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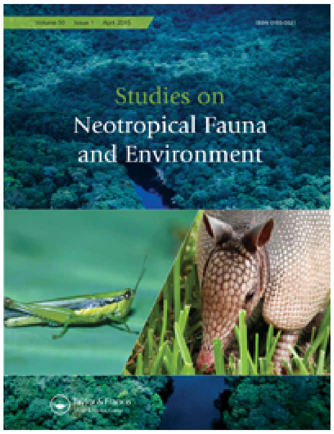

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We present the results of a three-year study on the bat species killed by wind turbines at the Osório Wind Farm, a large wind power complex in southern Brazil, and compare these fatalities to the composition of the local bat fauna. Fatality searches around wind turbines were conducted from 2006 to 2009, as well as a bat inventory through mist-netting and searches for colonies from 2004 to 2010. We found a total of 336 bat fatalities: *Tadarida brasiliensis* (*n* = 245), *Lasiurus cinereus* (*n* = 44), *Nyctinomops laticaudatus* (*n* = 12), *Molossus molossus* (*n* = 9), *Lasiurus blossevillii* (*n* = 6), *Promops nasutus* (*n* = 3), *Lasiurus ega* (*n* = 3), *Molossus rufus* (*n* = 1), and *Artibeus lituratus* (*n* = 1). By mist-netting, we recorded 13 bat species in the region, of which only six were killed by wind turbines. Our results are similar to mortality patterns from the Northern Hemisphere in terms of: (1) uneven distribution of fatalities among species; (2) dominance of migratory species, including foliage/tree-roosting bats; and (3) discrepancy between presence and abundance of species recorded in the wind farm area and in the fatality sample.

Nós apresentamos três anos de dados sobre as espécies de morcegos mortas por aerogeradores nos Parques Eólicos de Osório, um empreendimento de grande porte localizado no sul do Brasil, e comparamos a mortalidade com a composição da fauna local de morcegos. Foram realizadas buscas por carcaças ao redor das turbinas entre 2006 e 2009, assim como um inventário de morcegos através de amostragens com redes de neblina e buscas por colônias de 2004 a 2010. No total, 336 carcaças de morcegos foram encontradas: *Tadarida brasiliensis* (*n* = 245), *Lasiurus cinereus* (*n* = 44), *Nyctinomops laticaudatus* (*n* = 12), *Molossus molossus* (*n* = 9), *Lasiurus blossevillii* (*n* = 6), *Promops nasutus* (*n* = 3), *Lasiurus ega* (*n* = 3), *Molossus rufus* (*n* = 1) e *Artibeus lituratus* (*n* = 1). Através das amostragens com redes de neblina, nós registramos 13 espécies de morcegos na região, das quais apenas seis foram mortas por turbinas eólicas. Nossos resultados são semelhantes aos padrões de mortalidade observados no hemisfério norte em termos de: (1) distribuição desigual do número de fatalidades entre espécies; (2) dominância de espécies migratórias, incluindo morcegos que se abrigam em folhagem; e (3) discrepância entre presença e abundância das espécies na área do parque eólico e na amostra de fatalidades.

Keywords: *Artibeus lituratus*; collision mortality; lasiurine bats; Latin America; *Tadarida brasiliensis*; wind power

Introduction

Wind has been used to generate electricity since the early 20th century; however, the production of wind energy has increased rapidly in the past 40 years due to the search for alternative energy sources (Ackermann 2005). Currently, wind energy receives heavy government subsidies and constitutes an increasing share of the energy matrix in many countries, including in Latin America (Coyle 2011). Brazil has a large wind potential (Amarante et al. 2001) and, although hydroelectric energy still predominates, the exploitation of wind energy has been exponentially growing in southern and northeastern Brazil (ANEEL 2008). By the end of 2013, there were 142 wind farms producing 3.4 GW in Brazil, and this capacity is expected to triple by 2017 (ABEEólica 2013).

