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Research Article

Wind farm bat fatalities in southern Brazil: temporal patterns and influence of environmental factors

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Abstract

Energy demand created by the present model of economic growth has transformed the natural landscape. Changes in megadiverse environments should be accompanied by studies that describe and predict the effects of these changes on ecosystems, underpinning the avoidance or at least the reduction of impacts and species conservation. Wind farm impacts on bats are scarcely known in Brazil. To fulfill this gap on spatiotemporal patterns in bat fatalities in a wind complex in southern Brazil were analysed. Monthly surveys were done around 129 wind towers in search for bat carcasses between 2014 and 2018. The number of specimens found per species was analysed in annual sets and also seasonally to understand the influence of land use in the spatial pattern of bat fatalities. The activity of aerial insectivore bats was monitored using ultrasound detectors and modelled using Generalized Linear Models (GLM), using meteorological variables as predictors. As a result of 48 months of surveys, 266 carcasses of six insectivorous bat species were recorded. The highest number of fatalities belonged to *Tadarida brasiliensis*. Fatalities occurred exclusively between October and May (Austral Spring to Austral Autumn), mainly in towers near the closest urban centre. Most fatalities occurred in the first (69%) and fourth (17%) years of operation; fatalities were positively related to wind speed. Eighty-three percent of the bat activity occurred between 15 °C and 23 °C. To minimize fatalities of synanthropic bat species such as *T. brasiliensis*, we suggest that wind complexes should be located at least 4 km distant from the urban centres, where those species roost. Moreover, between December and March, when most species from subtropical and temperate South America reproduce, wind towers located closer to known roosts should shut down on warmer nights, when bats are more active.

Introduction

The search for renewable energy sources as alternatives to the burning of fossil fuels encouraged the diversification of the global energy matrix. The results of these changes are noticeable in Brazil. One example is the increasing number of new wind farms favoured by market availability and by adequate wind speeds across 71 thousand km^2 of the country's territory (Amarante et al., 2001). In 2019, Brazil has over seven thousand operating wind turbines in 601 wind farms, with wind becoming the second most used source for energy generation in the country (ABEEólica, 2019).

Wind power is apparently outstanding as it results in low pollutant emission, uses a renewable and abundant resource, creates jobs in all phases of development and allows for other economic activities to be fulfilled around wind towers (e.g., agriculture and livestock production) because it takes up little space in properties compared to other forms of energy generation (Terciote, 2002). However, the energetic demand created by the global economic development model has abruptly changed the natural landscape across the planet. When it comes to wind energy those changes result not only from the installation of wind towers but also from all the associated infrastructures as transmission lines, substations and access roads. In this context, particularly in regions that harbour a megadiverse biota such as the Neotropics, these potential rapid and intense changes in the landscape further demand studies that describe and may predict the effects of such changes aiming at avoiding, or at least reducing, impacts on biodiversity (Ribeiro et al., 2009), similarly to what has been done in Europe and North America in the last decades (González et al., 2013; Jain et al., 2011, 2009a,b,c, 2008, 2007; Baerwald et al., 2009).

In fact, wind energy is not free from negative impacts. Initially, it was thought that the main impact of wind farms was the death of birds and insects (Rogers, 1978). However, high numbers of bat fatalities in wind farms were recorded from the end of the 1980s throughout Europe and North America (Rydell et al., 2010; **?**; Erickson et al., 2002; Osborn et al., 1996). While there has been more than two decades since those first studies where made in the Northern Hemisphere, data about the impact of wind farms on the fauna of a megadiverse country such as Brazil is still extremely scarce (Barros et al., 2015; Bernard et al., 2014). This situation is especially critical due to the lack of basic knowledge, such as data on species occurrence and distribution. Indeed, it is estimated that at least 200 years would be needed for Brazilian bats to be properly surveyed (Bernard et al., 2011). Unclear technical criteria for impact evaluation (Ramos Pereira et al., 2017) and a large number of inexperienced professionals make the situation even more critical, since flawed monitoring may result in significant impacts on bat populations (Bernard et al., 2012; **?**; Kunz et al., 2007a,b). Thus, it becomes fundamental to understand how wind farms are impacting bats in Brazil and how to design them as to reduce those potential impacts. Studies

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Figure 1 – A: map of the Santa Vitória do Palmar Wind Plant, located in Brazil's extreme south. Yellow dots represent the 129 wind towers and red stars (1–5) represent the sampling points using audio recorders. B: sampling model with circular transects around each tower, each transect with a pre-set distance from the tower base. The analysed distances from the base to the transect were: 5 m, 15 m, 25 m, 35 m, 45 m (red lines), and the last transect covered, in a zigzag pattern, an area from 50 to 100 metre (yellow lines).

in the Northern Hemisphere have shown that the majority of bat mortality at wind farms happens for limited periods, particularly between the end of Summer and mid-Autumn, in nights with higher temperature and lower wind speed when bats are most active (Amorim, 2009; Baerwald et al., 2009; Arnett, 2005). However, there is no published data to understand if the pattern of bat fatalities in the Neotropics is similar, which would be expected at least in subtropical and temperate climates of the region, so that this study is pioneer by using this methodology in wind farms of the Neotropical ecozone.

Here we determined when, where, and under which weather conditions bats are killed by wind towers in a temperate region of Southern Brazil. From the patterns recognized in other temperate regions, we predict i) a seasonal pattern in bat fatalities resulting from an increase in bat activity during the (Austral) Summer; ii) a spatial pattern in bat fatalities associated to the proximity to bat roosts, and iii) increased bat activity and an associated higher number of bat fatalities under high night temperatures, low atmospheric pressure and low wind speeds.

Materials and methods

Study area

The Santa Vitória do Palmar Wind Plant (also known as the Geribatu Wind Plant and hereinafter simply called wind plant) (33°34′21.04″ S; 53°15′31.66″ W) consists of 129 towers extending over an area of 4749.99 ha. The region is characterized as the coastal plain of the Pampa biome (IBGE, 2004), showing a predominance of grasslands with introduced plant species such as eucalyptus (*Eucalyptus* ssp.) in small plantations and rice fields (Rambo, 2000). The wind plant is located between the urban centre of Santa Vitória do Palmar to the west and an environment of palustrine wetland and small riparian forests at the margin of the Mangueira Lagoon and Salles Marsh (Rambo, 2000), both parallel to the Atlantic Ocean, to the east (Fig. 1a). The buildings of the urban centre are known to roost large colonies of *Tadarida brasiliensis* (personal observation).

Monitoring bat fatalities

The monthly monitoring to search for carcasses of bats occurred around all 129 towers of 10 the wind farms, between July 2014, coinciding with the beginning of the wind plant operation, and June 2018. We followed the active search technique suggested by González et al. (2013), with adaptations. These adaptations included the definition of six circular transects around each tower, each transectn with a pre-set distance from the tower base: 5 m, 15 m, 25 m, 35 m, and 45 m. The last transect was covered in a zigzag between 50 m and 100 m. The visual coverage comprised a radius of 120 m. All objects within a distance of up to 200 m were examined (Fig. 1b).

Each circle around each tower was slowly covered for 25 min. Whenever a carcass was found, we recorded species, tower number and date. Additionally, the distance of each carcass to the tower base was registered to evaluate the sufficiency of the search radius. All carcasses were identified to the lowest possible taxonomic level according to Reis et al. (2007) and were later removed to avoid recount.

Estimation of rates of carcass removal and detectability

The number of observed bat carcasses may represent an underestimation of the real number of deaths due to carcass removal by scavengers (Baerwald et al., 2009) and/or search error by the observers in the field.

