and among regions, with the exception of the Great Plains, which showed both low and relatively precise means (i.e., narrow confidence intervals) for activity and fatality (Fig. 3). Bat fatality in the Basin-Desert was, on average, the lowest and most precise among the 4 regions, but differed substantially from the higher more variable activity in this Region. The Midwest Region had a lower mean activity level compared to fatality. Although the Midwest had a slightly higher mean fatality rate than the Eastern Forest, both regions showed similar high and variable fatality estimates compared to the other 2 regions. Activity in the Eastern Forest Region was, on average, the highest, and also the most variable among the 4 regions.

We used data from 12 paired studies (i.e., those possessing both pre-construction and post-construction data) to assess the predictive relationship between activity and fatality (Fig. 4). Of these studies, 4 were in the Basin-Desert, 3 in the Eastern Forest, 3 in the Midwest, and 2 in the Great Plains. Although our regression line was not significantly different from zero it did suggest a positive relationship ($F_{1,10} = 4.06$; $p = 0.072$). Only a small portion of the variation in fatalities was explained by activity (adj. $R^2 = 21.8\%$). The widely spaced 95% prediction intervals and negative values for the lower prediction interval indicate the inability to use acoustic data to predict bat fatality, given current available data.

Table 1. Regions of the United States and Canada defined for establishing activity and fatality rates for bats and wind energy facilities (derived from Arnett and Baerwald 2013), and number of sites with pre-construction and post-construction data.

REGION (Abbreviation)	# Pre-construction Sites	# Post-construction Sites	STATES/PROVINCES
Great Basin/Southwest Open Range-Desert (Basin-Desert)	22	28	Southern California and Central Valley; west Texas Pecos region; non-forested Arizona and New Mexico; Nevada; eastern Oregon, Washington and Idaho; western Utah and Colorado
Great Plains (Great Plains)	24	15	Southern Alberta, Saskatchewan, and Manitoba; eastern Montana; North and South Dakota; Nebraska; Kansas; Oklahoma; north and Central Texas; eastern Colorado; unforested portions of Wyoming
Northeastern Deciduous Forest (Eastern Forest)	15	19	Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont West Virginia, New Brunswick, southern portions of Newfoundland, Ontario and Quebec, Prince Edward Island, and Nova Scotia
Midwestern Deciduous Forest-Agricultural (Midwest)	31	13	Southern Ontario; Minnesota; Wisconsin, Iowa, Michigan, Illinois, Missouri, Indiana, Ohio

Table 2. Mean, median, and minimum and maximum values for pre-construction bat activity and post-construction bat fatality for four geographic regions.

	Bat activity (passes/detector-night)			Bat fatality (bats/MW)		
Region	**Mean**	**Median**	**Minimum–Maximum**	**Mean**	**Median**	**Minimum–Maximum**
Basin-Desert	10.69	4.49	0.02–77.14	1.29	1.17	0.12–3.92
Eastern Forest	25.2	6.40	1.24–141.70	9.49	4.67	1.11–35.62
Great Plains	4.19	2.22	0.15–17.45	3.07	2.15	0.12–10.85
Midwest	7.29	5.15	0.73–33.88	12.75	8.72	2.46–32.00