Although the production of wind energy is considered eco-friendly, wind farms can impact wildlife (NRC 2007). The main animal groups affected are birds and bats, which have been found dead around wind turbines at several wind facilities worldwide (Kuvlesky et al. 2007; Jana & Pogacnik 2008). There are records of bat collision with human-made fixed structures, such as lighthouses (Saunders 1930) and television towers (Van Gelder 1956; Crawford & Baker 1981), but there is no precedent for the high mortality rates observed at wind farms (Arnett et al. 2008).

The causes of bat fatalities are still unclear, but several hypotheses have been advanced. The high occurrence of external traumatic injuries and records from thermal infrared cameras indicate that bats

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collide more frequently with moving blades than with towers (Horn et al. 2008; Cryan & Barclay 2009). In addition, even without collision, bats can suffer injuries in their respiratory system when approaching operating turbines, as they may enter specific low air pressure zones around moving turbine blades (Baerwald et al. 2008). Forensic evidence suggests that bat mortality at turbines occurs more frequently as a result of traumatic injuries from collisions, and less frequently due to barotrauma (Rollins et al. 2012).

Bat fatalities at wind farms do not occur at random, as mortality samples do not reflect the composition of the local bat fauna in terms of species richness and abundance (Johnson et al. 2004). In general, the highest mortality rates at wind facilities are reported for foliage/tree-roosting migratory species, and mortality peaks coincide with autumn migrations (Arnett et al. 2008). Therefore, one frequently discussed hypothesis about the ultimate causes of fatalities is that migration would make some species more susceptible than others, probably because migratory bats fly at the heights of turbine rotors and use echolocation less often (Kunz, Arnett, Erickson, et al. 2007; Cryan & Barclay 2009). In addition, vulnerability may be related to some sort of behavior common to migratory species in sedentary periods. Bats could, for example, be attracted to turbines by mistaking them for tall trees where they usually search for roosts, social opportunities, or insect prey (Cryan 2008; Cryan et al. 2014).

Bat fatalities at wind farms have been broadly documented, especially in recent years (e.g. Piorkowski & O'Connell 2010; Ferri et al. 2011; Camina 2012), and guidelines for impact studies have been proposed (Kunz, Arnett, Cooper, et al. 2007; Rodrigues et al. 2008). However, most data available on the interactions between bats and wind turbines comes from North America (Arnett et al. 2008; Smallwood & Karas 2009; Baerwald & Barclay 2009; Jain et al. 2011) and Europe (Rydell et al. 2010; Voigt et al. 2012; Amorim et al. 2012; Georgiakakis et al. 2012). Recently, data from the Southern Hemisphere have been published (Doty & Martin 2013; Hull & Cawthen 2013), but there is no information about bat fatalities for the Neotropical region, where bat diversity is very high.

We conducted the present study at the Osório Wind Farm, one of the largest complexes of wind energy production of Latin America, located in southern Brazil, which became operational in 2006 (Ventos do Sul Energia c2009–2014). This wind farm is located in the state of Rio Grande do Sul, where 40 bat species (belonging to 21 genera) have been recorded, including one in the family Noctilionidae, 12 in Phyllostomidae, 15 in Vespertilionidae, and 12 in Molossidae (Passos et al. 2010). This is an important biogeographic region since it represents the southernmost portion of the Atlantic Forest biome. The objective of this study was to present a three-year record of bat species fatalities at the Osório Wind Farm, and to compare these fatalities with data on the composition of the local bat fauna.

Material and methods

Study area

The Osório Wind Farm (hereafter OWF) is located in the municipality of Osório, state of Rio Grande do Sul, southern Brazil, at an average altitude of 20 m asl (29°57′27″S, 50°17′30″W). The OWF is installed in areas that are mainly used as pasture for cattle and rice plantation. There are also small forest patches (*capões*) of exotic vegetation (mainly *Eucalyptus*), lagoons, marshes (*banhados*), and native fragments of *restinga* vegetation (Figure 1). In addition, the wind farm is very close to a rain forest area (Floresta Ombrófila Densa; Atlantic Forest biome), whose southernmost limit is located at the north of the OWF.

When we collected the data, the OWF had 75 turbines with 100 m high towers, rotor diameter of 70 m, rotor-swept area of 3960 m^2, and installed power of 150 MW (2 MW/turbine) (Ventos do Sul Energia c2009–2014). The wind farm has an approximate area of 11 × 2 km and is composed of the wind parks Sangradouro, Osório, and Índios. Each park has 25 turbines in two rows with a number of wind turbines that vary from nine to 16.