Thus, to obtain values closer to the true fatality rate, we first estimated the percentage of carcass removal (PR). For this we collected carcasses around the towers and/or on nearby roads of bats and birds of similar size to those of the bat species occurring in the region, as there is no apparent difference in removal rates between birds and bats of the same size (Jain et al., 2009a,b,c, 2008, 2007). We maintained the carcasses in freezers until we achieved a sample of at least 20 carcasses per trimester. We arranged the animals randomly in the surroundings of the towers and monitored the carcasses every 24 h. We calculated PR for a period of 7 days. Secondly, we estimated the percentage of loss by non-detection (PD). One person randomly distributed the carcasses around the wind turbines and then another person, unknowing the position or number of dead animals set in the field, searched for carcasses on the same day they were distributed. We then calculated the percentage of distributed carcasses that were found. This was done once per season.

We estimated the number of deaths for each month in each season for the period between August 2017 and July 2018 through the estimated fatality rate (EFR) formula modified from Erickson et al. (2004): EFR = OFR · (1/(1-PR)) · (1/(1-PD)), where OFR is the observed fatality rate, PR the percentage of carcass removal and PD the percentage of loss by non-detection of the carcasses.

Analysis of temporal and spatial patterns in bat fatalities

We evaluated significant variation in observed fatalities across the years using a Friedman test. Subsequently, we organized data per season to analyse the relation between fatalities and landscape features in each season. For land-use classification we used images from the Instituto Nacional de Pesquisas Espaciais (INPE), captured with the Satellite Resourcesat II using the sensor LISSIII with a precision of 30 m^2 and the coordinate systems Universal Transverse Mercator (UTM) and datum WGS84 (Pereira et al., 2016; Prakash et al., 2015). The images used for each season with the record of bat fatalities are described in Table S1 in supplementary online material. Using QGIS, we used the spectral bands red, near infrared and mid-wave infrared to compose TIFF images for classifying land use in each sampled season. We used the plugin *dzetsaka* to determine the classes of land-use by the Gaussian Mixture Model (Fauvel et al., 2015). We obtained five classes: rice culture, water surface, grasslands with native species, exposed soil and pasture plantation. After the classification, we extracted a 100-meter-radius buffer around each of the 129 wind turbines; this section was converted into shapefile format and the area of each class within each buffer was calculated. As fatalities were only recorded during Spring, Summer and Autumn (see Results), data on land use were taken for these three seasons only across the years. We analysed 516 buffers for each station where fatalities occurred, in a total of 1548 buffers. To measure the distance between the wind towers and potential roosts for synanthropic species, we used the "rule" tool in Google Earth measuring in meters the distance between the tower and the closest point of the municipality's urban area.

We evaluated the influence of land use and the proximity to the urban centre on bat fatalities using multiple regression (Hammer et al., 2001) for each season, using the number of bat carcasses per wind turbine as response variable and the area of each land use class and tower position (distance from the urban centre) as predictors.

Bat activity analysis and modelling

We monitored bat activity using SM3BAT (Wildlife Acoustics) bat detectors which records bat calls passively in real time; we used a sampling rate of 384 kHz, with high frequency filter (High Pass Filter) to reduce recordings of sounds in frequencies below those produced by bats occurring in the area. The bat detector was set to record from dusk to dawn (1800 h–600 h) in rainless nights, during five days per month, between August 2017 and July 2018. The device was set to be automatically activated whenever the ultrasound microphone captured frequencies between 10 kHz and 190 kHz, and to record for five seconds. The device was attached to the anemometric towers found in the wind plant at about 6 m from the ground. The chosen points were P1 (grassland environment, wind farm closest to the urban centre, 53°19′38″ W, 33°32′0″ S), P2 (grassland environment, 53°15′39″ W, 33°33′20″ S), P3 (grassland environment, 53°16′12″ W, 33°35′35″ S), P4 (rice field, 53°14′22″ W, 33°31′4″ S) and P5 (wind farm closest to the Salles marsh, 53°12′28″ W, 33°34′9″ S), located at about 3 km from each other (Fig. 1a).

Activity was assessed according the number of bat-passes per hour. A bat-pass was considered a record with more than three pulses (Rodrigues et al., 2015; Kitzes and Merenlender, 2014; Berthinussen and Althingham, 2012; Georgiakakis et al., 2010). For each one-hour interval, the number of bat-passes was counted and meteorological conditions (temperature, wind speed, wind direction, atmospheric pressure and relative air humidity) were assessed using the anemometer located in the wind farms set at 56 m from the ground. Sound classification was conducted manually using the software Raven Pro 1.5.0 (Bioacoustics Research Program, 2017), and identifications as bat calls according to Arias-Aguilar et al., 2018, using parameters such as duration, maximum intensity frequency and maximum and minimum frequency of the pulses.

The activity patterns throughout the night, such as activity distribution and mean time of maximum activity, were evaluated using circular analyses using R, version 3.3.2 (R Development Core Team, 2016). Data were analysed by season.

The relation between bat activity and meteorological variables (relative humidity, atmospheric pressure, temperature, wind speed and wind direction) was analysed using generalized linear models (GLM) with Gaussian distribution with a quadratic fit for the explanatory variables. The second-order Akaike's Information Criterion (AICc) and the coefficient of determination (R2) were used to rank and select the models, comparing models with all possible combinations of the predictors. The model's level of empirical support is considered adequate when the AIC difference (ΔAIC) is smaller than 2 (Burnham and Anderson, 2002). Thus, models having with ΔAIC<2 were considered equally adjusted.

Results

Temporal and spatial patterns of bat fatalities

During the 48 months of monitoring the 129 wind towers of the Santa Vitória do Palmar wind plant from 2014 to 2018, we collected 266

