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Impact of wind facilities on bats in the Neotropics

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We monitored the bat fatalities caused by a 13 turbines wind facility installed in western Puerto Rico (West Indies) over a period of 23 months. The post-construction monitoring includes observed fatalities and a corrected fatality estimate expressed as bats/turbine/year adjusted for bat carcass removal rates, searcher efficiency, and percent area searched. Data on seasonality of fatalities and distance of carcasses from turbines is also provided. Eleven out of the 13 species of bats in Puerto Rico suffered fatalities, including all five species of phyllostomids. These were: *Molossus molossus* and *Tadarida brasiliensis* (Molossidae); *Artibeus jamaicensis*, *Monophyllus redmani*, *Stenoderma rufum*, *Brachyphylla cavernarum* and *Erophylla bombifrons* (Phyllostomidae); *Noctilio leporinus* (Noctilionidae); *Eptesicus fuscus* and *Lasiurus minor* (Vespertilionidae); and *Mormoops blainvillei* (Mormoopidae). This is one of the first published reports of the impact of wind turbines on bats in the Neotropics.

Key words: bats, Neotropics, Vespertilionidae, wind installation, Phyllostomidae, Mormoopidae, Molossidae, eolic energy

Introduction

Bat fatalities at wind farms were first reported in Australia over 40 years ago (Hall and Richards, 1972). Since then many studies have been carried out, mostly in temperate zones of North America and in Europe (reviewed in Arnett *et al*., 2007; Kunz *et al*., 2007; Rydell *et al*., 2010*a*). Based on these studies it is clear that wind farms can pose serious threats to migrating bats, as well as to species that forage in open spaces (e.g., Arnett and Baerwald, 2013). However, the Neotropics show a notable lack of published information about the impact of wind turbines on its native, and highly diverse, bat fauna (but see Barros *et al*., 2015). This high diversity reveals itself not only in number of species, but also in roosting and foraging behaviors, making it even more difficult to extrapolate results obtained from the temperate zones. The abundance of phyllostomid bats in the Neotropics pose the added challenge of obtaining reliable results from pre-construction surveys. Prediction of risk based on pre-construction surveys, typically performed through acoustic monitoring, is imprecise (Hein *et al*., 2013). By and large, phyllostomid bats are whispering bats, difficult to detect through their echolocation calls, making preconstruction surveys based on acoustic monitoring even less accurate.

The deployment of wind turbines in the Neotropics is growing fast (Kozulj, 2010; Ledec *et al*., 2011). Therefore, it is important to understand how the local bat faunas interact with this relatively recent technology. The island of Puerto Rico, in the Greater Antilles, sustain 13 species of bats in five families: five species in the family Phyllostomidae, three Mormoopidae, two Molossidae, two Vespertilionidae and one Noctilionidae. This bat fauna includes species that form large aggregations in caves, but also solitary tree-dwelling species, and species using anthropogenic structures (Gannon *et al*., 2005). The foraging behavior of these species include open-space, swift-flying foragers, as well as maneuverable, canopy and understory foragers that feed on insects, fruits or nectar. This study represents one the few published results of the impact of wind farms on bats from the Neotropics.

Materials and Methods

We monitored the bat fatalities caused by a 13 turbines wind facility installed in eastern Puerto Rico (18°11’04”N; 65°41’41”W) over a period of 23 months, from February 2013 through December 2014 (an image of the facility can be searched through Google Earth). Each turbine has a 1.8 MW capacity, for a combined potential of 23.4 MW, and are located along a small altitudinal gradient from about 7 to 70 m above sea level. Turbines 1 and 2 are located on top of the hills, with the rest of the turbines at decreasing elevations, between the hills and mangrove areas or secondary growth subtropical moist forest (Ewel and Whitmore, 1973). Each tower rises 80 m above ground, with 49 m long blades. This represent the smaller of two wind facilities on the Island. A 101 MW facility consisting of 44 turbines is located on the south coast of Puerto Rico.

