Importance of Green Areas for Insectivorous Bat Activity

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Abstract

The impact of urbanization might differ between insectivorous bats that forage in open space as opposed to edge space, with the latter usually persisting only in well preserved areas, such as parks and natural reserves. We investigated the influence of vegetation patches of different sizes on the activity of these two groups of insectivorous bat in the urban area of the Metropolitan region of Vitória, Espírito Santo State, Brazil. For this purpose, we monitored bat activity with an ultrasound detector for a total of two years in three habitats: large-green areas (> 30ha), small-green areas (< 5 ha) and non-green areas. Large-green areas showed the greatest bat activity followed by small-green areas and non-green areas. Although both groups of bats showed an increase in activity in the green areas compared to the non-green areas, this effect was higher for edge-space foragers than for open-space foragers in the large green-areas, whereas in the small green areas, the increment in activity did not differ between them. We also present a list of eight species we identified in the study area. Two of the species represent the first record for the region: *Promops centralis* and *Peropteryx trinitatis*. We conclude that in the Metropolitan Region of Vitória, even small parks are important for bat fauna conservation and, despite being more adapted to urban environments, even open-space foraging bats can benefit from them.

Introduction

The greatest alterations to ecosystems have occurred in landscapes where natural habitats have been completely removed and replaced by different land-uses. This process is particularly evident in urban areas (van der Ree and McCarthy 2005). Urbanization and urban expansion result in fragmentation where natural or seminatural habitats have been reduced to small and highly disturbed patches of vegetation distributed within a human-made matrix (Ávila-Flores and Fenton 2005). However, although urbanization has generally a negative impact on biodiversity, the response can be highly species-specific (Russo and Ancillotto 2015; Frick et al. 2019; McDonald et al. 2020). Some species may be able to navigate urban landscapes and exploit remaining, or constructed, habitat patches (McDonald-Madden et al. 2005).

The group of aerial insectivorous bats in particular includes highly mobile species some of which are able to cover large distances of many kilometers in a single night (Jung and Kalko 2011). Moreover, some bat species are tolerant of the urban environment and able to take advantage of the presence of man-made structures. For example, some bats use urban constructions as roost sites in replacement of natural roosts such as caves and hollow trees (Pacheco et al. 2010; Russo and Ancillotto 2015). Also, artificial light is considered favorable for some insectivorous bat species, since these animals are not inhibited by human light sources and actually prey on insects that are attracted by street lights (Gaisler et al. 1998; Ávila-Flores and Fenton 2005; Loeb et al. 2009; Jung and Kalko 2011; Lewanzik and Voigt 2017)).

Nonetheless, even though many species are able to explore urban settings, numerous studies reveal negative consequences of high levels of urbanization for insectivorous bats, which result in decreasing of richness and diversity of these animals (Gaisler et al. 1998; Ávila-Flores and Fenton 2005; Loeb et al. 2009; Basham et al. 2011). Bats roosting in cities may not find suitable foraging grounds near their

roosts and thus must travel longer distances to reach them. Although some species may successfully exploit urban roosting sites, their flexibility may not extend to foraging behavior (Russo and Ancillotto 2015).

Even though their importance might vary regionally (Jung and Threlfall 2018), the ability of aerial insectivorous bats to persist in urban areas is usually attributed to their echolocation and flight characteristics (Ávila-Flores and Fenton 2005; Duchamp and Swihart 2008; Jung and Kalko 2011; Russo and Ancillotto 2015). Fast-flying bats that emit long low-frequency narrowband calls, such as molossid bats (Norberg and Rayner 1987), are considered to be more capable of exploring urban environments (Jung and Kalko 2011; Krauel and LeBuhn 2016). These bats are adapted to forage in open spaces since they are able to detect distant targets and travel for long distances (Norberg and Rayner 1987; Schnitzler and Kalko 2001; Denzinger and Schnitzler 2013). Such abilities allow these bats to explore dispersed resources in an urban setting (Ávila-Flores and Fenton 2005; Duchamp and Swihart 2008; Jung and Kalko 2011). Conversely, bats that emit short high-frequency broadband calls, such as small vespertilionids and some emballonurids (Norberg and Rayner 1987; Schnitzler and Kalko 2001; Jung et al. 2007), rarely occur in urban environments or occur only in well-vegetated areas (Gaisler et al. 1998; Ávila-Flores and Fenton 2005; Rodríguez-Aguilar et al. 2017). These bats typically have a slow and maneuverable flight and short range of detection. These characteristics make these bats adapted to forage near edge spaces, such as forest edges, and above water surfaces (Norberg and Rayner 1987; Schnitzler and Kalko 2001; Denzinger and Schnitzler 2013), but apparently prevent them from exploring environments in which resources are dispersed, such as urbanized areas (Ávila-Flores and Fenton 2005; Duchamp and Swihart 2008).