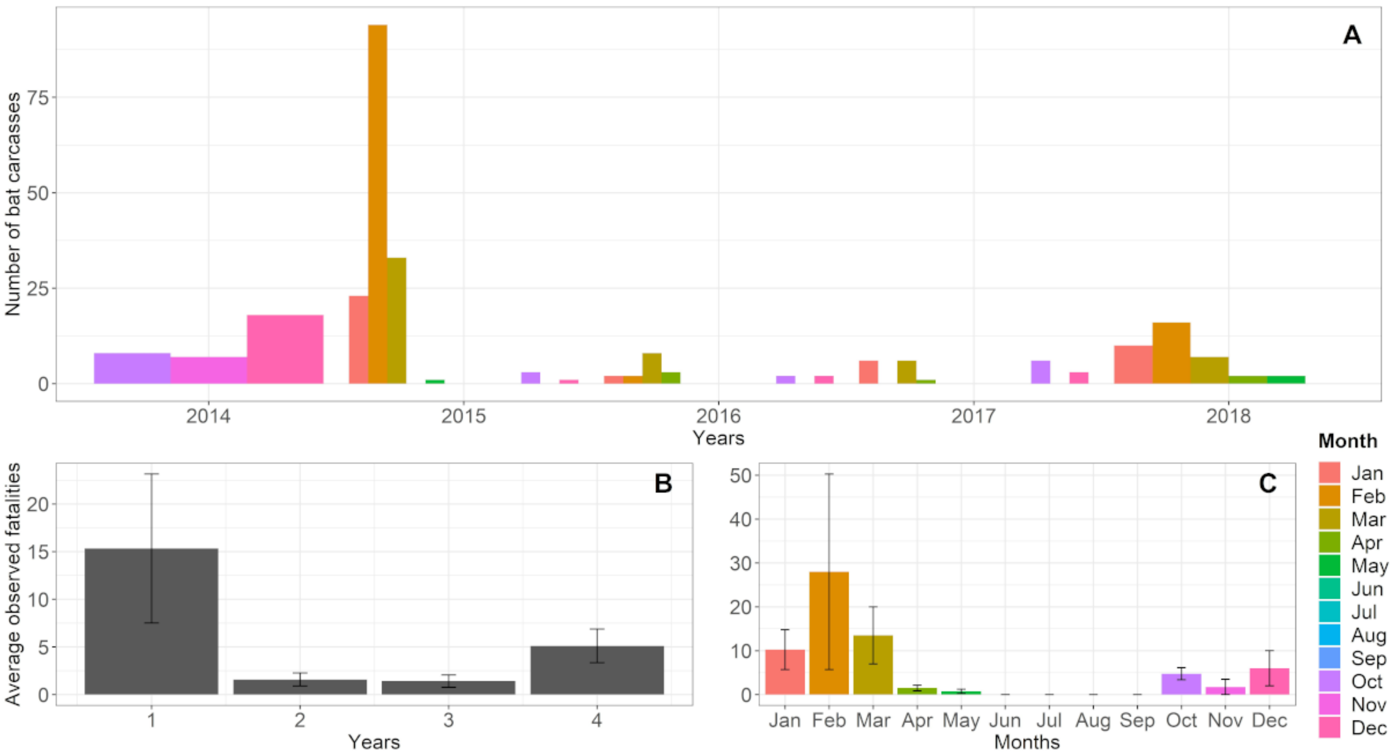

Figure 2 – A: number of recorded bat carcasses around the wind turbines of the Santa Vitória do Palmar Wind Plant during 48 months of monitoring, from July 2014 to June 2018. Only months with death records are shown. B: average monthly bat fatalities observed over four years in the Santa Vitória do Palmar Wind Plant, in Brazil's extreme south. C: average annual bat fatalities observed in the Santa Vitória do Palmar Wind Plant, southern Brazil, over a four-year period.

bat carcasses (Fig. 2a) belonging to six species of insectivorous bats: *Tadarida brasiliensis* (I. Geoffroy, 1824) was the most recorded species (n=233), followed by *Lasiurus blossevillii* (Lesson and Garnot, 1826) (n=15), *Lasiurus cinereus* (Beauvois, 1796) (n=9), *Eptesicus brasiliensis* (Desmarest, 1819) (n=1), *Eptesicus furinalis* (d'Orbigny and Gervais, 1847) (n=1) and *Lasiurus ega* (Gervais, 1856) (n= 1). Six individuals were identified only to the genus *Lasiurus* due to their high level of decomposition.

Fatalities were unequally distributed across the four years of monitoring (Friedman test χ^2=7.07; df=3; p=0.01). Most fatalities occurred in the first year (69% of deaths), between 2014 and 2015, followed by the fourth year (Fig. 2a and 2b) and significant differences occurred between the first year and the following years (1^{st}–2^{nd} year, p=0.02; 1^{st}–3^{rd} year, p=0.02; 1^{st}–4^{th} year, p=0.05) and the third and fourth years (3^{rd}–4^{th} year, p=0.02). Fatalities were registered from October to May (Austral Spring, Summer and Autumn), with higher occurrence from February to March (Fig. 2c). Thus, there seems to be a seasonal pattern in bat fatalities, with most deaths occurring during the Austral Spring and, particularly, late Summer.

To calculate the distance of the point where the carcasses were found, 21 carcasses were excluded, because they were found in nests of the firewood-gatherer *Anumbius annumbi* (Furnaridae; Vieillot, 1817), so the bird could have transported those carcasses from elsewhere. The great majority of the remaining carcasses were found at distances less than 60 m from the towers. Indeed, only two bat carcasses were found beyond 60 m from the tower base (Fig. 3a). Also, the wind farm closest to the urban centre, containing 15 towers, was the one were most carcasses were found (39.6%). While the 129 towers monitored for bat fatalities were distant between 0.9 km and 13 km from the urban area, 44% of the carcasses were found between 0.9 km and 4 km from the urban centre.

Across one year (August 2017 to July 2018), 112 carcasses were placed to obtain the percentage of loss by non-detection and, later, the same carcasses were used to calculate the percentage of carcass removal (PR). The results of non-detection rate along the seasons indicated that between 13% and 16% of carcasses were not found during the tests, and between 80% and 88% of carcasses were removed in only seven days by scavengers (Undetected – Winter:14%; Spring: 16%; Summer: 13%; Autumn: 14%; Removed – Winter:87%; Spring: 84%; Summer: 88%; Autumn: 80%).

The estimated fatality rate (EFR) for the sampled days was 380.7 deaths (Fig.3b). When this value is multiplied by 4 (mean number of weeks in a month), the EFR for one year is equal to 1,522.8 deaths, totalling 11.8 deaths per tower per year. Overall, the results suggest that only a small fraction of the deaths is recorded by direct observation.

The relation between fatality seasonality and land use and the position of the towers was significant in all seasons (Spring R^2==0.039; F=3.44, df=6, p=0.002; Summer R^2=0.026, F=2.31, df=6, p=0.032, and Autumn R^2=0.025, F=2.23, df=6, p=0.038). In Spring, bat fatalities were negatively correlated with grassland and exposed soil and in Summer, negatively correlated with rice fields. In Autumn, the number of bat fatalities was negatively correlated with grasslands and positively correlated with pastures (Tab. S2 to S4 of supplementary online material). Water surface was the only variable with no significant relation with fatalities in any season. Distance between the towers and the urban centre was negatively correlated with the number of bat fatalities (Tab. S2 to S4 of supplementary online material).

Patterns of bat activity

We recorded 1640 bat-passes. The site with the highest activity was the one closest to the urban area, point 1 (n=530), followed by point 2 (n=358), point 3 (n=325), point 5 (n=307) and point 4 (n=120) (Fig. 4a), following a concurrent spatial pattern with that of bat fatalities. Bat activity pattern also followed the same temporal pattern of fatalities, with highest activity levels during the Summer. Nightly activity varied according to season. In Winter, most activity occurred during the early evening, with the estimated activity peak occurring around 10 pm. In Spring, two moments of increasing activity were noticed: one around 8 pm and one later, around 2 am, with the estimated activity peak occurring around 11 pm. In Summer and Autumn, bat activity was more evenly distributed throughout the night, with the estimated activity peak occurring between 12 pm and 1 am (Fig. 4b).