Mist-netting and searches for colonies

We conducted a bat inventory at the OWF region from April 2004 (pre-construction phase) to March 2010 (three months after the end of the operation monitoring phase). We carried out mist-netting in potential areas of bat activity and also searched for colonies.

We carried out 25 sampling nights with mist nets in 17 sampling sites from June 2004 to March 2010. Sampling was performed in the area under direct influence of the OWF (in sites located from 0.1 to 4 km away from the closest turbine) during 15 nights, and in the surroundings of the wind farm in native forests and *restinga* forests close to lagoons (in sites located 4–20 km away from the closest turbine) during 10 nights. Every night, we set up two to eight mist

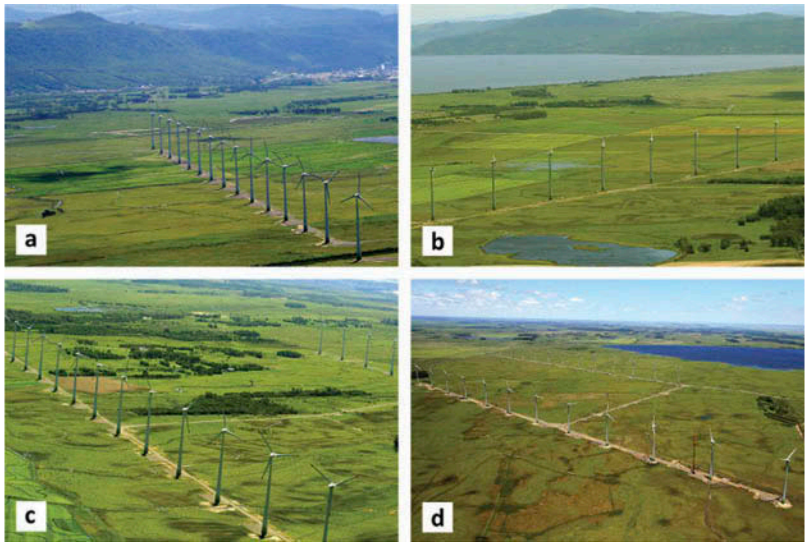

Figure 1. Landscapes that compose the region of the Osório Wind Farm (OWF), southern Brazil, with a predominance of pasture areas for cattle and rice plantation. (a) Northern portion of the OWF (Sangradouro Wind Park) in the vicinity of a hill slope with Atlantic Forest cover (mount Morro da Borússia in the background) and of the urban center of the city of Osório (in the background to the right); (b) western portion of the OWF (Osório Wind Park) in the vicinity of a lagoon (Lagoa dos Barros in the background) with the occurrence of marshes (*banhados*) and *restinga* vegetation; (c) eastern portion of the OWF (Osório Wind Park) with fragments of native and exotic arboreal vegetation; (d) southern portion of the OWF (Índios Wind Park) in the vicinity of a lagoon (Lagoa dos Índios in the background to the right) with a predominance of grassland vegetation.

nets, opened at sunset for two to six consecutive hours.

We searched for colonies by checking 33 properties (where wind turbines have been installed, as well as neighboring properties) for potential roosts from April 2004 to February 2010. We checked all potential roosts for bats according to the owner's/manager's information, and also the availability of possible roost sites in the area such as: cavities in large trees, trees with peeling barks, hollows in fence posts and poles, unoccupied houses and sheds, attics of buildings, rainwater drainage tunnels, and bridges. In the OWF area, there are no caves, caverns, or mines. Potential roosts were selected for bat surveys based on presence of feces, odor, vocalizations, and/or suggestion from local people. By mist-netting, we captured bats leaving the roost at sunset, and measured, weighed, and identified them in the field. We also collected some specimens of each species to confirm the identification and to be kept as vouchers.

Fatality searches

We carried out the monitoring of bat mortality during the first three operation years of each of the three parks that form the OWF complex. We monitored the Osório Wind Park from July 2006 to June 2009, the Sangradouro Wind Park from September 2006 to August 2009, and the Índios Wind Park from January 2007 to December 2009.