One way to mitigate the negative effects of urbanization on biodiversity is the establishment and protection of green spaces within urban areas (Lepczyk et al. 2017). Several studies have demonstrated that urban parks and other green areas have an important role in the conservation of regional biodiversity (Fernandez-Juricic and Jokimäki 2001; Ferreira 2009; Loeb et al. 2009; Krauel and LeBuhn 2016; Mimet et al. 2020). Urban and suburban parks can have a high species richness (Cornelis and Hermy 2004) and can also serve as refuges for bats, including sensitive species (Loeb et al. 2009; Araujo and Bernard 2016), even though this effect might depend on the size of the vegetation patch (Ávila-Flores and Fenton 2005; Krauel and LeBuhn 2016; Tena et al. 2020).

The tropical rainforest biome, such as found along the Brazilian coast, is where some of the most rapidly expanding urban areas are located (McDonald et al. 2020). Extending along the Brazilian coast, the Atlantic Forest, one of the most critically endangered of the 36 global biodiversity hotspots, covers 15 out of the 27 states of Brazil and is home to more than 125 million Brazilians (Rezende et al. 2018). This domain houses the economic engine of Brazil, contributes to 70% of the gross domestic product (GDP) and is responsible for two thirds of the industrial economy, as well as having Brazil's most productive farm lands (Rezende et al. 2018). In the metropolitan region of Vitória, Espírito Santo state, Southeastern Brazil, urbanization occurred with the destruction of mangroves, beaches and the coastal vegetation, known as restingas, in areas along the coast and as the city expanded deforestation of Atlantic Forest further inland. What remains of these ecosystems is mostly restricted to urban parks or isolated green

areas within cities (Oprea et al. 2009). Oprea et al. (2009) demonstrated that urban parks favor higher richness, relative abundance and biodiversity of bats in the city of Vitória. The authors used mist nets to sample the bat fauna, which while sampling low flying phyllostomid bats is not an effective sampling method for aerial insectivorous bats (Kalko et al. 1996; Macswiney et al. 2008). Almeida et al. (2007), using a bat detector, found higher general and feeding activity of insectivorous bats in vegetated areas than in distant sites from preserved fragments of vegetation. However, the authors did not attempt to identify the species or to differentiate between open and edge-space foragers. Therefore, there is still little information about the impact of urbanization on insectivorous bats and the real role of the preserved green areas for conservation of these animals in the metropolitan region of Vitória.

The purpose of this study was to compare the levels of insectivorous bat activity recorded with an ultrasound detector in protected-green areas of different sizes and non-green areas located in the urban zones of three Municipalities of the metropolitan region of Vitória. We measured two kinds of activity: general activity and feeding activity. The general activity only indicates that the bats are flying by, whereas the feeding activity provides an estimation of attempts of bats to catch and eat insects. We predicted that general and feeding activity of bats foraging in open and edge spaces would be higher in more vegetated areas. However, since edge-space foragers are supposed to be more impacted by urbanization and dependent on surviving patches of native vegetation, we expect this green area effect to be larger for these bats. We also present a list of several species we identified in the recordings.

Material And Methods

Study area

We monitored insectivorous bat activity between October 2012 and March 2015 in the municipalities of Vitória, Vila Velha and Cariacica, which are located within the metropolitan region of Vitória (Espírito Santo state, Southeastern Brazil). These three cities together comprise an area of 586.03 km² and the sum of their population is estimated at 1,237,220 (IBGE 2017, <https://cidades.ibge.gov.br/>). The annual average temperature of the region is approximately 24° C (de Souza et al. 2013) and precipitation ranges from 1,351 to 1,400 mm (Incapar: <https://meteorologia.incapar.es.gov.br/>).