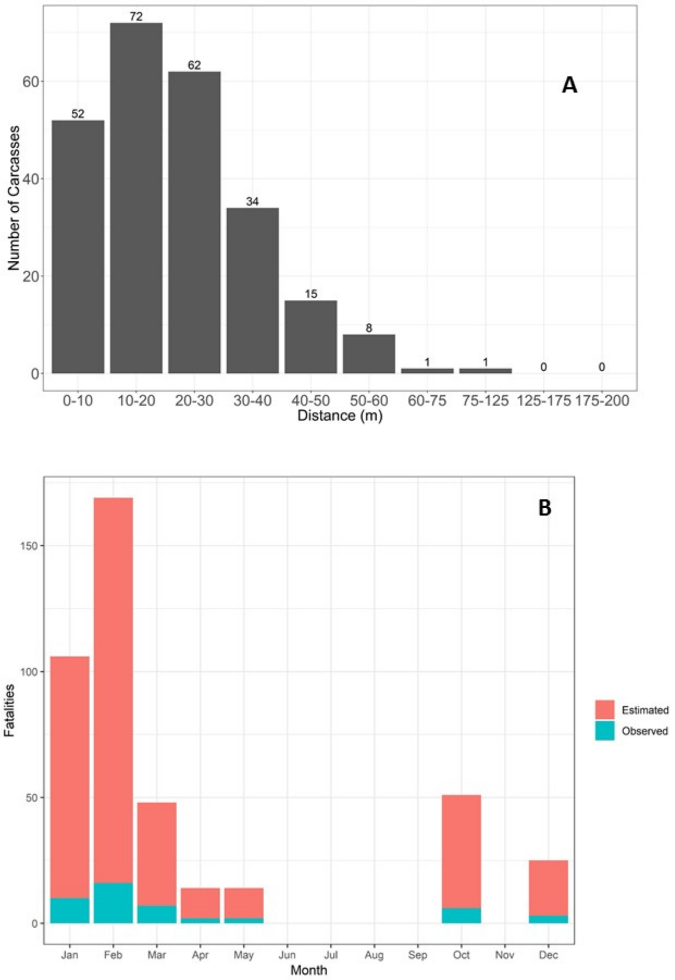

Figure 3 – A: number of bat carcasses found in each distance interval (m) from the wind tower bases of the Santa Vitória do Palmar Wind Plant, southern Brazil, between July 2014 and June 2018. B: relation between the observed bat fatalities and the estimated bat fatalities during a seven-day period in the Santa Vitória do Palmar Wind Plant, southern Brazil. Blue: observed fatalities; orange: estimated fatalities.

Bats were active between 11 °C and 27 °C (the highest night temperature recorded during sampling). However 83% of the recorded activity (Fig. 5a) occurred between 15 °C and 22 °C. Sixty-seven percent of bat activity was recorded between 5 and 10 m s^{-1} wind speed, with peak of activity at 6 m s^{-1}. The best ranked GLM was the null model (AICc=4435.3), followed by the models including exclusively average temperature or wind speed or relative air humidity, but all with ΔAIC slightly above 2. In none of the models, including the full model (AICc=4453.4) or those with all possible combinations of the predictors the tested variables were significant (in Supplementary Material Tab. S5 we present the estimates and confidence intervals for all the variables in the full model).

Although bat activity was not explained by the evaluated weather variables, there seems to be a trend for an increase in bat activity according to wind speed, at approximately 5 m s^{-1}, and gradually decreasing beyond 10 m s^{-1} (Fig. 5b). Fatalities did not show a significant relation with the activity of the previous night (z= 0.33; p=0.74). Bat activity and bat fatalities show two peaks each, in November (Spring) and March (Summer), however, of varied intensity (Fig. 5c).

Discussion

Here we present the first comprehensive study of spatial and temporal patterns of bat fatalities in a large wind plant in Southern Neotropics.

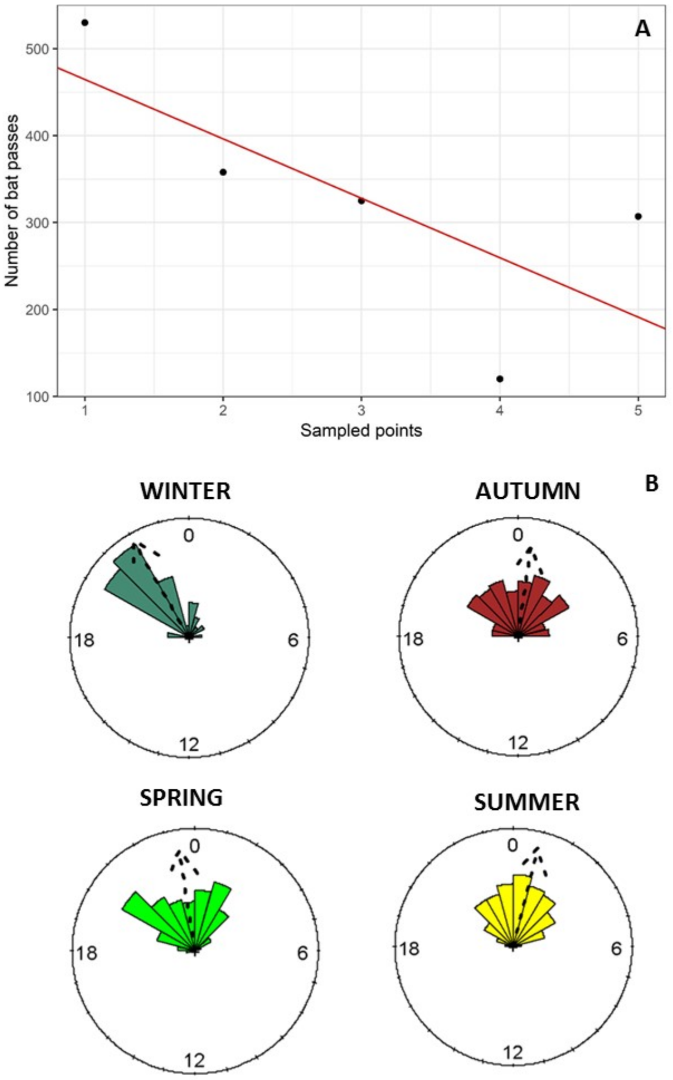

Figure 4 – A: number of bat passes recorded in each sampled point in the Santa Vitória do Palmar Wind Plant, southern Brazil. X-axis presents the sampling points from 1 to 5. The points were named according to the distance to the urban centre, where point 1 is the closest and point 5 is the farthest. Line represents the tendency and B: bat activity (hours) throughout the night over the seasons in the Santa Vitória do Palmar Wind Plant, southern Brazil. Each bar represents a one-hour interval. The arrow represents the estimated activity peak in each season.