We trained a team to search for bat carcasses using a standardized method, modified from Johnson et al. (2003). We marked a polygon of 1 ha (100 × 100 m) around each turbine. Two observers simultaneously walked this area, so that each covered half of it (5000 m^2). We altered this search protocol occasionally in some turbines during the land preparation and/or flood periods for planting rice. In these cases, we searched on the area of construction pads and access roads connecting the wind turbines, which corresponded to approximately 25% of the regular search area ($\cong$ 2500 m^2). This reduction in the search area accounted for 11% of the monitoring effort, and occurred in most spring and summer months, making it impossible to check for seasonal patterns in mortality.

We checked the 75 turbines every four weeks (27.9 ± 1.7 days), during the three-year monitoring in the wind parks Osório and Índios, and during the first year of monitoring in the Sangradouro Wind Park. In the second and third years of operation of the Sangradouro Wind Park, we selected six of the 25 turbines and started monitoring them weekly (7.0 ± 1.3 days). The time taken to search for carcasses varied for each turbine, due to differences in vegetation type and visibility condition. During typical search periods, the average time was

24.3 ± 4.2 min per turbine, whereas during the periods of rice plantation, the average search time was 10.5 ± 1.2 min per turbine.

For each bat located, we recorded the following data: date, park, turbine number, species, and sex. During walks in the study area, the team was attentive to carcasses in the areas surrounding the turbines; these carcasses were also collected and considered in the present study.

Results

Mist-netting and searches for colonies

We captured bats by mist-netting in 40% of the sampling nights, and at nine of the 17 sampling sites. A total of 38 bats of 10 species were captured, 22 at the OWF area (0.1–4 km from turbines), and 16 in the vicinities of this wind farm (4–20 km from turbines) (Table 1). In addition, two bats of two extra species were recorded by direct observation, i.e. by visual observation of an individual in flight at the OWF, and by location of a carcass in the Osório urban area (Table 1). We also found 24 bat roosts, 15 at the OWF area (0.1–4 km from turbines), and nine in the OWF surroundings (4–20 km from turbines) (Table 2). In these roosts, 251 bats of four species were recorded; 221 bats were captured using mist nets at the roost entrance, and 30 were counted inside the roosts. Of the 24 roosts, 54% (n = 13) were occupied by a single species, 33% (n = 8) were cohabited by two species, and 13% (n = 3) were cohabited by three species.

Considering all records (Tables 1, 2), we found 13 bat species of the families Phyllostomidae, Noctilionidae, Molossidae, and Vespertilionidae in the OWF region. *Molossus molossus* was the most frequently recorded species; it was mist-netted in three different habitats and located in 17 day roosts, 11 of them situated from 0.1 to 3 km from the wind turbines. In addition, *M. molossus* accounted for 72% (n = 160) of the total number of bats captured by mist-netting at roost entrance. The species *Molossus rufus, Eptesicus brasiliensis* and *Glossophaga soricina* were also relatively common; they were recorded, respectively, in nine (day roosts), eight (one habitat and seven roosts), and seven (two habitats and five roosts) different sites in the OWF region. The remaining species were recorded in a smaller number (from one to three) of habitats and/or roosts in the OWF region.

Table 1. Number of individuals per bat species recorded at different habitat types, by mist-netting and occasionally by direct observation, in the Osório Wind Farm region, southern Brazil, from June 2004 to March 2010.