We compared bat activity among three habitats: large-green areas (urban parks or protected green areas larger than 30ha), small-green areas (urban parks smaller than 5 ha) and non-green areas (urban sites distant from protected green areas). Within each habitat, we selected five sampling sites to monitor the bat activity. In each of the two green habitats, these five sampling sites were distributed among three parks. In some cases, there was more than one sampling site within the same park or protected area but the minimum distance among them was never shorter than 100 m. The sampling sites within the green areas were located at the edge of wooded patches or on the shore of lakes. The vegetation contained in the green areas was predominantly composed of Atlantic Forest with some areas of mangrove. Some of the sampling sites of the non-green areas were also located at tree-lined sites but never close to dense fragments of vegetation as found in the green areas. All the non-green sites were surrounded by buildings

and streets and most of their surface was impermeable, i.e. pavement or tarmac. Artificial lights were present near all sampling sites of the three habitats (for a list of the sampling sites with their respective geographic coordinates see Table 1).

Table 1
Sampling sites with their respective geographic coordinates.

Urban habitats	Park/Neighborhood name	Sampling site	coordinates
Large green	Parque da Fonte Grande	1	-20°18'33,6"S, -40°20'29,4"W
	Universidade Federal do Espírito Santo	2	-20°16'42,6"S, -40°18'15,6"W
	Universidade Federal do Espírito Santo	3	-20°16'41,4"S, -40°18'19,8"W
	Universidade Federal do Espírito Santo	4	-20°16'55,2"S, -40°18'21"W
	Parque da Manteigueira	5	-20°19'50,4"S, -40°18'52,2"W
Small green	Parque Pedra da Cebola	1	-20°16'36,6"S, -40°17'49,8"W
	Parque Pedra da Cebola	2	-20°16'37,2"S, -40°17'56,4"W
	Parque Pedra da cebola	3	-20°16'39"S, -40°17'51"W
	Parque da Fazendinha	4	-20°14'29,4"S, -40°16'23,4"W
	Parque Padre Alfonso Pastore	5	-20°16'31,8"S, -40°17'10,2"W
Non green	Jardim Camburi	1	-20°15'19,2"S, -40°16'9"W
	Vila Independência	2	-20°19'58,2"S, -40°24'6,6"W
	Campo Grande	3	-20°20'21,6"S, -40°23'13,2"W

Urban habitats	Park/Neighborhood name	Sampling site	coordinates
	Vila Capixaba	4	-20°20'15"S, -40°24'01"W
	Praia da Costa	5	-20°19'46,2"S, -40°16'24"W

Bat activity

We recorded bat activity with a Griffin Ultrasound detector (Stag Electronics, London) at a sampling rate of 441 kHz and a resolution of 16 bits, which resulted in 10-times expanded recordings. Each night, bat activity was monitored for three hours after sunset. Within this period, we made 18 five-minute recordings with five-minute intervals between them. At each successive night a different habitat was monitored and, since most sampling sites were very distant from each other, only one sampling site was monitored per night. Whenever one of the habitats was monitored, we monitored the other two habitats within a period no longer than one week to minimize possible effects of variation on bat activity due to climatic condition and moon phase. In total, we monitored bat activity for 12 nights in each habitat, resulting in 216 recordings per habitat (1080 min in total).

The recording files were transferred to a computer and then analyzed with Avisoft Saslab Pro Software (Raimund Specht, Berlin). For estimating bat activity, we examined spectrograms generated in a Hamming window, with FFT size of 256 and 93,75% overlap. As a measure of general bat activity, we estimated the acoustic activity index described by Miller (2001). For this purpose, we divided each five-minute recording into five segments of one minute, then we counted the number of one-minute segment in which we could observe a sequence of two or more echolocation pulses. We performed this procedure to measure the activity of both groups of insectivorous bats, open-space foragers and edge-space foragers. These two groups could be easily distinguished by the characteristics of their vocalizations visualized in the spectrograms (described in Schnitzler and Kalko [2001] and in Denzinger and Schnitzler [2013]). We also counted the number of feeding buzzes (defined as an increase in pulse repetition rate associated with attempted captures of prey as an estimation of feeding activity (Ávila-Flores and Fenton 2005; Macswiney et al. 2009)). We also differentiate between feeding buzzes emitted by open-space foragers and edge-space foragers.