This work was performed under permits from the Department of Natural Resources and Environment of Puerto Rico to AR-D. Ten turbines were randomly selected for monitoring. The remaining three turbines (Turbines 6, 9 and 12) were searched irregularly and any bat found at these turbines recorded as an incidental. During the first six months of the study the area under each turbine was monitored twice a month along transects 6 meter apart. We delimited a 50 m radius plot around each turbine, which is the area where most bats are known to fall (Hull and Muir, 2010). Since the terrain precluded us from searching the entire 50 m area, the area searched was measured and a Proportion Area Searched (P_s) was calculated as P_s = area searched/$50\pi R^2$, and used to calculate a Corrected Mortality Estimate (CME). We searched a total of 32,913 m^2 out of the total 78,500 m^2 originally defined as search area, for a Proportion Area Searched of $P_s = 0.42$. Initially all search areas were devoid of vegetation. All carcasses found (C) were photographed and species, date, location, carcass condition, searcher, and distance to the nearest turbine were recorded. Sex was determined whenever possible.

Carcass scavenging was measured through Carcass Removal Trials (CRT). One CRT was performed at the beginning of the project and a second one at the beginning of the third trimester. A Scavenger Correction Factor (S_c) was calculated based on this data. For the first CRT three previously frozen *Artibeus jamaicensis* and three *Pteronotus quadridens* were thawed and randomly placed within the searched area of Turbines 1, 10 and 11. For the second CRT, 11 previously frozen bats of the species *Brachyphylla cavernarum, Pteronotus quadridens, Monophyllus redmani* and *Artibeus jamaicensis* were thawed and randomly placed within the searched area of Turbines number 1, 3, 4, 5, 7, 10, 11 and 13. Carcasses were monitored on five occasions over the following two weeks and their presence/absence and condition recorded. Scavenger Correction Factor for the first trial was calculated at $S_c = 0.74$ and at 0.75 for the second. A value of 0.75 was used for the calculations.

Searcher efficiency (S_E) was calculated after the third, sixth and twenty-third month, and incorporated into the equation to estimate the CME. We used ten bat carcasses previously preserved in alcohol to test for searcher efficiency: five *A. jamaicensis* and five *Molossus molossus*. Searchers knew that they were being tested. However, prior knowledge by searchers does not have an effect on their performance during tests of efficiency (Smallwood, 2013). Searcher efficiency for the first trial was calculated as S_E =0.7. As the vegetation cover and cattle activity around the turbines increased, a calibrating trial was performed that resulted in a reduction in efficiency to 0.5. Therefore, transect separation was reduced to three meters. With this calibration searcher efficiency was retested and the results showed that it had been restored to 0.7. The S_E was 0.7 at the end of the second year, when it was tested again. Thus, I used a $S_E = 0.7$ for the calculations.

At the beginning of the project we also performed preliminary CRT's and S_E using a combination of 10 mice and rats as surrogates. Results obtained from searches using rats and mice as surrogates were lower than 0.5, possibly as a result of lack of a search image by the searchers. Use of surrogates was thus discontinued. The CME was calculated following the protocol established by the Ontario Ministry of Natural Resources (2011) as: CME = $c/(P_s \times S_c \times S_E)$.

Results

Eleven out of the 13 species of bats present on the Island suffered fatalities, including all five species of phyllostomids. These were: *Molossus molossus* and *Tadarida brasiliensis* (Molossidae), insect-eating bats that forage in open spaces high above the canopy; the fruit-eating *Artibeus jamaicensis, Stenoderma rufum*, *Brachyphylla cavernarum* and the nectar-feeding *Monophyllus redmani* and *Erophylla bombifrons* (Phyllostomidae), all canopy and understory foragers; the fish-eating *Noctilio leporinus* (Noctilionidae); *Eptesicus fuscus* and *Lasiurus minor* (Vespertilionidae), insect-eating bats that forage in forest edges; and *Mormoops blainvillei* (Mormoopidae), a predominantly moth-eater that forages in forests and open spaces below canopy level.

A total of 35 carcasses were located during year one, 26 of them at the 10 turbines selected for the study (Table 1). In addition to the carcasses found at the 10 turbines selected, incidentals found at other turbines during the first year included three *M. molossus*, one *M. redmani* and one *E. fuscus* at Turbine 6, one *S. rufum* and three *M. molossus* at Turbine 9. Bats were not found at Turbine 12. Incidentals were not used for the calculations of CME. Most fatalities (48% including incidentals) involve what is probably the most common species of bat on disturbed areas of the island, the open space insect-eating *M. molossus* (Table 2). A carcass of *L. minor*, a species considered extremely rare in Puerto Rico, was recorded during the first semester. The five species of phyllostomids which are considered understory and canopy foragers represent unexpected fatalities.