Species	Site	Habitat type	Distance from closest turbine (km)	Record type	Number of individuals
Phyllostomidae					
Artibeus fimbriatus	1	Atlantic Forest	4.4	Mist-netting	2
Artibeus lituratus	1	Atlantic Forest	4.4	Mist-netting	2
Glossophaga soricina	1	Atlantic Forest	4.4	Mist-netting	3
	2	*Eucalyptus* stand	0.6	Mist-netting	1
Sturnira lilium	1	Atlantic Forest	4.4	Mist-netting	1
	3	Fragment of native vegetation	0.7	Mist-netting	3
	4	Atlantic Forest	6.6	Mist-netting	1
Noctilionidae					
Noctilio leporinus	2	*Eucalyptus* stand	0.6	Observation in flight	1
Molossidae					
Molossus molossus	5	Fragment of native vegetation	0.3	Mist-netting	3
	6	Grassland with sparse trees	0.7	Mist-netting	3
	7	*Restinga* forest	20.3	Mist-netting	4
Tadarida brasiliensis	8	Urban area of Osório city	4.5	Carcass location	1
Vespertilionidae					
Eptesicus brasiliensis	9	Area with houses and arboreal vegetation	0.8	Mist-netting	1
Eptesicus diminutus	6	Grassland with sparse trees	0.7	Mist-netting	2
	9	Area with houses and arboreal vegetation	0.8	Mist-netting	8
Lasiurus blossevillii	10	*Eucalyptus* stand	0.4	Mist-netting	1
Lasiurus ega	7	*Restinga* forest	20.3	Mist-netting	1
Myotis nigricans	1	Atlantic Forest	4.4	Mist-netting	1
	7	*Restinga* forest	20.3	Mist-netting	1
Total					40

Table 2. Number of individuals per bat species recorded at different roost types, by mist-netting at roost entrance and occasionally by direct observation, in the Osório Wind Farm region, southern Brazil, from April 2004 to February 2010.

Species	Roost number	Roost type	Distance from closest turbine (km)	Record type	Number of individuals
Phyllostomidae					
Glossophaga soricina	1	Wooden hut	0.6	Counting of bats inside the roost	8
	2	Uninhabited house	0.6	Counting of bats inside the roost	4
	3	Uninhabited house	10.8	Counting of bats inside the roost	3
	4	Uninhabited house	12.9	Counting of bats inside the roost	10
	5	Uninhabited house	13.9	Counting of bats inside the roost	5
Molossidae					
Molossus molossus	6	Cavity in *Ficus cestrifolia*	0.1	Mist-netting at roost entrance	3
	7	Cavity in *Ficus cestrifolia*	0.6	Mist-netting at roost entrance	41
	8	Cavity in *Ficus cestrifolia*	0.6	Mist-netting at roost entrance	26
	9	Cavity in *Ficus cestrifolia*	0.6	Mist-netting at roost entrance	11
	10	Cavity in *Casearia sylvestris*	0.6	Mist-netting at roost entrance	3
	11	Cavity in *Ficus cestrifolia*	0.7	Mist-netting at roost entrance	10
	12	Cavity in *Ficus cestrifolia*	0.7	Mist-netting at roost entrance	12
	13	Cavity in *Myrsine umbellata*	0.7	Mist-netting at roost entrance	6
	14	Cavity in *Eucalyptus* sp.	0.7	Mist-netting at roost entrance	2
	15	Cavity in *Ficus cestrifolia*	1.3	Mist-netting at roost entrance	8
	16	Wooden attic	3.0	Mist-netting at roost entrance	3
	17	Wooden attic	4.7	Mist-netting at roost entrance	2
	18	Attic of a brick house	6.9	Mist-netting at roost entrance	9
	19	Attic of a brick house	8.0	Mist-netting at roost entrance	9
	20	Cavity in *Coussapoa microcarpa*	15.6	Mist-netting at roost entrance	7
	21	Wooden attic	16.8	Mist-netting at roost entrance	1
	22	Cavity in *Ficus cestrifolia*	20.3	Mist-netting at roost entrance	7
Molossus rufus	6	Cavity in *Ficus cestrifolia*	0.1	Mist-netting at roost entrance	1
	7	Cavity in *Ficus cestrifolia*	0.6	Mist-netting at roost entrance	1
	8	Cavity in *Ficus cestrifolia*	0.6	Mist-netting at roost entrance	3
	9	Cavity in *Ficus cestrifolia*	0.6	Mist-netting at roost entrance	1
	14	Cavity in *Eucalyptus* sp.	0.7	Mist-netting at roost entrance	1
	18	Attic of a brick house	6.9	Mist-netting at roost entrance	2
	19	Attic of a brick house	8.9	Mist-netting at roost entrance	3
	20	Cavity in *Coussapoa microcarpa*	15.6	Mist-netting at roost entrance	1
	23	Cavity in *Ficus cestrifolia*	0.3	Mist-netting at roost entrance	2
Vespertilionidae					
Eptesicus brasiliensis	7	Cavity in *Ficus cestrifolia*	0.6	Mist-netting at roost entrance	1
	8	Cavity in *Ficus cestrifolia*	0.6	Mist-netting at roost entrance	9
	10	Cavity in *Casearia sylvestris*	0.6	Mist-netting at roost entrance	11
	12	Cavity in *Ficus cestrifolia*	0.7	Mist-netting at roost entrance	11
	14	Cavity in *Eucalyptus* sp.	0.7	Mist-netting at roost entrance	1
	21	Wooden attic	16.8	Mist-netting at roost entrance	6
	24	Cavity in *Erythrina crista-galli*	0.7	Mist-netting at roost entrance	7
Total					251