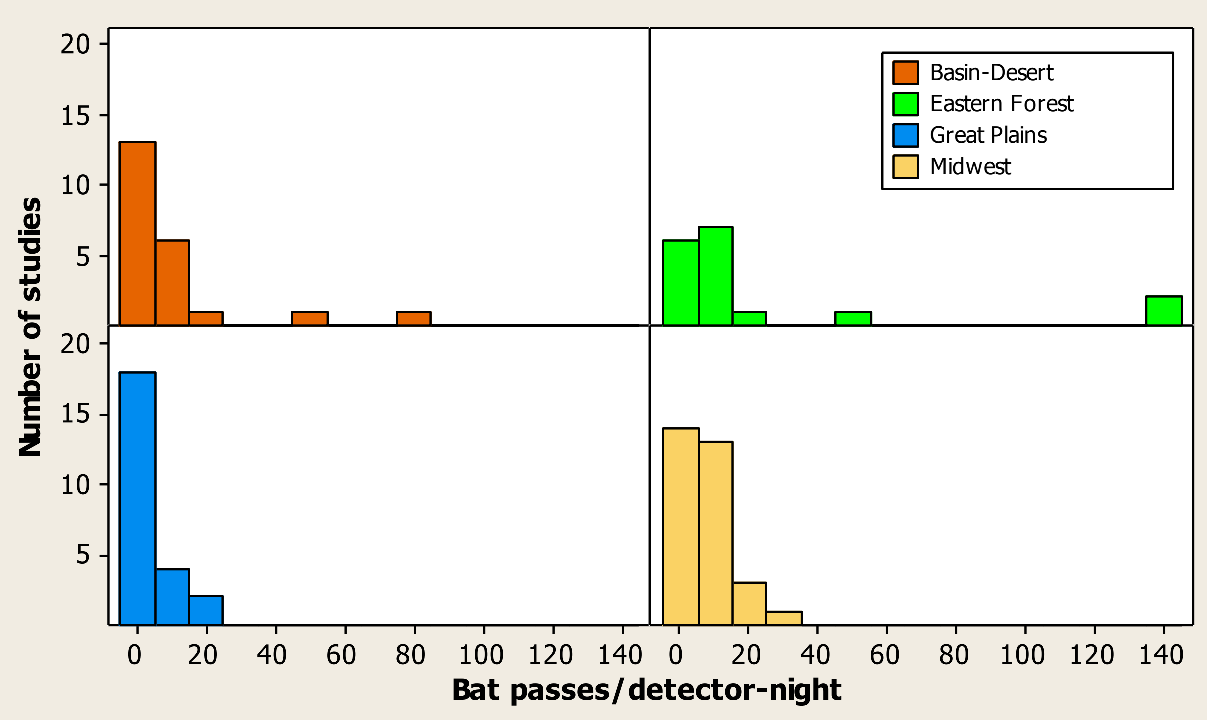

Figure 1. Mean bat activity (passes/detector-night) by frequency (i.e., number of studies) for four geographic regions of the United States.