Based on the values obtained of $P_s = 0.42$, $S_c = 0.75$, and a $S_E = 0.7$, the cumulative CME for the first year added up to 118.2 bats, 11.8 bats/turbine/year for the 10 turbines monitored or a total estimate of 153 fatalities for the park. A total of 11 carcasses were located during year two, all of them at six of the 10 turbines selected for the study. Based on the 11 carcasses at these turbines, and the same values of P_s, S_c, and S_E, the cumulative CME added up to 50 bats, five bats/turbine/year for the 10 turbines monitored or a total estimate of 65 fatalities for the park for the second year. This reduced number of carcasses during the second year was statistically significant (*U*-test, $P < 0.05$).

TABLE 1. Number of carcasses and species found at each one of 10 turbines from February 2013 through January 2014 (Year 1) and February 2014 through December 2014 (Year 2)

Turbine ID	Carcasses found	
	Year 1	Year 2
1	None	None
2	None	1 *M. molossus*
3	1 *B. cavernarum*	None
4	1 *A. jamaicensis*, 1 *L. minor*, 1 *M. molossus*	1 *A. jamaicensi*
5	None	None
7	None	1 *M. molossus*
8	1 *A. jamaicensis*, 4 *M. molossus*	1 *S. rufum*, 1 *M. molossus*
10	1 *S. rufum*, 1 *M. redmani*, 2 *M. molossus*, 1 *M. blainvillei*, 1 *N. leporinus*, 1 *A. jamaicensis*, 2 *B. cavernarum*, 1 *E. bombifrons*	1 *M. redmani*, 1 *M. molossus*
11	1 *M. molossus*, 1 *M. blainvillei*	None
13	2 *M. molossus*, 1 *T. brasiliensis*, 2 *M. redmani*	2 *M. molossus, 2 M. redmani*

All but five out of 40 carcasses for which we measured the distance from the turbine tower, were found within 25 m (Fig. 1). Out of these five, three, all *M. molossus,* were found more 40 meters from the turbine. Throughout the study, fatalities were concentrated mostly along the lowlands of the park, at Turbine #10, and, to a lesser extent #13. We found no evidence of seasonal patterns of fatalities (Fig. 2).

Few potential scavengers were identified. Most dead bats were promptly scavenged by ants, which left identifiable remains, or the carcasses dried under the sun before being scavenged. Eleven carcasses were found fresh, all with evidence of traumatic injury by physical contact, presumably with the rotor blades. Another two carcasses in an early state of decomposition also showed evidence of trauma. Eight individuals were sexed, of these five were males and three were females.

DISCUSSION

The ultimate reason behind bat fatalities remains unknown. Bats may be attracted to turbines (Kunz *et al*. 2007, Cryan, 2008; Cryan *et al*., 2014), or they may be unable to detect the blades on their flight path (Long *et al*., 2009). Nearly all bat species on the island suffered fatalities at our study site, including all five species of phyllostomids. The relationship between bat post-construction activity at wind farms and fatalities was first noted by Kunz *et al.* (2007), and estimates at some wind farms suggest that they are a significant factor of bat mortality (Hayes, 2013; Smallwood, 2013). High rates of