Bat fatalities

We found 336 bats (329 carcasses + seven live individuals), 80% regularly within the search perimeter and 20% occasionally at intervals between monitoring. Most carcasses were complete (92%), but fragments of bats were also found (8%). About half of the carcasses (51%) were found fresh, indicating recent death, 24% were relatively deteriorated, and 25% were in advanced state of decomposition. It was possible to identify 96% of the carcasses to species.

The carcasses belonged to nine species of the families Molossidae, Vespertilionidae, and Phyllostomidae (Table 3). *Tadarida brasiliensis* accounted for the largest number of fatalities (73%), followed by *Lasiurus cinereus* (13%). The number of

Table 3. Number of fatalities per bat species recorded at Osório Wind Farm, southern Brazil, from July 2006 to December 2009.

Species	Males	Females	Unknown sex	Total	%
Phyllostomidae					
Artibeus lituratus	—	1	—	1	0.3
Molossidae					
Molossus molossus	4	4	1	9	2.7
Molossus rufus	—	—	1	1	0.3
Nyctinomops laticaudatus	4	8	—	12	3.6
Promops nasutus	1	—	2	3	0.9
Tadarida brasiliensis	85	86	74	245	72.9
Unidentified Molossidae*	1	—	5	6	1.8
Vespertilionidae					
Lasiurus blossevillii	1	3	2	6	1.8
Lasiurus cinereus	12	17	15	44	13.1
Lasiurus ega	1	1	1	3	0.9
Unidentified Chiroptera*	—	—	6	6	1.8
Total	109	120	107	336	100

Note: *Carcasses that were too deteriorated to determine species and/or family.

fatalities of the remaining species was considerably smaller (from 0.3% to 3.6%). Considering the most frequent species, the number of individuals of each sex was relatively similar with a small bias towards females. However, due to the decomposition state of most carcasses, the number of individuals of undetermined sex was as large as the number of males and females for each species.

We found seven live individuals during the search for carcasses: five *T. brasiliensis* (three males, one female and one individual with undetermined sex that escaped during the capture attempt), one *N. laticaudatus* (female), and one *L. cinereus* (female). Six of these individuals were found in the Sangradouro Wind Park, and one in the Osório Wind Park. None of these bats presented signs of external injury, suggesting that they had not been injured by the turbines' blades. Two of them, one *L. cinereus* and one *T. brasiliensis*, were in good enough condition to fly and so were released, whereas the remaining individuals were collected for further analysis.

Discussion

The number of species killed by wind turbines at the OWF corresponds to 5% of the total number of species known to occur in Brazil (Nogueira et al. 2014), and to 23% of the total number of species in the state of Rio Grande do Sul (Passos et al. 2010). These proportions are low in comparison to wind facilities in North America. In the USA and Canada, 11 (24%) of the 45 bat species have been found killed at wind farms (Johnson 2005). The number of bat species killed ranged from two to seven per facility, and accounted for 13–86% of the number of species that occur in each state or province (Arnett et al. 2008). The lower proportion at the OWF is primarily related to the high bat richness in Brazil and Rio Grande do Sul, where 178 and 40 species, respectively, occur (Passos et al. 2010; Nogueira et al. 2014). Considering only the 16 bat species recorded in the Osório region (present study), 56% were killed by wind turbines at OWF.