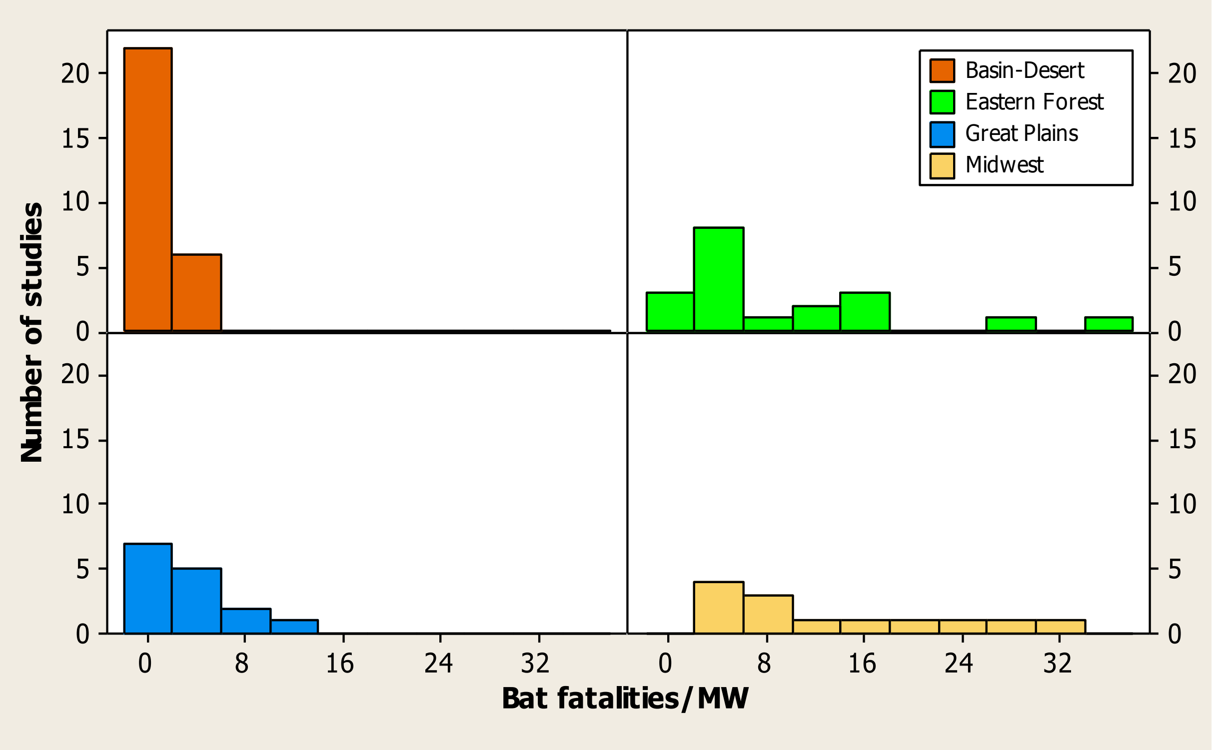

Figure 2. Mean bat fatality (bats/MW) by frequency (i.e., number of studies) for four geographic regions of the United States.

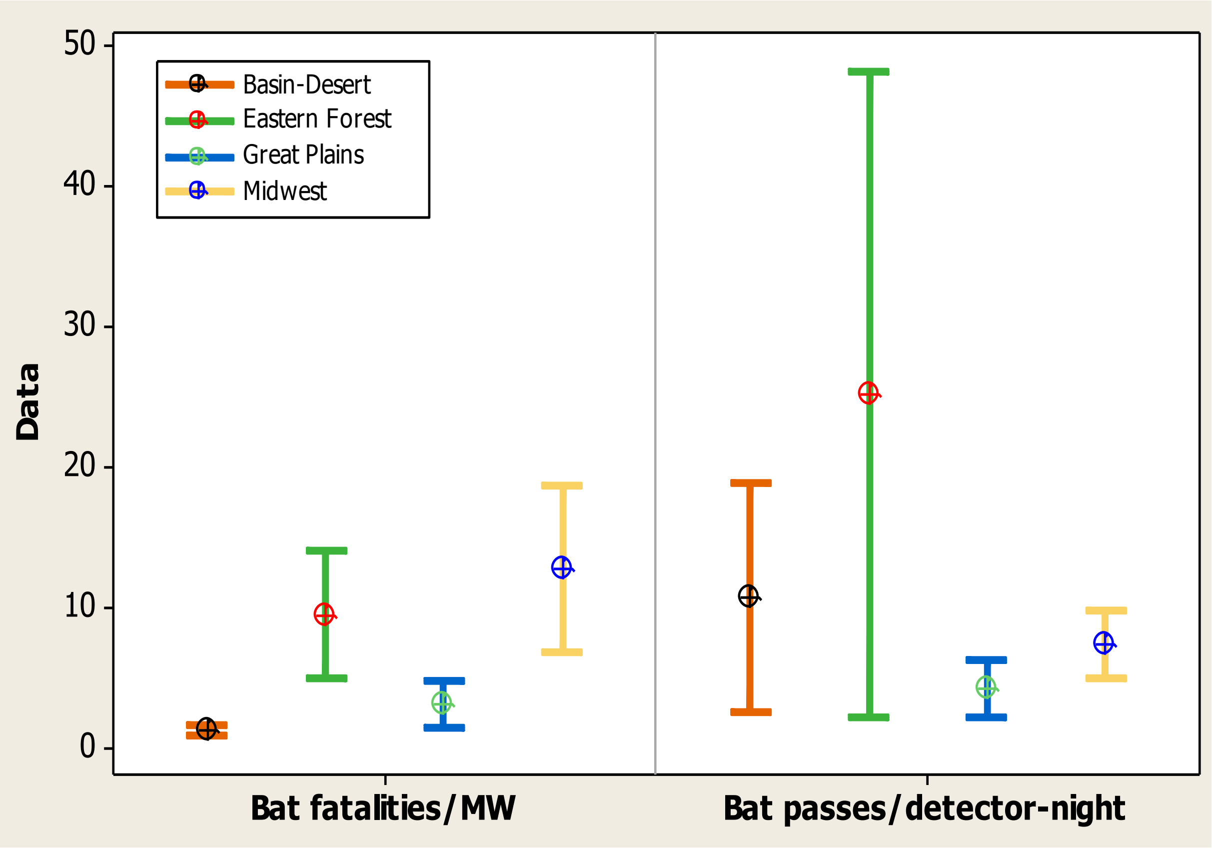

Figure 3. Mean and 95% confidence intervals for bat fatality (left) and bat activity (right) for four geographic regions of the United States.