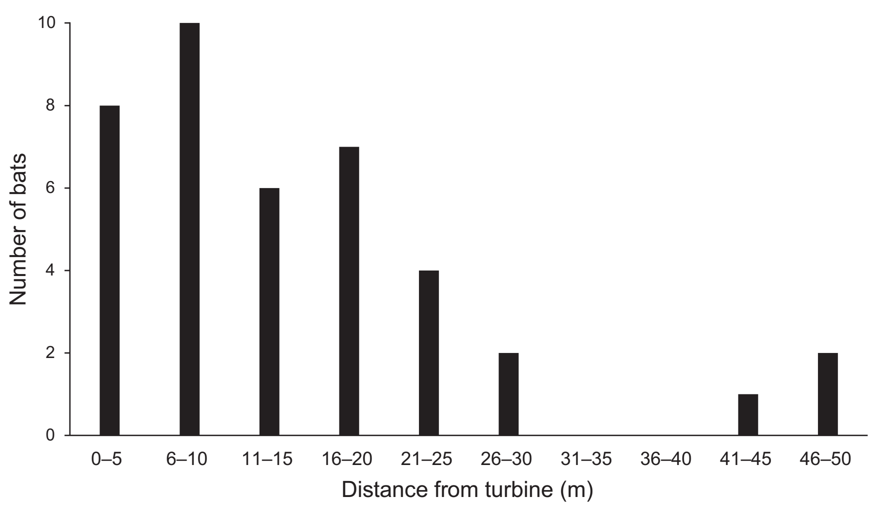

FIG. 1. Number of carcasses recovered at 5-m intervals from the turbine from February 2013 through December 2014. The average (± SD) distance was 14.83 ± 11.70 m. Distance from turbines ranged from 2 to 47 m. All bats recovered at a distance of over 40 m were *M. molossus*

TABLE 2. Number of fatalities recorded per species from February 2013 through January 2014 (Year 1) and February 2014 through December 2014 (Year 2)

Species	Carcasses found	
	Year 1	Year 2
A. jamaicensis	3	1
M. molossus	10	6
N. leporinus	1	0
S. rufum	1	1
L. minor	1	0
M. blainvillei	2	0
B. cavernarum	3	0
M. redmani	3	3
T. brasiliensis	1	0
E. bombifrons	1	0

mortality, combined with low reproductive rates, can limit the capacity of bats to recover from severe population declines (Barclay and Harder, 2003; Rodríguez-Durán, 2009). Unfortunately, there is little or no population data for most species of bat, making it difficult to place bat fatalities at windfarms in context (O'Shea *et al*., 2003).

At our study site, fewer fatalities appear to have occurred during the second year of survey (Fig. 1). Although a clean-out search was conducted prior to the initiation of the survey, some carcasses obtained during the first month could have accumulated prior to the onset of our study. Even after discounting February of 2013, we found a significantly higher number of carcasses during the first year. We do not know the reasons for this difference. Our tests of searcher efficiency and carcass removal did not reveal changes in these two parameters during the study. One possible explanation could be that, as use of the area by cattle increased from the first to the second year, the area around any given turbine could change from one search to the next, depending on the activity of cattle during the days immediately prior to the search. This effect could have potentially reduced searcher efficiency in a way difficult to assess with our tests, especially during the second year. Scavenging was not tested during the second year of this study, in part due to the apparent scarcity of scavengers in the area that would leave no trace of the bats (see results). However, it is possible that the activity of feral dogs could have increased during this second year. The combination of these two factors could have resulted in an underestimate for the second year. Alternatively, the reduced number of carcasses could have been the result of fewer bats been present in the area. Given the CME for the first year, and the small size of the wind installation, this latter explanation seems unlikely.

Experimental data and modeling of carcasses distribution indicate that the number of carcasses decreases with distance from the turbine (Hull and Muir, 2010). These results are supported by the data obtained during this survey (Fig. 1). Thus, like most estimators, the equation used to correct mortality values may not adequately account for unsearched area (Huso and Dalthorp, 2013), and could have the effect of overestimating fatalities. Nevertheless, our results show that the impact of wind turbines on Neotropical families of bats, such as Phyllostomidae

