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Green remnants are hotspots for bat activity in a large Brazilian urban area

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Abstract Urbanization tends to remove or isolate green areas into fragments or restrict them to narrow corridors inserted in a matrix of buildings. Nevertheless, urban green areas may act as refuges for fauna and bats are among the animals able to use such habitats. Using bioacoustics we investigated the influence of green areas on the activity of insectivorous bats in the metropolitan area of Recife, a conurbation of 4 million people in the Atlantic forest of Northeastern Brazil. Bat activity was statistically higher in green areas, based on calls ($t=2.5298$, $p=0.0165$), but not on *feeding buzzes* ($t=1.8132$, $p=0.0817$) or social calls ($t=-1.5551$, $p=0.1329$). Several species were able to persist in an urban matrix and calls were classified into 16 sonotypes, belonging to five families (Emballonuridae, Molossidae, Noctilionidae, Phyllostomidae and Vespertilionidae). However, activity was significantly more associated with areas with vegetation, indicating that green remnants are hotspots for bat activity. Our results indicate that most insectivorous bats have a biased use of the urban landscape and the maintenance of urban green areas is essential to preserve them and the environmental services they provide.

Keywords Activity · Bioacoustics · Chiroptera · Echolocation · Urban fauna

Introduction

Urbanization tends to transform habitats in an extreme way, with the conversion of natural landscapes into environments dominated by human constructions (Mckinney 2006). The

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traditional urban development tends to remove or isolate the existing green areas in fragments immersed in a matrix of buildings, or restrict those areas to narrow corridors (Baschak and Brown 1995). The situation is more problematic in developing countries, where the urbanization process has often little or no planning, with the maintenance of few or no green areas in urban centers (Pickett et al. 2001). The ecological requirements necessary to maintain the wildlife that may remain in urban environments are frequently not taken into consideration. When existing, urban planning usually ignore ecological issues such as minimum sizes for green remnants, the connectivity among them, or the mitigation of the deleterious effects of the surrounding urban matrix (McKinney 2002). As a result, urban green areas usually are small, isolated and distant from each other forming almost green islands within the urban matrix.

Nevertheless, urban environments can still retain a diverse fauna, with some green areas acting as the only refuge options for animals that manage to persist in urban environments (Pickett et al. 2001; Goddard et al. 2008). Bats are among the animals able to use urban areas and they are an important and frequently ignored component of the fauna associated with urban environments (Evelyn et al. 2004; Hourigan et al. 2010; Ethier and Fahrig 2011; Russo and Ancillotto 2015). In urban areas, bats provide environmental services such as the control of insect populations, pollination and dispersal of remaining plant species, including fruit trees or those used in urban landscaping (Federico et al. 2008; Uieda et al. 2008; Kunz et al. 2011).

Free-tailed bats (Molossidae) and evening bats (Vespertilionidae) are known to persist in urban environments (Lee and McCracken 2002), however, studies on urban bat communities often show a reduction in the abundance and diversity of species, including the disappearance of rare or less tolerant species, or changes in the bats' ecology (Geggie and Fenton 1985; Kurta and Teramino 1992; Gaisler et al. 1998; Ávila-Flores and Fenton 2005; Hourigan et al. 2006; Loeb et al. 2009; Hale et al. 2012; Luck et al. 2013). Flight gives bats the potential to cross matrices which could be unfavorable for other animals. Some species have a high mobility and may tolerate certain degrees of habitat alteration better than other mammals (Bernard and Fenton 2007; Jung and Kalko 2010, 2011; Basham et al. 2011; Dixon 2012). Such characteristics may give bats a role as maintainers of ecological processes in urban landscapes and for these reasons bats are an ideal group for investigating the effects of urbanization on wildlife (see Russo and Ancillotto 2015).

The conservation of urban green areas and their wildlife is receiving more attention from city inhabitants, which are demanding their preservation and, in some cases, the recovery and expansion of urban green spaces. The study of urban ecology grows in importance due to the fact that most of the human population now lives in cities, and there is growing evidence that urban green areas and their wildlife can provide ecological services for this population (Niemela 1999; Pickett et al. 2001). Here, using bioacoustics, we addressed the influence of green areas on the activity of insectivorous bats in the metropolitan area of Recife, a conurbation of 4 million people in the Atlantic forest of Northeastern Brazil. Recife is a typical Third World megalopolis: Located in a center of high biological diversity, its current configuration is the result of decades of intense population growth, which has not been accompanied by the necessary urban planning. As a result, the city area is an intense urbanized matrix, with a high human density, but suffering from a severe lack of green areas. Therefore, results here presented are very likely to reflect the reality for most of the major cities in Latin America, Asia and Africa.