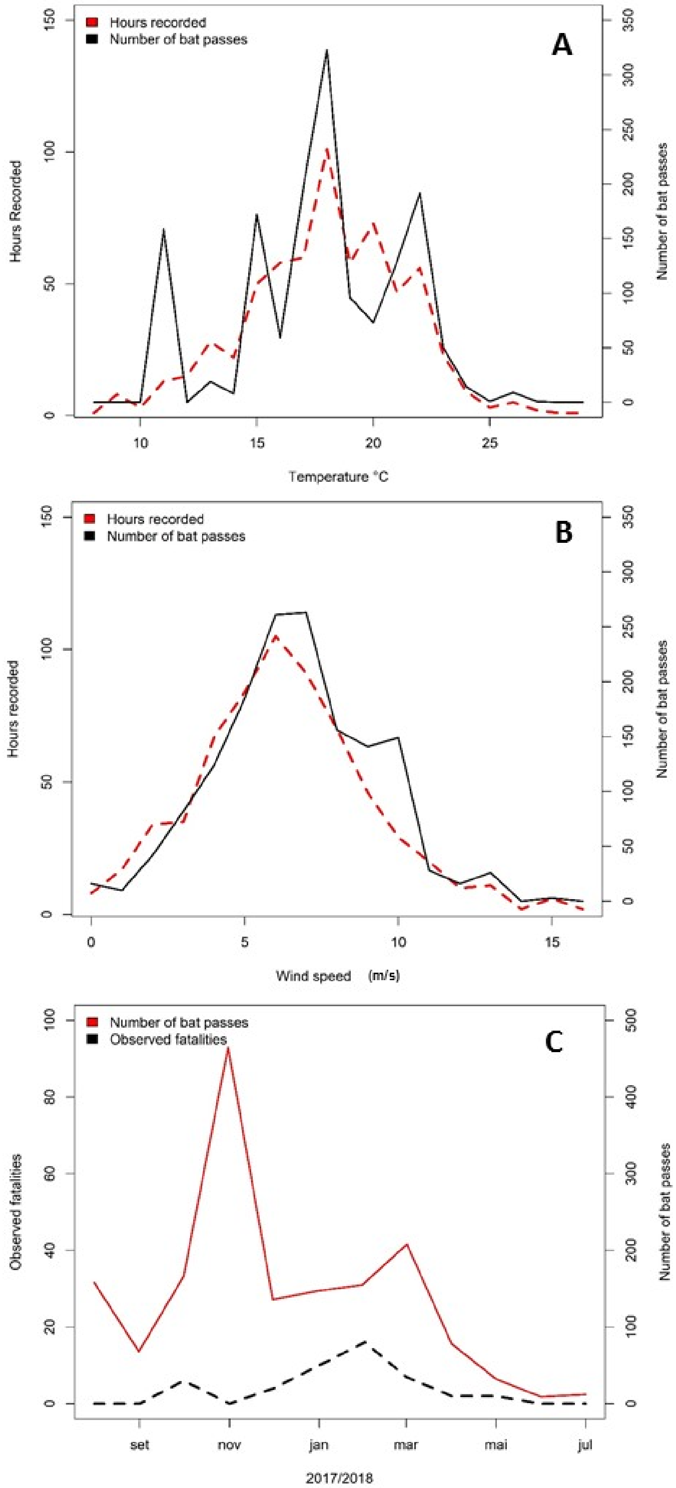

Figure 5 – A: bat passes recorded during a certain number of hours across a temperature gradient in the Santa Vitória do Palmar Wind Plant, southern Brazil; B: bat passes recorded during a certain number of hours across an average wind speed gradient in the Santa Vitória do Palmar Wind Plant, southern Brazil, and C: number of observed bat fatalities and record of bat passes during one year of monitoring (August 2017 to July 2018) in the Santa Vitória do Palmar Wind Plant, southern Brazil.

Bat fatalities showed a clear seasonal pattern, occurring between late Austral Spring and mid-Autumn, coinciding with periods of increased bat activity, similar to the Northern Hemisphere (e.g. Sánchez Navarro et al., 2012; Amorim, 2009). Our hypothesis of a spatial pattern in bat fatalities associated to the proximity to bat roosts was confirmed, with most fatalities concentrated around the towers closest to the urban centre, known to roost large colonies of *Tadarida brasiliensis*, the species most found death near the wind turbines. Moreover, we confirmed the influence of weather conditions on bat fatality trends, with the peak activity occurring between 15 °C and 22 °C.

Bat activity and behaviour explains temporal patterns of bat fatalities

In the Santa Vitória do Palmar Wind Plant most bat carcasses were found in Spring and Autumn, when bats showed highest levels of activity. Bat activity was not explained by any of the evaluated weather variables, but it decreases in cold nights, particularly below 15 °C.

Other authors have found that bats tend to increase activity with higher temperatures and atmospheric pressures (González et al., 2013) or to decrease activity with increased wind speed (Atienza et al., 2011; Nicholls and Racey, 2006; Russo and Jones, 2003), but we found no such relations. Still, these results may have been influenced by the atypical record of 159 bat-passes within 3 hours at a temperature of 11 °C, the minimum temperature at which bat activity was recorded; this extreme event occurred in a night following a unusually warm day (for the Austral Winter), during which temperatures reached 21 °C rapidly decreasing after sunset. Still 83% of the activity was recorded between 15 °C and 22 °C, with an activity peak (n=323) at 18.5 °C, similar to González et al. (2013) results. We speculate that increased wind speeds at higher elevations may lead bats to fly at lower elevations. Indeed, the increase in bat activity according to wind speed that we registered between 5 and 10 m s^{-1} may result from a vertical migration of bats towards lower elevations – while we measured wind speed at 56 m, we set the ultrasound detector at approximately 6 m from the ground. In this context, we recommend that future studies should deploy the record devices simultaneously at the maximum height reached by the blades in rotation (about 100 m), and closer to the ground (Collins and Jones, 2009); setting two detectors in at least two different heights may help understand this possible use of the vertical space by bats depending on the weather conditions.

Overall bat activity concentrates from dusk to midnight, which is probably related to patterns of arthropod activity (Arbuthnott and Brigham, 2007). Intense bat activity during the first hours of the night is also due to the long fasting period during the day, which generates intense search for food as soon as bats leave their roosts (Hayes, 1997; Kunz, 1973). It is possible to speculate that the observed bimodal pattern especially during the Spring may be explained by the return of lactating females to the roost to feed their young, followed by a second foraging excursion (Swift, 1980; Gaisler, 1963). Indeed, bimodal patterns (one in the early evening and another after midnight) seem to occur in distinct environments, from grasslands to savannas and tropical forests (Meyer et al., 2004; Hayes, 1997; Taylor and O'Neill, 2006). In late Summer, when most juveniles are probably already flying and night temperatures are less variable, bat activity seems to be more evenly distributed throughout the night. These seasonal differences have consequences regarding potential measures to reduce bat fatalities in wind plants: in Summer and Autumn there may be the need to shut down some of the turbines in some nights for the entire nocturnal period, while in Spring the need for such measure may be specific for some hours in some of the nights.

Tadarida brasiliensis reproductive patterns in the Southern Hemisphere and, particularly, of subadult recruitment may explain the clear seasonal pattern in bat fatalities. Indeed, in southern Brazil, *T. brasiliensis* females give birth in the late Spring, and the first subadult flights occur between January and March (Franco and Rui, 2011; Fabián and Marques, 1996). Young bats of this species are known to have reduced flying and echolocation skills (Buchler, 1980), increasing their chances of colliding with wind towers and turbines or to be caught within air masses under rapid air pressure reduction near the wind turbines, potentially suffering barotrauma, and thus explaining the increased rates of fatalities in late Summer (Tuttle, 1976).

In southernmost Brazil, winter nights get cold, below 10 °C, and the species occurring in the area, particularly *T. brasiliensis*, but also species of the Vespertilionidae such those of the genus *Eptesicus* and *Lasiurus*, also found dead near wind towers, may migrate towards more mild climates or simply reduce their activity by entering torpor (Fabián and Marques, 1996) or hibernation, a behaviour yet to be described in the Neotropics. This reduction in activity levels may in fact explain the absence of carcasses detected during the Winter months (June to September) from 2014 to 2017.

Spatial patterns of bat fatalities reflect roosting and foraging behaviours

Bat fatalities were more numerous close to the urban centre, where *T. brasiliensis* is known to congregate in large colonies (personal observation). On the other hand, the rural area mostly consisting of open areas, harboring few trees, rocks buildings, thus presenting few possibilities for roosting bats. Aerial insectivorous bats present home ranges, in this context, *T. brasiliensis* is known to travel up to 56 km in a single night (Vicent et al., 2011). So, lower densities of flying bats are expected as these gregarious bats leave and move further away from their roosts, as well as juvenile bat's behaviour of not exploiting environments far from shelter in the first weeks of flight (Tuttle, 1976) explaining the trend for fewer fatalities the further away from the urban centre.