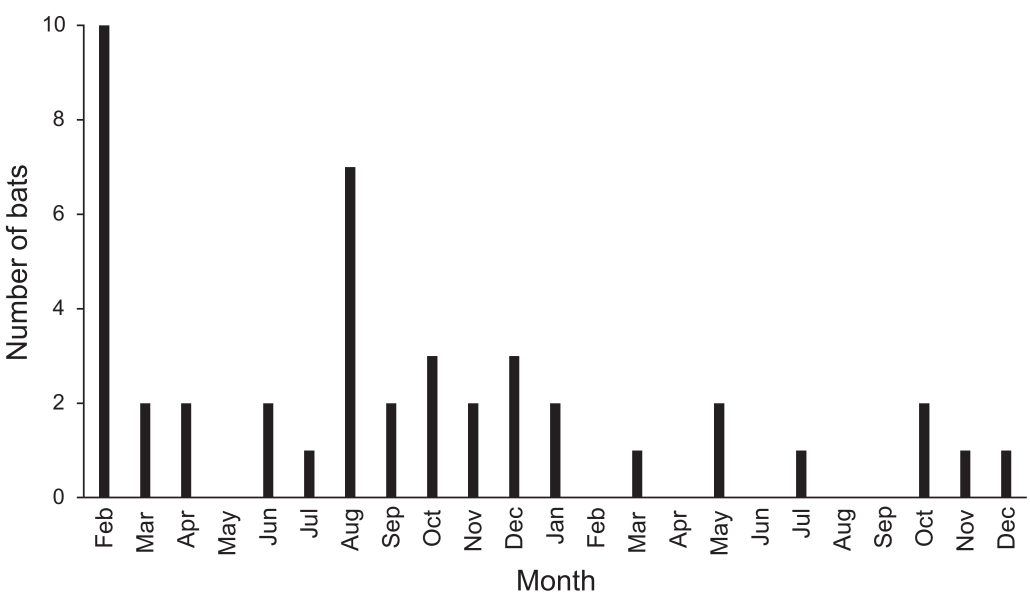

FIG. 2. Number of fatalities per month (February 2013 through December 2014) for all species, including incidentals

and Mormoopidae, is important and needs further attention.

Most of the fatalities at our study site were *M. molossus*. This was an expected result, as this bat forages high in open spaces, and is common in disturbed areas (Rodríguez-Durán and Christenson, 2012). However, the number of *A. jamaicensis* and *M. redmani* fatalities, fruit and nectar-feeding bats that typically forage in the understory, as well as the other phyllostomid and mormoopid bats, represent unexpected fatalities. Barros *et al*. (2015) found carcasses of nine out of the 13 species of bats present at their study site in southern Brazil. Most of the fatalities at this location were molossids, but *A. lituratus* was also recovered. Differences in protocol preclude direct comparison of the results of the two studies. Moreover, the lack of more published studies on the impact of wind facilities on bats in the Neotropics does not permit the establishment of trends at this time. Nevertheless, at both locations *Artibeus* appears as an unexpected fatality and molossids represent the majority of the carcasses found. Two of the phyllostomids (*M. redmani* and *E. bombifrons*) and the mormoopid found at our study site in Puerto Rico represent species that roost exclusively in hot-caves (Gannon *et al*., 2005). Although there are no known hot-caves near our study site, bats using these roosts form large colonies that fly long distances to foraging areas (Rodríguez-Durán, 2009; Ladle *et al*., 2012). Piorkowski and O'Connell (2010) documented fatalities in the temperate zone that could be related to bats displaying commuting behavior similar to mormoopids and some phyllostomids in the Neotropics. Therefore, the proximity to karst regions, where hot-caves are likely to occur, must be taken into consideration before licensing wind facilities.

It has been suggested that bats may be attracted to turbines as they search for potential roost sites (Cryan, 2008) or food (Kunz *et al*., 2007; Rydell *et al*., 2010*b*). Such behavior could explain the fatalities of tree-roosting *A. jamaicesis* and *S. rufum*, and possibly that of the other phyllostomids. Alternatively, the fatalities of understory species could be the result of turbines located along the flying pathway of bats. Differential fatality rates have been reported in relation to topography at other localities (e.g. Baerwald and Barclay, 2009; Piorkowski and O'Connell, 2010). At our site, turbines on top of the hills caused few or no fatalities, whereas Turbine 10 was responsible for most of the fatalities. This turbine is located at the junction of two hills, in what could be a pathway toward forested areas. The search interval of our study, together with the speed with which ants scavenged, reduced our sample of fresh carcasses. However, based on the limited number of fresh samples it seems that direct contact with the blades was the main reason for fatalities. These results are in agreement with forensic examination of bat carcasses elsewhere (Rollins *et al*., 2012).

In dealing with the issue of bat fatalities at wind facilities, Europe and temperate North America have developed mitigating measures based, to a large extent, on the seasonal patterns of activity of bats in these northern latitudes (e.g. Arnett *et al*., 2008, 2011; Rydell *et al*., 2010*b*; Arnett and Baerwald, 2013). As could have been expected, our results show no seasonal pattern of fatalities (Fig. 2). Bat activity in the tropics occur year-round. This will likely become a difficulty in trying to extrapolate some mitigating measures from the temperate to the tropical zones. Given the foreseen increase in the use of wind facilities throughout the Neotropics, and the results from this study, it appears that the development of mitigation measures for the region must be an issue of high priority. A first step in that direction is the need to standardize protocols and make public the data obtained from surveys in the region.

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