The expansion of the knowledge about bats in urban areas, the environmental services they provide, and the role they may have in maintaining ecological processes in urban matrices is identified as a research priority not just in Brazil (Pacheco et al. 2010; Bernard et al. 2012) but elsewhere (Russo and Ancillotto 2015). Previous knowledge on the bat fauna of Recife is almost inexistent, but due to eco-morphological differences among aerial insectivorous bats (Marinello and Bernard 2014), we hypothesized taxa-specific habitat use patterns, with rapid flyers aerial insectivores –like molossidae- being less affected by urbanization and more prone to adapt towards urban environments. Conversely, species more specialized on feeding on insects in highly cluttered habitats – like emballonurids or some vespertilionids- will be negatively affected by urbanization, being more active in or restricted to green urban remnants.

Methods

Sampling sites

The Metropolitan Area of Recife (hereafter MAR - 8°04′03″S, 34°55′00″W), in Pernambuco state, Northeastern Brazil, comprises 14 municipalities (ca. 2,800 km^2), with a population of nearly 4 million inhabitants and a per capita income of US$ 6,805.77 (IBGE 2010). The MAR has one of the highest demographic densities in Brazil (1,342.88 inhabitants/km^2) and the average human development index is 0.680, varying from 0.772 to 0.592 among its 14 municipalities. Although the first local settlements were established in 1535, the MAR is characterized by poor urbanization planning and a shortage of green areas. The municipality of Recife alone (218.5 km^2) has an estimated 55,8 km^2 of green remnants, and 75 of its 94 neighborhoods have less than 40 % of green cover, usually concentrated in a few sites (Oliveira et al. 2013). We used satellite images in *Google Earth* (www.google.com.br/intl/pt-BR/earth/) to select five sampling sites in the MAR. Each site consisted of a green area (from 15,239 m^2 to 139,457 m^2) and an adjacent non-green paired area, at least 200 m apart (Fig. S1), and were sampled five times. Sites were selected based on a combination of accessibility, contrast with the surrounding matrix and safety for night sampling. Considering that a few sites were qualified, we did not control for other variables, like urban matrix density, distance to water, or illumination, for example.

Recordings

Insectivorous bats use echolocation calls to search, detect and chase flying insects and some have species-specific calls (Schnitzler and Kalko 2001). When a prey is detected, bats alter their normal echolocation signals increasing the signal output and reducing the duration and the time interval between them. These calls are then called feeding buzzes and characterize a feeding attempt by the bats. Feeding buzzes are very different from search calls and can be easily recognized, allowing their unequivocal identification (See Fig. S2). Bats may also use social calls for communication between individuals from the same social group or co-specifics. Social calls generally have lower frequencies and are also very different from search calls and feeding buzzes. Therefore, any experienced observer is able to recognize those three types of calls. We used normal echolocation calls, feeding buzzes and social calls as proxies of bat activity (Jung and Kalko 2010; Basham et al. 2011). For the purposes of this study, the identification of the species responsible for each signal was not an essential condition and, therefore, we have identified calls at family level only.

All recordings were made during the dark phase of the moon (between the 1st day of the waning moon to the 1st day of the crescent), from September 13th 2012 to January 6th 2013. We set a scheme of 3 min recording/12 min interval, between 17:15 and 19:30 h. In general, our recordings covered the period with the highest bat activity, which coincides with the 2-h interval after sunset (17:14 h in September, and 17:46 h in January). We used two Songmeter SM2BAT (www.wildlifeacoustics.com) recording simultaneously, one inside the green area, close to its central part, and the other in the paired site, at least 200 m apart (Fig. S1). To avoid noise interference, in the green areas we avoided setting microphones near sidewalks or any other places with heavy traffic. Recorders were set at a sample rate of 192 kHz (able to record calls up to 96 kHz), cutoff frequency of 1 kHz, gain of 36 dB, and filter preventing recordings bellow 12 kHz and 12 dB.