Changes in land use interfere directly with arthropod availability and dynamics (Wang et al., 2010; Akasaka et al., 2009) and, consequently on bat habitat use and activity patterns (Wickramasinghe et al., 2003). Intensive rice production is one of the major human activities in the study area (Santiago et al., 2013) and is likely to present low prey availability for aerial insectivorous bats due to the use of pesticides (Wickramasinghe et al., 2003). Rice farms are thus likely to be avoided by bats (Walsh and Harris, 1996) that probably search for insects in other habitats; during summer, rice fields are irrigated with a water layer that varies between 5 and 15 cm, creating considerably large green biomass (Santiago et al., 2013). The fewer number of carcasses detected in rice fields may thus reflect the avoidance of these environments by foraging bats or our inability to detect carcasses there, especially when these sites are flooded.

There were less fatalities in larger areas of native grasslands and exposed soil during Spring months, possibly due to the lower biomass of arthropods available in these environments during this season. Indeed, areas of exposed soil are usually being prepared for rice plantations, while native grasslands, mostly composed by C4 plants, drastically reduce their growth between Autumn and Spring (Pettorelli et al., 2011; Nabinger et al., 2000). Bat fatalities were positively associated with rice plantations in Summer, probably due to the largest proportion of green biomass and wetland, and thus potential prey in those environments in that season (Pettorelli et al., 2011). However, in the Autumn, rice fields are generally drained, drastically altering the environment for seizing (Santiago et al., 2013), eventually becoming unsuitable as foraging- habitat. On the other hand, pastures probably become more attractive for bats during this season, which may explain the increased number of fatalities in towers located in this environment.

A negative relation between fatalities and the distance to the base of towers, together with the maximum distance where fatalities were detected, suggested that radius of search of 60 m was comprehensive for wind towers of 130 m height with blades of 50 m long. Similar results were obtained in the US, where 80% of the fatalities were detected up to 40 m from the wind towers (Arnett et al., 2008).

Another important information revealed by this study is the first record of bats carcass removal by *Anumbius annumbi* (known as firewood-gatherer). This small-sized bird is very common in the Pampa biome (Belton, 1994), and it builds large nests on the access ladders of the towers. Eight percent of bat carcasses were found in these nests, probably collected by these birds around the towers at different distances.

Observed fatalities may represent a small percentage of the true number of fatalities

Our estimates of the fatality rate show that with one search per month per tower, the number of carcasses found represents about 2.5 to 5% of the estimated deaths in one year. The estimated fatality rate per tower for a period of four years was 11.8 deaths, with 2.9 deaths per tower per year, on average. The estimated value somewhat higher that of the Altamont Pass wind farm (California), where the EFR was of 0.15 bats per wind turbine per year (NWCC 2004), or that of the Vansycle wind farm (Oregon), with 38 wind turbines of the VESTAS V-47 type with an EFR of 0.4 bats per turbine per year (Hotker et al., 2006). However, our estimated EFR was similar to that of the Buffalo Mountain wind farm (Tennessee), where 2.3 bats are estimated to be killed per turbine per year (Hotker et al., 2006).

In the European Union and the United States wind farm bat fatalities monitoring has been publicly available for some years, supporting the design of better monitoring schemes and the definition of effective mitigation proposals (González et al., 2013; Atienza et al., 2011; Jain et al., 2011; Amorim, 2009; Meyer et al., 2004). In Brazil, the further laxation of environmental policies, together with the lack of legislation compelling wind developers to publicly share wind farm monitoring data does not envisage a sustainable application of the environmental impact mitigation hierarchy – avoidance, minimization, rectification, reduction and offsetting. In this sense, our work is pioneer in sharing medium-term monitoring data for a large wind plant in the country, adding to the works of Barros et al. (2015) and Ramos Pereira et al. (2017) towards the promotion of sustainable environmental impact assessment practices in the Neotropics. From our results, but also from deficiencies we identified in our data we recommend the following:

i bat activity monitoring at wind farms in southern Brazil must be based on a representative grid of fixed points starting from the beginning of the environmental impact assessment, passing through the installation and throughout wind farm operation. These points should, preferably, monitor bat activity at different heights to understand how bats respond to changes in weather conditions through the night and along the year.

ii The search for carcasses in wind farms should occur in an area of at least 60 m from the base of each tower, and throughout the year. Indeed, while the largest percentage of fatalities seems to be concentrated in warmer parts of the year, bat activity may peak in response to abrupt changes in weather, events that are likely to increase in frequency do to global climate changes.

iii Wind farms should be implemented at least 4 km away from roots of large bat colonies. In the case of gregarious synanthropic species with large home-ranges, such as *T. brasiliensis*, this means that wind farms should be set at least 4 km away (preferably more distant) from urban centres.

iv Pilot programs including changes in turbine cut-in speed and turbine shut down should be implemented taking into consideration year periods and weather conditions when bat activity is likely to be highest, looking for changes in the number of fatalities and for financial impacts on wind production. In fact, in the Northern Hemisphere increasing cut-in speed to 5 m s^{-1}, resulted in marginal annual power loss, below 1% of the total annual output (Amorim et al., 2012; Arnett et al., 2010).

References

ABEEólica, 2019. Associação Brasileira de Energia Eólica. http://abeeolica.org.br/noticias/eolica-ja-e-a-segunda-fonte-da-matriz-eletrica-brasileira-com-15-gw-de-capacidade-instalada [Accessed on 10 May 2019, in Portuguese]

Akasaka T., Nakano D., Nakamura F., 2009. Influence of prey variables, food supply, and river restoration on the foraging activity of Daubentons bat (*Myotis daubentonii*) in the Shibetsu River, a large lowland river in Japan. Biol. Conserv. 142: 1302–1310.

Amarante O.A.C., Brower M., Zack J., Al de Sá, 2001. Atlas do Potencial Eólico Brasileiro. MME. Brasília. [in Portuguese]

Amorim F., 2009. Morcegos e Parques Eólicos: Relação entre o Uso do Espaço e a Mortalidade, Avaliação de Metodologias, e Influência de Fatores Ambientais e Ecológicos sobre a Mortalidade. 152p. Dissertação, Instituto de Conservação da Natureza e Biodiversidade. Universidade de Évora, Portugal [in Portuguese]

Amorim F., Rebelo H., Rodrigues L., 2012. Factors influencing bat activity and mortality at a wind farm in the mediterranean region. Acta Chiropterologica 14(2), 439–457. doi:10.3161/150811012X661756

Arbuthnott D., Brigham R.M., 2007. The influence of a local temperature inversion on the foraging behaviour of big brown bats, *Eptesicus fuscus*. Acta Chiropterologica 9(1): 193–201.

Arias-Aguilar A., Hintze F., Aguiar L.M.S., Rufray V., Bernard E., Ramos Pereira M.J., 2018. Who's calling? Acoustic identification of Brazilian bats. Mammal Research Institute, Polish Academy of Sciences, Bia.

Arnett E.B., 2005. Relationships between bats and wind turbines in Pennsylvania and West Virginia: an assessment of bat fatality search protocols, patterns of fatality, and behavioral interactions with wind turbines. A final report submitted to the Bats and Wind Energy Cooperative. Bat Conservation International.

Arnett E.B., Brown K., Erickson W.P., Fiedler J., Henry T.H., Johnson G.D., Kerns J., Kolford R.R., Nicholson C.P., O'Connell T., Piorkowski M., Tankersley R. Jr., 2008a. Patterns of fatality of bats at wind energy facilities in North America. J Wildl Manage 72(1): 61–78.