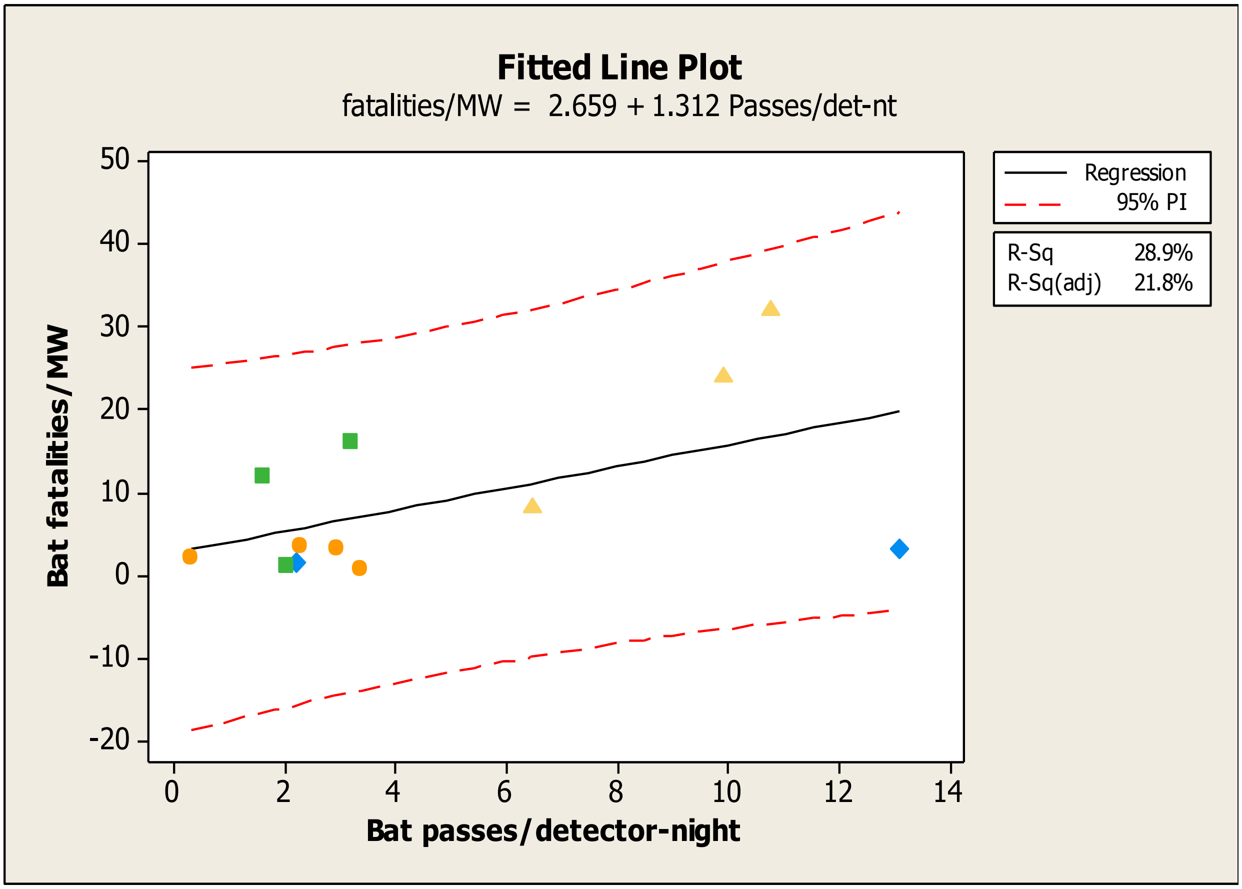

Figure 4. Linear regression with 95% prediction intervals relating 12 paired studies with pre-construction bat acoustic activity and post-construction bat fatality. Green squares represent the Eastern Forest Region; orange circles represent the Basin-Desert Region; blue diamonds represent the Great Plains Region; yellow triangles represent the Midwest Region.