Analysis

Files were recorded originally in the proprietary format *Wildlife Acoustics Audio Compression* (wac), with low compression rate (wac0), and later converted to wav format using the software WAC2WAV (www.wildlifeacoustics.com). Files were then imported into the software CallViewer18, a custom made program developed by Mark Skowronski, and analyzed with division rate 16, Fast Fourrier Transformation (FFT) 256, in Blackman windows. Using CallViewer18's Auto Detection function, we extracted five variables for each call detected in a file: call duration (D, in milliseconds), minimum frequency (Fmin, in kHz), frequency with maximum energy (FME, in kHz), maximum frequency (Fmax, in kHz), and call intensity (E, in dB). We set a minimum interval of six frames between calls, minimum energy of 20 dB, and used a filter of 17 dB to avoid echoes and the interference of external noise. The number of calls in each file was obtained using CallViewer's Quick Summary function. We separated search calls from feeding buzzes and social calls based on their shape and characteristics.

Classification of calls and statistical analysis

Search calls were classified into sonotypes and families, based on their shape and on the variables D, Fmin, FME, Fmax, and E, and by comparing them with data from the literature (Farias 2012, and references therein). In order to verify our classification, we performed a discriminant function analysis using the five variables extracted from search calls as predictive variables. We used a *t-student* test to compare the activity in and outside the green remnants, based on normal echolocation calls, feeding buzzes and social calls. We used a Chi-square residual test to check possible associations between families and sites (in×outside green remnants). All analyses were performed using the software BioEstat 5.0 (Ayres et al. 2007).

Results

We analyzed 500 files and 1,500 min of recordings. Twenty-four empty files were excluded from our analysis. A total of 145,087 calls, 517 feeding buzzes and 67 social calls were recorded inside green remnants, and 59,987 calls, 105 feeding buzzes and two social calls outside them. We identified 16 sonotypes and based on comparisons with the literature we assigned them to the families Emballonuridae (sonotypes 1 to 3), Phyllostomidae (sonotypes 4 to 7), Vespertilionidae (sonotypes 8 to 13), Noctilionidae (sonotypes 14 and 15) and Molossidae (sonotype 16) (Table S1). The discriminant function analysis confirmed the 16 sonotypes we identified were different from each other, validating our classification and the use of the sonotypes as a proxy for taxon identification.

Green remnants had a higher richness of sonotypes (Table 1) and higher activity based on the number of echolocation calls (t=2.5298; p=0.0165), but not on feeding buzzes (t=1.8132; p=0.0817), nor on social calls (t=−1.5551; p=0.1329). Signals of vespertilionid species were recorded in 46 % of the files from green remnants; emballonurids in 39 %; phyllostomids in 29 %; molossids in 4 %, and noctilionids in just 0.8 % (Fig. 1). In non-green areas vespertilionids were recorded in 8 %, emballonurids in 24 %, phyllostomids in 26 %, molossids in 11 %, and noctilionidsin 0.4 %. The Chi-square residual test indicated that Vespertilionidae and Molossidae showed the highest difference among habitats, with the former family more associated with green remnants and the later more associated with non-green areas (r=6.2734, and r=4.7090, respectively).

Discussion

Using an analysis of echolocation calls, we identified that at least 16 bat species belonging to five families use the metropolitan area of Recife, a 4 million people conurbation in Northeastern Brazil. Although we had a small sample size (five paired sites sampled five

Table 1 Presence of bat families and sonotypes recorded in 25 nights in and outside green urban remnants in the Metropolitan Area of Recife, Northeastern Brazil, between September 2012 and January 2013

Families and sonotypes	Green remnants (n=250 files)	Outside (n=250 files)
Emballonuridae		
Sonotype 1	45	23
Sonotype 2	51	38
Sonotype 3	2	0
Phyllostomidae		
Sonotype 4	44	50
Sonotype 5	6	4
Sonotype 6	1	0
Sonotype 7	22	12
Vespertilionidae		
Sonotype 8	94	20
Sonotype 9	2	0
Sonotype 10	1	0
Sonotype 11	1	0
Sonotype 12	15	0
Sonotype 13	1	0
Noctilionidae		
Sonotype 14	1	1
Sonotype 15	1	0
Molossidae		
Sonotype 16	10	27
Total	297	175