Arnett E.B., Huso M.P., Schirmacher M.R., Hayes J.P., 2010. Altering turbine speed reduces bat mortality at wind-energy facilities. Front. Ecol. Environ. 9: 209–214. doi:10.1890/100103.

Atienza J.C., Fierro M., Isabel I., Octavio V., Del Valle J., Del Valle D., Jon., 2011. Directrices para la evaluación del impacto de los parques eólicos en aves y murciélagos (versión 3.0). [in Portuguese]

Baerwald E.F., Edworthy J., Holder M., Barclay R.M.R., 2009. A Large-Scale Mitigation Experiment to Reduce Bat Fatalities at Wind Energy Facilities. J Wildl Manage 73(7): 1077–1081.

Barros M.A., Magalhães R.G., Rui A.M., 2015. Species composition and mortality of bats at the Osório Wind Farm, southern Brazil. Studies on Neotropical Fauna and Environment.

Belton W., 1994. Aves do Rio Grande do Sul: Distribuição e biologia. São Leopoldo: UNISINOS. [in Portuguese]

Bernard E., Aguiar L.M.S., Brito D., Cruz-Neto A.P., Gregorin R., Machado R. B., Oprea M., Paglia A.P., Tavares V.C., 2012. Uma análise de horizontes sobre a conservação de morcegos no Brasil. In: Freitas T.R.O., Vieira E.M. (Eds) Mamíferos do Brasil: Genética, Sistemática, Ecologia e Conservação, vol II. Rio de Janeiro: Sociedade Brasileira de Mastozoologia. ISBN 978-85-63705-01-3. 19–35. [in Portuguese]

Bernard E., Aguiar L.M.S., Machado R.B., 2011. Discovering the Brazilian bat fauna: A task for two centuries. Mammal Review 41: 23–39.

Bernard E., Paese A., Machado R.B., Aguiar L.M.S., 2014. Blown in the wind: bats and wind farms in Brazil. Natureza & Conservação. [in Portuguese]

Berthinussen A., Althingham J., 2012. The effect of a major road on bat activity and diversity. Journal of Applied Ecology 49: 82–89. doi:10.1111/j.1365-2664.2011.02068.x

Bioacoustics Research Program, 2017. Raven Pro: Interactive Sound Analysis Software (Version 1.5) [Computer software]. Ithaca, NY: The Cornell Lab. of Ornithology. Available at http://birds.cornell.edu/raven

Buchler E.R., 1980. The development of flight, foraging, and echolocation in the Little Brown Bat (*Myotis lucifugus*). Behav. Ecol. Sociobiol. 6: 211–218.

Burnham K.P., Anderson D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach (2nd ed).

Collins J., Jones G., 2009. Differences in bat activity in relation to bat detector height: implications for bat surveys at proposed windfarm sites. Acta Chiropterologica 11: 343–350.

Efe M.A., Mohr L.V., Bugoni L., 2001. Guia ilustrativo das aves dos Parques de Porto Alegre. Porto Alegre: PROAVES, SMAM, COPESUL, CEMAVE. [in Portuguese]

Erickson W.P., Johnson G.D., Young D.P., Strickland M.D., Good R.E., Bourassa M., Bay K., Sernka K., 2002. Synthesis and comparison of baseline avian and bat use, raptor nesting and mortality information from proposed and existing wind developments. WEST, Inc. Central Ave. Cheyenne, WY 82001.

Erickson W.P., Jeffrey J., Kronner K., Bay K., 2004. Stateline wind project wildlife monitoring final report, July 2001–December 2003. Technical report peer-reviewed by a submitted to FPL Energy, the Oregon Energy Facility Siting Council, and the Stateline Technical Advisory Committee.

Fabián M.E., Marques R.V., 1996. Aspectos do comportamento de *Tadarida brasiliensis brasiliensis* (I. Geoffroy, 1824) (Quiróptera, Molossidae) em ambiente urbano. Biociências 4(1): 65–86. [in Portuguese]

Fauvel M., Dechesne C., Zullo A., Ferraty F., 2015. Fast forward feature selection of hyperspectral images for classification with Gaussian mixture models. Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal 8(6): 2824–2831.

Franco A.D., Rui A.M., 2011. Uso de abrigo e composição de colônia de *Tadarida brasiliensis* (Quiróptera, Molossidae) no sul do Rio Grande do Sul, Brasil. In: X Congresso de Ecologia do Brasil, 2011, São Lourenço – MG. X Congresso de Ecologia do Brasil. [in Portuguese]

Gaisler J., 1963. Nocturnal activity in the lesser horseshoe bat, *Rhinolophus hipposideros* (Bechstein, 1800). Zool. Listy, 12 (3): 223–230.

Georgiakakis P., Vasilakopoulos P., Mylonas M., Russo D., 2010. Bat species richness and activity over na elevation gradiente in Mediterranean Shrublands of crete. Hystrix 21(1): 43–56 doi:10.4404/hystrix-21.1-4485

González F., Alcalde J.T., Ibáñez C., 2013. Directrices básicas para el estúdio del impacto de instalaciones eólicas sobre poblaciones de murciélagos en España. SECEMU. Barbastella, 6 (núm. especial): 1–31. [in Portuguese]

Hammer O., Harper D.A.T., Ryan P.D., 2001. PAST: Paleontological Statistics software package for education and data analysis. Palaeontologia Electronica 4(1): 9.

Hayes J.P., 1997. Temporal variation in activity of bats and the design of echolocation monitoring studies. Journal of Mammalogy 78: 514–524.

Hotker H., Thomsen K.M., Jeromin H., 2006. Impacts on biodiversity of exploitation of renewable energy sources: the example of birds and bats - facts, gaps in knowledge, demands for further research, and ornithological guidelines for the development of renewable energy exploitation, Michael-Otto-Institut im NABU, Bergenhusen.

IBGE, 2004. Mapa de Biomas do Brasil. Ministério do Meio ambiente (MMA), Ministério do Planejamento, Orçamento e Gestão, Instituto Brasileiro de Geografia e Estatística.

INPE (Instituto Nacional de Pesquisas Espaciais). Manuais – Tutorial de geoprocessamento. Available at http://www.dpi.inpe.br/spring/portugues/tutorial/classific.html [accessed on 20 october 2018, in Portuguese]

Jain A., Kerlinger P., Curry R., Slobodnik L., 2007. Annual report for the Maple Ridge wind power project post-construction bird and bat fatality study – 2006. Annual report prepared for PPM Energy and Horizon Energy, Curry and Kerlinger LLC, Cape May Point, New Jersey.

Jain A., Kerlinger P., Curry R., Slobodnik L., 2008. Annual Report for the Maple Ridge Wind Power Project Postconstruction Bird and Bat Fatality Study – 2007. Prepared for PPM Energy and Horizon Energy and Technical Advisory Committee (TAC) for the Maple Ridge Project Study.

Jain A., Kerlinger P., Curry R., Slobodnik L., 2009a. Annual Report for the Maple Ridge Wind Power Project Postconstruction Bird and Bat Fatality Study – 2008. Prepared for PPM Energy and Horizon Energy and Technical Advisory Committee (TAC) for the Maple Ridge Project Study.

Jain A., Kerlinger P., Curry R., Slobodnik L., Quant J., Pursell D., 2009b. Annual Report for the Noble Bliss Windpark, LLC Postconstruction Bird and Bat Fatality Study – 2008. Prepared for Noble Environmental Power, LLC.

Jain A., Kerlinger P., Curry R., Slobodnik L., Histed J., Meacham J., 2009c. Annual Report for the Noble Clinton Windpark, LLC Postconstruction Bird and Bat Fatality Study – 2008. Prepared for Noble Environmental Power, LLC.