The general mortality patterns observed at the OWF in southern Brazil have many similarities with those from wind facilities in the Northern Hemisphere. Among these similarities we point out: (1) uneven distribution of the number of fatalities between species in the mortality sample; (2) dominance of migratory species, including foliage/tree-roosting bats; and (3) selective mortality, i.e. difference between the presence and abundance of bat species in the wind farm area and in the fatality sample (Johnson et al. 2004; Arnett et al. 2008; Amorim et al. 2012; Camina 2012).

Tadarida brasiliensis, L. cinereus, and *L. blossevillii* had already been recorded as killed by wind turbines (Arnett et al. 2008). As at OWF, mortality of *T. brasiliensis* at wind turbines is high in some regions of North America (Arnett et al. 2008). In mid-southern USA, where this species accounted for 85% of the total fatalities, the high mortality was attributed to the proximity (≅ 15 km) of the wind farm to numerous colonies (Piorkowski & O'Connell 2010). At the OWF, the high proportion of fatalities is probably related to high levels of *T. brasiliensis* activity in the area, as this species is very abundant in urban areas in southern Brazil (Pacheco et al. 2010), and there are colonies relatively close (≅ 3.5 km) to the wind farm, in Osório city (M.A.S. Barros, pers. obs.). It is likely that individuals from colonies at Osório use the wind farm as a foraging zone, flight route, or both, due to vegetation and flooded areas that may concentrate insects, as well as landscape elements that can help bats navigate, such as the mount Morro da Borússia (to the north) and the lagoon Lagoa dos Barros (to the west). There is also the possibility that the area of the OWF coincides with a *T. brasiliensis* migratory route. *Tadarida brasiliensis* makes seasonal movements in North America (Wilkins 1989) and probably also in southern Brazil, since in late autumn and winter the roosts are empty or show only a reduced number of animals (Fabián & Marques 1996).

The relatively low number of dead *L. cinereus* found at the OWF is in contrast to North America, where this species made up to 88% of all fatalities in the Rocky Mountains (Arnett et al. 2008). The high mortality of *L. cinereus* at wind facilities is probably related to the migratory and reproductive behavior of this species. Tree-roosting bats are likely attracted to wind turbines in search of resources (e.g. roosts, mating partners, and/or insect prey) that they expect to find in tall trees along autumn migratory routes (Cryan 2008; Cryan et al. 2012, 2014). Seasonal movements and mating behavior of *L. cinereus* are unknown in South America, but it is considered a migratory and summer resident species in Rio Grande do Sul, which is supported by anecdotal evidence (Silva 1984, 1985). In southern Brazil and Argentina, reproductively active individuals were found in November (Barquez et al. 1999; Bianconi & Pedro 2007). In addition, specimens of *L. cinereus* in scientific collections in Rio Grande do Sul date from December, January, and February (M.A.S. Barros, pers. obs.), which suggests that this species is mainly present in the state in summer.

Like the former two species, *L. blossevillii* is considered migratory (Cryan 2003), but fatalities were rare at OWF. This finding is similar to that observed at a wind farm in northwestern USA, where the species accounted for only 4% of all fatalities (Arnett et al. 2008). However, the magnitude of the impact on this species cannot be inferred since the population size is unknown. *Lasiurus borealis*, a closely related species, makes up a large proportion of bat fatalities in North America (Arnett et al. 2008), possibly because it tends to be more abundant throughout the eastern part of this continent than *L. blossevillii* is in the western part (Pierson et al. 2006). *Lasiurus blossevillii* was uncommon in mist-netting surveys at the OWF area, and other regions in southern Brazil (e.g. Ortêncio-Filho & Reis 2009; Bernardi et al. 2009; M.A.S. Barros, pers. obs.), but we do not know whether *L. blossevillii* – as well as *L. cinereus* and *L. ega* – are really rare or just underestimated by mist-netting, because lasiurines usually fly high above the ground (LaVal et al. 1977; Kurta & Lehr 1995; Peurach 2003).