Some files contained more than one sonotype

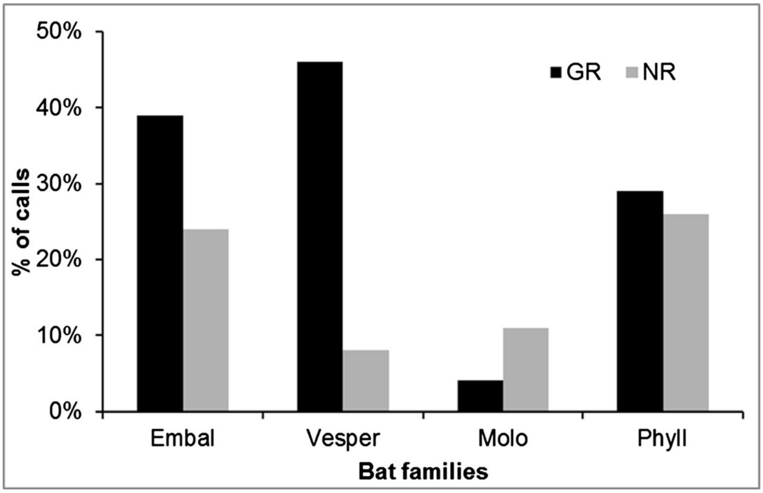

Fig. 1 Activity of different bat families in green urban remnants (GR) and outside them (NR) in the Metropolitan Area of Recife, Northeastern Brazil, based on echolocation calls recorded in 25 nights between September 2012 and January 2013. *Embal* Emballonuridae, *Vesper* Vespertilionidae, *Molo* Molossidae; *Phyll* Phyllostomidae. Noctilionidae accounted for < 1 % and was not shown

times each), our analysis was based on more than 205,000 calls recorded, and such high number of calls allowed us to unequivocally detect that bats showed a heterogeneous use of the urban matrix, with green remnants being hotspots of bat species richness and activity.

Brazil has a rich bat fauna, with nearly 180 species but, in general, the knowledge of Brazilian bats remains scarce and heterogeneous (Bernard et al. 2012). The knowledge on urban bats is even more limited and the available information is usually restricted to sporadic records of individuals, usually collected by health and/or agriculture institutions. Although the bat fauna tend to be simplified with the urbanization process, several species can persist in these environments (Luck et al. 2013). There are records of at least 47 bat species from five families in urban and peri-urban Brazil (Pacheco et al. 2010). Here we recorded at least 16 species using green remnants and surroundings in Recife. Using acoustic monitoring to investigate the habitat use in a tropical forest-town interface in Panamá, Jung and Kalko (2010) recorded a total of 25 aerial insectivorous bat species in the study area and found a subset of 20 species in town of which 18 frequently foraged around streetlights. Similarly to our results, they suggest that aerial insectivorous bats have a high potential to adapt to anthropogenically altered environments, but the tolerance level to disturbance is species-specific depending on light type, distance to vegetation, and relative light intensity. In our study, the families Emballonuridae, Phyllostomidae and Vespertilionidae contributed most with the activity in and outside green urban remnants. Vespertilionidae was primarily associated with the remnants, while Molossidae were more active outside those areas.

The observation that some species may cope with urbanization while other species seems less tolerant has led some authors to propose that species may be classified as “urban adapters” and “urban avoiders” (Jung and Kalko 2010; Hale et al. 2012). In a tropical forest–town interface in Panamá, five out of 25 species recorded were exclusively present at the forest sites (Jung and Kalko 2010, 2011). In Australia, radio-tracked *Nyctophilus gouldi* used bushland in an almost obligate manner, with little to no use of urban areas (Threlfall et al. 2013). Molossids, on the other way, are able to adapt more easily to urban matrices probably because they are favored by the availability of roosts in buildings, house roofs, bridges or other urban structures (Ávila-Flores and Fenton 2005). Members of this family can fly at higher altitudes and longer distances (Griffin and Thompson 1986) crossing distinct habitats in an urban matrix easily. In Sydney, Australia, studies found a relationship between the morphological characteristics of the species and the type of habitat they used; fast-flying species with low frequency echolocation calls –like molossids- may be favored by urbanization, while slow-flying, high-frequency species –like vespertilionids- seem to prefer patches of vegetation (Threlfall et al. 2011).