DISCUSSION

Bat acoustic activity often varies across space and time (Hayes 1997, 2000, Lacki et al. 2007). Although high variability both within and among regions was not surprising, the lack of precision in bat activity for the Eastern Forest Region may indicate the diversity of habitat and weather conditions for the region and our categorization may warrant further refinement. High variation in bat activity levels also could result from poor sampling design and level of effort required to obtain accurate estimates of activity. Minimizing the number of nights sampled can increase the probability of obtaining mean estimates of activity that differ greatly from those calculated from large datasets (Hayes 1997). Low-intensity sampling could result in under- or over-estimates of activity and the most precise and accurate estimates will likely come from intensive sampling efforts (Hayes 1997). Unfortunately, the cost of intensive sampling can often exceed the project budget (Fenton 2000). But if acoustic monitoring is to be used to predict bat fatality at wind facilities, accurate measures of activity and fatality, both before and after construction are critical. We did not address variable sampling effort in our synthesis. Future analyses should evaluate costs relative to accuracy and precision needed to link bat activity and fatality, with the ultimate goal of optimizing sampling designs and data requirements for employing acoustic monitoring to predict bat fatality at wind facilities, should this effort be continued.

Findings from our synthesis of pre-construction acoustic data, and those of individual studies, also may have been influenced in part by the location of sampling sites and the influence of vegetation structure adjacent to acoustic detectors. Weller and Zabel (2002) found that detectors oriented toward the direction with the fewest trees recorded 24–44% more detections of bats than those oriented in two other directions. Patriquin et al. (2003) found that while sound transmission varied among forest types (conifer, deciduous, and mixed), increases in vegetation density among open, thinned, and intact forest patches did not significantly reduce the ability to detect 40 kHz sound. They did find that 25 kHz sound was less detectable in intact patches of forest and best in thinned stands in all forest types they studied. Also, some studies chose to sample consistently in the same direction, regardless of vegetation structure and possible biases induced by vegetation, rather than aiming microphones in a direction so as to maximize the number of bat detections (Weller and Zabel 2002).

Acoustic detectors have been used during post-construction monitoring, offering some insight into the use of detectors to predict fatality. Kunz et al. (2007b) presented post-construction acoustic and fatality data that suggested a possible relationship between activity and fatality. Fiedler (2004) found that bat activity levels generally were greater during nights when fresh killed bats were found during searches the next day compared to those days when no fresh bats were found. However, Fiedler also reported the logistic regression model using bat activity as an explanatory variable for evaluating the likelihood of fatality performed poorly. She noted that three species (big brown bat [*Eptesicus fuscus*], tri-colored bat [*Perimyotis subflavus*], and silver-haired bat [*Lasionycteris noctivagans*]) were found proportionally less as fatalities at turbines than were acoustically recorded, whereas two species (eastern red bat [*Lasiurus borealis*] and hoary bat [*Lasiurus cinereus*]) were found proportionally more frequently, suggesting greater collision risk for the latter species than would be predicted with acoustic monitoring alone. Similarly, Gruver (2002) reported that while hoary bats represented 88.1% of turbine fatalities at Foote Creek Rim, Wyoming, they only made up 7.8% of acoustical recordings. Johnson et al. (2004) found no difference in the mean number of bat passes/detector night when detectors were located at turbines with ($\bar{x}$ = 2.4) and without ($\bar{x}$ = 2.1) fatalities found the following day in Minnesota. Jain (2005) found that specific wind turbines in his study did not show a significant relationship between mortality and ultrasonic activity. Baerwald and Barclay (2009) did not find a correlation between activity at 30 m and fatality, but when they compared 5 sites with fatality and activity data, and only tall turbines (towers $\geq$65 m), there was a significant relationship between activity and fatality. In that analysis, they found that for every migratory-bat pass recorded per detector night, bat fatalities varied from 1.7–13.5 fatalities/turbine/year, depending on the site. These findings suggest that predicting bat fatality from post-construction activity indices is quite variable and may not be possible for the species killed most frequently at wind facilities (Johnson 2005, Arnett et al. 2008). However, the aforementioned studies all noted that seasonal increases in bat activity closely coincided with the overall incidence of mortality at these sites.