Jain A., Koford R. R., Hancock A. W., Zenner G. G., 2011. Bat Mortality and Activity at a Northern Iowa Wind Resource Area. The American Midland Naturalist 165(1): 185–200.

Kitzes J., Merenlender A., 2014. Large roads reduce bat activity across multiple species. PLoS one 9(5): e96341. doi:10.1371/journal.pone.0096341

Kunz T.H., 1973. Resource utilization — temporal and spatial components of bat activity in central Iowa. Journal of Mammalogy 54: 14–32.

Kunz T.H., Arnett E.B., Cooper B.M., Erickson W.P., Larkin R.P., Mabee T., Morrison M.L., Strickland M.D., Szewczak J.M., 2007a. Assessing impacts of wind-energy development on nocturnally active birds and bats: A guidance document. J. Wildl Manage 71(8): 2449–2486.

Kunz T.H., Arnett E.B., Erickson W.P., 2007b. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Front Ecol Environ 5(6): 315–324.

Meyer C.F.J., Schwarz C.J., Fahr J., 2004. Activity patterns and habitat preferences of insectivorous bats in a West African forest-savanna mosaic. Journal of Tropical Ecology 20(4): 397–407.

Nabinger C., de Moraes A., Maraschin G., 2000. Campos in Southern Brazil, grassland ecophysiology and grazing ecology. CAB International 355–376.

Nicholls B., Racey P.A., 2006. Habitat selection as a mechanism of resource partitioning in two cryptic bat species *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*. Ecography 29: 697–708.

NWCC, 2004. Wind Turbine Interactions with Birds and Bats: A Summary of Research Results and Remaining Questions, Fact Sheet: Second Edition, National Wind Coordinating Committee.

Osborn R.G., Higgins K.F., Dieter C.D., Usgaard R.E., 1996. Bat collisions with wind turbines in southwestern Minnesota. Bat Res. News 37: 105–108.

Pereira B.W.D.F., Maciel M.D.N.M., Oliveira F.D.A., Alves M.A.M.D.S., Ribeiro A.M., Ferreira B.M., Ribeiro E.G.P., 2016. Land use and water quality degradation in the Peixe-Boi River watershed. Rev. Ambiente & Água 11(2): 472–485.
Pettorelli N., Ryan S., Mueller T., Bunnefeld N., Jedrzejewska B., Lima M., Kausrud K., 2011. The Normalized Difference Vegetation Index (NDVI): Unforeseen successes in animal ecology. Climate Research 46(1): 15–27.
Prakash C.R., Asra M., Venkatesh J., Sreedevi B., 2015. Monitoring Urban Land-Cover Features using Resourcesat LISS-III Data. International Journal of Advanced Remote Sensing and GIS 4(1): 1064.
R Development Core Team., 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.
Rambo B., 2000. A fisionomia do Rio Grande do Sul. São Leopoldo: Editora UNISINOS. [in Portuguese]
Ramos Pereira M.J., Barros M., Chaves T.S., Rui A.M., Dotto J.C., Braun A., Barbosa J., Bernard E., Aguiar L.M.S., Kindel A., Sana D.A., 2017. Guidelines for consideration of bats in environmental impact assessment of wind farms in Brazil: a collaborative governance experience from Rio Grande do Sul. Oecologia Australis 21: 232–255.
Reis N.R., Peracchi A.L., Pedro W.A., Lima I.P., 2007. Morcegos do Brasil. Universidade de Londrina. [in Portuguese]
Ribeiro M.C., Metzger J.P., Martensen A.C., Ponzoni F.J., Hirota M.M., 2009. The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? Implications for conservation. Biol. Conserv. 142(6): 1141–1153.
Rodrigues L., Bach L., Dubourg-Savage M.J., Karapandza B., Kovac D., Kervyn T., Dekker J., Kepel A., Bach P., Collins J., Harbusch C., Park K., Micevski B., Minderman J., 2015. Guidelines for consideration of bats in wind farm projects – revision 2014. UNEP/EUROBATS Secretariat, Bonn, Germany. N 6 http://www.eurobats.org/sites/default/files/documents/publications/publication_series/pubseries_no6_english.pdf [accessed 1 August 2015]
Rogers S.E., 1978. Environmental studies related to the operation of wind energy conversion systems. Washington: National Technical Information Service.
Russo D., Jones G., 2003. Use of foraging habitats by bats in a Mediterranean area determined by acoustic surveys: conservation implications. Ecography 26: 197–209.
Rydell J., Bach L., Dubourg-Savage M.J., Green M., Rodrigues L., Hedenström A., 2010. Bat mortality at wind turbines in northwest Europe. Acta Chiropterol. 12(2) 261–274.
Sánchez Navarro S., Berrío-Martínez J., Ibáñez C., 2012. Patrones de mortalidad de murciélagos en Parques Eólicos del Sur de la Península Ibérica. In: I Congreso Ibérico sobre Energía Eólica y Conservación de la Fauna, Jerez, Cádiz, enero 2012. [in Portuguese]
Santiago C.M, Breseghello H.C.P., Ferreira C.M., 2013. Arroz: o produtor pergunta, a Embrapa responde – 2. ed. rev. ampl. – Brasília, DF: Embrapa. 245 p. il. – (Coleção 500 Perguntas, 500 Respostas). [in Portuguese]
Swift S.M., 1980. Activity patterns of pipistrelle bats (*Pipistrellus pipistrellus*) in north-east Scotland. J. Zool. 190: 285–295.
Taylor D.A.R., 2006. Forest Management and Bats. Bat Conservation International.
Taylor R.J., O'Neill G., 1988. Summer activity patterns of insectivorous bats and their prey in Tasmania. Australian Wildlife Research 14: 533–539.
Terciote R.A., 2002. Energia Eólica e o Meio Ambiente. In: Encontro de Energia no Meio Rural. Campinas. [in Portuguese]
Tuttle M.D., 1976. Population Ecology of the Gray Bat (*Myotis grisescens*): Factors influencing growth and survival of newly volant young. Ecology. 57(3): 587–595.
Vicent S., Nemoz M., Aulagnier S., 2011. Activity and foraging habitats of *Miniopterus schreibersii* (Chiroptera: Miniopteridae) in southern France: implications for its conservation. Hystrix 22(1): 57–72. doi:10.4404/hystrix-22.1-4524
Walsh A.L., Harris S., 1996. Foraging habitat preferences of Vespertilionid bats in Britain. J Appl. Ecol. 33: 508–518.
Wang J., Gao W., Wang L., Metzner W., Ma J., Feng J., 2010. Seasonal variation in prey abundance influences habitat use by greater horseshoe bats (*Rhinolophus ferrumequinum*) in a temperate deciduous forest. Can. J. Zool. 88: 315–323.
Wickramasinghe L.P., Harris S., Jones G., Vaughan N., 2003. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. J Appl. Ecol. 40: 984–993.

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Supplemental information

Additional Supplemental Information may be found in the online version of this article:

Table S1 List of images downloaded from the National Institute of Space Research (INPE).

Table S2 Multiple regression models relating bat fatalities with land-use during Spring (2014 to 2018).

Table S3 Multiple regression models relating bat fatalities with land-use during Summer (2014 to 2018).

Table S4 Multiple regression models relating bat fatalities with land-use during Autumn (2014 to 2018).

Table S5 Estimates, standard error, t-value and significance for the predictor variables in the full model.