Bats can be selective about the environment they use, and some species make their choices based on favorable characteristics, like shelter availability, food and water supply and feeding opportunities (Threlfall et al. 2011, 2012; Hanspach et al. 2012; Russo and Ancillotto 2015). Areas with a higher density of trees and water bodies tend to be wetter, attracting more insects (Glendell and Vaughan 2002; Gehrt and Chelsvig 2003). Studies in islands of vegetation in an urban matrix of Montreal, Canada, indicate that the distribution pattern and activity varies with bat species, some more selective than others. Vespertilionids of the genus *Myotis* were recorded more often in sites with greater tree density and presence of watercourses, whereas species of the genera *Lasiurus* and *Eptesicus* were less selective, and showed a more uniform distribution in the urban landscape (Fabianek et al. 2011). In our study, although we did not detect a difference in habitat use based on feeding buzzes or social calls, we observed that bat activity inside green areas was nearly 2.4 times greater than outside.

The presence of artificial illumination provided by street lights, which may attract a large quantity of insects in specific sites, may be a positive factor for urban bats (Jong and Ahlén 1991; Gaisler et al. 1998). In Mexico City, one of the largest conurbations in the world, f*eeding buzzes* were more frequent in large paks and more illuminated areas due to a higher presence of insects when compared with residential areas (Ávila-Flores and Fenton 2005). The drivers determining why and how a species will persist in an urban landscape remains elusive, but ecological and behavioral plasticity is certainly important for succeeding in urban environments (Russo and Ancilloto 2015). Considering that bats are pointed out as good indicator species (Jones et al. 2009; Russo and Jones 2015), investigating their response to urbanization in other large cities in Latin American, Asia and Africa could provide new insights on how different families and species respond to the conversion of their natural habitats into urban matrices, as well as its changes over time and different conditions.

Conserving urban green remnants and bats

Studies on the effects of urbanization on bats indicate the removal of the remaining vegetation is a major driver decreasing bat species richness in dense urban areas, as it reduces the number of species that can overcome these new spatial configurations (Gaisler et al. 1998; Hourigan et al. 2010). Green areas such as parks, *plazas* and gardens within the urban matrix serve as greenways and refuge for urban wildlife (Basham et al. 2011) and more interconnected habitats make the dispersion of species easier, increasing the chances for maintaining the richness and abundance of urban wildlife (Goddard et al. 2008; Magle et al. 2009). In Australia, the amount of bushland within 0.5–3 km surrounding a site and the tree density were the most common predictors of individual bat species presence, particularly rare species (Basham et al. 2011). Very fragmented and urbanized environments with large paved surfaces and little trees can compromise the maintenance of a richer bat fauna (Dixon 2012), and the protection and establishment of larger green patches interconnected within the urban matrix may assist to mitigate the effect urbanization in bat populations (Hale et al. 2012).

However, most of the cities in developing countries suffer from poor urban planning and lack of green areas. The Metropolitan Area of Recife, for example, has few and small urban green areas and in recent years there has been a loss of remaining green cover, leaving only 5,580 ha of forested areas (Oliveira et al. 2013). Due to the importance of green urban areas, not just for bats but for the overall fauna, maintaining and expanding the green cover in cities like Recife should be a priority. Bats can remove large quantities of insects per night (Clare et al. 2009; Boyles et al. 2011) and, therefore, may provide the service of pest controllers to urban residents. Study in New Hampshire, USA, showed that a single individual of the species *Myotis lucifugus* can eat approximately 4 to 8 g of insects per night (Anthony and Kunz 1977). Subsequently, a similar study also conducted in the USA indicated that a single colony of 150 *Eptesicus fuscus* can eat nearly 1.3 million insects/year including agricultural pests (Whitaker 1995). Estimating the value of the environmental services provided by bats is a priority for the conservation of bats in Brazil (Bernard et al. 2012) and making the environmental services bats may provide to urban residents more evident may contribute to their conservation. Further studies are needed to measure the impact that the removal of urban bats may have on these environments and on the overall quality of life of residents. In any case, our data suggest that urban green areas are necessary for the maintenance of the bat fauna in cities.

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