Fatality rates also varied within and among regions, but less so compared to activity. Although, the confidence intervals overlap, indicating no significant difference, the mean fatality estimate for the Midwest Region trended higher than the Eastern Forest Region. Projects located on the mid-Atlantic forested ridgelines of the Appalachian Mountains consistently report higher fatality estimates than other sites across the U.S. (Kunz et al. 2007a, Arnett et al. 2008), but the Eastern Forest Region also contains areas reporting relatively low fatality estimates, thus lowering the Region’s overall average (NWCC 2010). As more studies have become available, it is clear that fatalities in the Midwest Region can be high and cause for concern because higher percentages of cave hibernating bats, those affected by White-nose Syndrome (Frick et al. 2010, Turner et al. 2011) are reported (Gruver et al. 2009, BHE 2010, Jain et al. 2011). The Great Plains appears to have relatively low and consistent activity and fatality across projects, presumably due to similar conditions within the region. The Basin-Desert had the lowest overall fatality estimate among the 4 regions. However, few publicly available studies for the Great Plains and Basin-Desert Regions exist in the range of the Brazilian free-tailed bat (*Tadarida brasiliensis*), particularly in Texas (Curry and Kerlinger 2006, Miller 2008, Piorkowski and O’Connell 2010). This species congregates in large colonies throughout its range and limited data suggest this species is vulnerable to wind development.

Several studies have examined patterns of bat fatality at wind energy facilities (Johnson 2005, Barclay et al. 2007, Kunz et al. 2007a, Kuvlesky et al. 2007, Arnett et al. 2008, Arnett and Baerwald 2013). Because most studies share common traits, including species composition (i.e., majority of fatalities are migratory tree-roosting bats) and timing of fatalities (i.e., roughly July–

mid-October), impacts presumably could be reduced were it possible to locate wind energy facilities away from migratory pathways (Arnett et al. 2008, Weller and Baldwin 2011). Yet, for activity and fatality rates to be correlated, fatalities would have to occur from random collisions, and not from bats being attracted to the facility or turbines, implying that fatalities are proportional to the presence of bats, otherwise it may never be possible to accurately assess risk to bats prior to construction based on bat acoustic activity (Cryan and Barclay 2009). Currently, no data exist regarding the number of bats present or passing through a site to support or refute the random collision hypotheses. Moreover, thermal videography of bats interacting with turbines supports attraction-related hypotheses and suggests collisions are not random (Horn et al. 2008).

To our knowledge, this is the first synthesis examining the relationship between pre-construction acoustic activity and post-construction fatality. It is this relationship that has been of interest since unexpectedly high bat fatalities were reported in the eastern U.S. (Arnett 2005). We were able to compile data from a total of 169 projects (75 pre-construction bat acoustic and 94 post-construction bat fatality studies), of which 12 included pre- and post-construction comparative data. Our analysis suggests a weak relationship between pre-construction bat activity and post-construction bat fatality. However, our sample of paired studies was relatively small, with studies spread out across the 4 regions, and the precision in the estimated relationship was poor as evidenced by the low adjusted R^2 value and wide prediction intervals. Given the amount of variation, particularly in pre-construction data, it is likely that a sample of 12 studies was not sufficient to assess whether or not a relationship exists. These data represent but a fraction of the total number of wind energy facilities in North America (n = 1,050; in the U.S. alone). Factors likely contributing to the paucity of studies with both pre- and post-construction data include facilities with only pre- or post-construction data, and pre- and post-construction studies conducted but not available for this synthesis.