In spite of its abundance in the OWF area where it occupied several roosts near the wind turbines, less than 3% of the fatalities belonged to *M. molossus.* Although it is considered an aerial insectivorous species that forages in uncluttered habitats (Kalko et al. 1996), *M. molossus* can be captured with similar frequency both at ground level and in elevated mist nets, from 7 to 38 m high (Simmons & Voss 1998). This species forages near watercourses and ponds (Eisenberg & Redford 1999), and it was often captured at 2.5 m high above streams in southeastern Brazil (Costa et al. 2011). Thus, it is possible that *M. molossus* forages, at least partially, at lower heights than that of the turbine blades, reducing the mortality risk. Selective mortality, i.e. lack of direct relationship between the abundance of bat species and occurrence of fatalities at a wind farm, was also reported from facilities in North America (Johnson et al. 2004) and Europe (Georgiakakis et al. 2012), and suggests that the probability of mortality of a species is determined primarily by behavior and only secondarily by abundance.

Nyctinomops laticaudatus, M. molossus, P. nasutus, M. rufus, L. ega, and *A. lituratus* are new records of bat species killed by wind turbines, and *A. lituratus* is the first record of collision for a phyllostomid bat. *Lasiurus ega* occurs from southern USA to Brazil and Argentina; *N. laticaudatus, M. molossus, M. rufus*, and *A. lituratus* occur from Mexico to Brazil and Argentina; and *P. nasutus* is endemic of South America (Simmons 2005). None of these species is considered migratory, except *L. ega*, which possibly migrates in both North and South America, although some individuals are present year-round even on their northern limit of range (Kurta & Lehr 1995; Esbérard & Moreira 2006; Bianconi & Pedro 2007). While *L. ega* roosts mainly in foliage, especially of palm trees, *N. laticaudatus, M. molossus, M. rufus*, and *P. nasutus* usually roost in buildings, hollow trees, cracks, and caves (Barquez et al. 1999; Reis et al. 2007). The behavior of these species is poorly known in Brazil, but bats from the genera *Lasiurus, Molossus, Promops*, and *Nyctinomops* are considered aerial insectivores that hunt in open spaces high above the ground or in the canopy (Schnitzler & Kalko 2001; Jung et al. 2014), which would make them more susceptible to collisions.

Artibeus lituratus is a primarily frugivorous bat that forages in highly cluttered spaces, very close to or within vegetation (Kalko et al. 1996). Moreover, *A. lituratus* is abundant in forests of the region, and it is easily captured with mist nets (Rui & Fabián 1997), so the lack of captures within the wind farm suggests low use of the area by this species. However, the wind turbine where the *A. lituratus* specimen was killed (at Índios wind park) is surrounded by pasture areas without forest fragments or trees. So, the collision of the specimen may have occurred during commuting between roosts and foraging areas, as *A. lituratus* is highly mobile (Menezes Jr. et al. 2008).

Eptesicus brasiliensis, E. diminutus, M. nigricans, N. leporinus, G. soricina, S. lilium, and *A. fimbriatus* have never been found dead around wind turbines. Fruit-eating (like *S. lilium* and *A. fimbriatus*), nectar-feeding (like *G. soricina*), and fishing bats (like *N.*

leporinus) usually forage in edge or narrow spaces, flying at low height above the ground, vegetation, or water (Denzinger & Schnitzler 2013), which reduced their probability of being killed by wind turbines in southern Brazil. In North America and Europe, mortality of *Myotis* and *Eptesicus* spp. at wind turbines may be high in some regions (Arnett et al. 2008; Jain et al. 2011), but tends to be uncommon at most facilities (Piorkowski & O'Connell 2010; Rydell et al. 2010; Georgiakakis et al. 2012). Low mortality at wind turbines can be also attributed to their behavior, since these bats typically forage in background-cluttered space such as forest edges and gaps (Schnitzler & Kalko 2001).

The fast expansion of wind power in Brazil and other regions of Latin America may lead to cumulative regional impacts on bats, whose population sizes and trends are still unknown. Further studies on natural history and fatality patterns at wind turbines should contribute to understanding and estimating the impact of wind facilities on bats in the Neotropical region.

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