The relative limited data for this synthesis was compounded by: 1) the manner in which data were collected among studies; 2) differences in metrics reported; and, 3) changes in environmental conditions between pre- and post-construction studies. Comparability among studies is challenging because of different sampling protocols and intensity for both acoustic (e.g., acoustic detectors used, detector placement and study duration) and fatality (e.g., search interval, transect width, quantifying bias) studies. Consistency in study methodology would greatly enhance our understanding of bat/turbine interactions and assist regulatory agencies and wind developers during decision making (Arnett et al. 2007, Strickland et al. 2011). Studies of pre-construction activity and post-construction fatality occur at different times and generally under different weather and habitat conditions. The spatio-temporal activity patterns of bats vary within and among nights, and among seasons and years (Hayes 2000). Weather can influence patterns, as bats are known to suppress their activity during periods of rain, low temperatures and strong winds (Anthony et al. 1981, Erkert 1982, Barclay 1985, Erickson and West 2002, Kerns et al. 2005, Lacki et al. 2007). Changes in local habitat conditions (e.g., clearing of forest areas for roads and pads, and construction of turbines) also effects behavior of bats (Kalko and Schnitzler 1993, Walsh and Harris 1996, Brigham et al. 1997, Grindal and Brigham 1999). Conducting studies with similar methodologies, intensity and analysis, and evaluating the predictive relationship within each region will assist in minimizing these confounding factors. Even when the differences in pre- and post-construction studies were minimal, the inability to control for the addition of large wind turbines on the landscape, a possible attraction factor (Kunz et al. 2007a, Horn et al. 2008, Cryan and Barclay 2009) remains problematic and potentially confounds the ability to determine a predictive relationship.

The goal of this synthesis was to assess the predictive ability of pre-construction acoustic bat activity on post-construction bat fatality. We did not include variables that might explain additional variation in bat activity or fatality. Few studies have reported information on spatial patterns of fatalities, although such information would be useful in understanding the extent to which proposed projects will pose risk to bats. Variables potentially important for future analyses could include proximity to local habitat features (e.g., open water sources or known cave roost; Arnett et al. 2008) or regional landscape elements (e.g., coastlines, and mountain chains; Baerwald and Barclay 2009). In Minnesota Johnson et al. (2004) did not find a significant relationship between fatalities and land cover types, or distance to wetlands or woodlots. However, Jain et al. (2007) suggested that turbines located closer to wetlands may kill more bats. In Oklahoma, Piorkowski and O’Connell (2010) attributed high fatality rates of Brazilian free-tailed bats to the close proximity of monitored turbines to two known colonies. They also suggested that fatalities were higher near wooded ravines, but only during the first year of the study. At the landscape-scale, Baerwald and Barclay (2009) observed higher fatality rates at facilities closer to the Rocky Mountains. Thus, developing and evaluating a number of competing models with information theoretic approaches, such as AIC (Burnham and Anderson 2002) may assist in determining the influence of habitat or landscape features, in conjunction with activity, that best explain fatality.

Based on the data available for this analysis, it remains unclear whether pre-construction acoustic data are able to adequately predict risk of post-construction fatality. Given the number of facilities in operation across the U.S. and Canada within the 4 regions presented here, we expect that more data exist to aid in this assessment, but were not available for this synthesis. Considerable resources are being expended in studying bat activity and fatality at wind energy facilities, but using this information to assess risk of a proposed project is a tenuous proposition at present, at least based on the data currently available. Acoustic surveys can provide valuable data useful for understanding the timing and conditions under which bats are more or less active at a site, particularly for regions in which wind development is relatively new. Modeling bat activity or species presence using acoustic detectors as a function of time (i.e., night, season, or year) and meteorological conditions can provide powerful insight to predict when bats are most at risk, and which strategies are best suited to minimize fatalities while maximizing power production.

We caution that neither activity nor fatality rates for a region provide any indication of local abundance or population levels for bats. Population estimates for most species of bats do not exist (O'Shea et al. 2003), making it difficult to place in context the impact of wind energy development on bats (Arnett and Baerwald 2013). Although understanding population levels is important in evaluating the biological impacts, measures to mitigate existing and future impacts should proceed in the absence of population data (Arnett et al. 2011).

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