Species identification

Most of the recordings were made in a very noisy environment and, therefore, did not have a quality good enough to be analyzed. For the purposes of this study, the identification of the calls to species level was not a necessary condition. However, in order to have a rough knowledge of the bat fauna present in the study area, we selected some recording segments with good signal-to-noise ratio that contained the

record of a bat pass with a sequence of at least three echolocation calls from the search phase. Once we selected an adequate segment, we created a sonogram using the parameters described in the previous section.

To analyze the selected passes we used the automatic analysis function of Avisoft, with two thresholds, both set to -20 db. The first threshold detects the pulse to be analyzed and the second determines its beginning and ending. We measured the following parameters: maximum frequency, minimum frequency, peak frequency, pulse duration, interval between pulses and bandwidth.

We identified the calls to the species level based on the acoustic identification key proposed by Arias-Aguilar et al. (2018) and, in the case of species belonging to the genus *Molossus*, we also used our own database of echolocation calls from live specimens that were captured and released on previous studies.

Statistical analysis

We used hierarchical linear effect models (HLM) or linear mixed effect models (LMM) to investigate differences in general bat activity or feeding activity between habitat categories. This analysis allows testing the interaction between different hierarchical levels, such as bats (level 1) and its habitats (level 2), regarding the existence of random variation among the levels (Bolker et al. 2009). Thus, we could control random effects caused by the sampling method and the different levels of interaction of information. In order to find the best model to explain the data, we performed the exploratory strategy step-up, so that the complexity of the model was incremented as it showed a better adjustment of the data starting from a basal model (Maroco 2014). In the basal model the variable activity was defined as the dependent variable and sampling night was included as factor of random effects. Since each habitat contained five sampling sites and each site was monitored for two or three nights, in a first step, we included night and, in a second step, we included site as a control of random effects, and we used general activity as dependent variable. In the third and final step, we added habitat (non-green areas, small-green areas and large-green areas) as predictor variable of second level, as fixed factor, using the large-green areas as the reference category for comparison. Therefore, our final model was formed by the general activity as dependent variable, habitat as fixed factor and sampling nights and sampling sites as random factors. In relation to feeding activity, we followed the same steps using the number of feeding buzzes as dependent variable, habitat type as fixed factor and sampling nights and sampling sites as random factors. The model was adjusted by maximum likelihood as used by Jung and Kalko (2011).

Since sampling night and sampling sites were not adequate for comparing the general activity of the two categories of foragers, open-space and edge-space foragers, we used a new variable called *observation* to control the random effect, which corresponds to 5-min recordings. In this step we used a structure of repeated measures through the LMM with the type of forager as the dependent variable (to control for variation in general activity), habitat type as a fixed factor and the *observation* as a random factor. The comparison between the forager types was also performed with feeding activity, however in this case, it was not possible to control for the random effect, due to the low variability of the data. Therefore, for feeding activity we used a General Linear Model (GLM) Repeated Measures, with the forager type as

dependent variable (to control for variation in feeding activity) and the habitat type as fixed factor. Pairwise comparisons were performed to better identify the effect of habitat on general and feeding activity, using the Sidak method.

In order to test the hypothesis that the effect of habitat on activity was greater on edge-space foragers we calculated the effect size (Cohen's *d*) for the general activity followed by a Z-test (Alliger, 1995) to compare the effect sizes between the forager types. The analyses were performed with SPSS 21 and Excel.

Results

General activity

We observed a significant effect of non-green areas ($b = -2.184$; $t_{(512.294)} = 10.953$; $p < 0.001$) and small-green areas ($b = -0.699$; $t_{(512.294)} = 3.505$; $p < 0.001$) on general bat activity. That indicates that the general bat activity varies among the different areas. Pairwise tests demonstrated that general activity was significantly lower at small-green areas ($p < 0.001$) and non-green areas ($p < 0.001$) compared to large green areas, and lower at non-green areas compared to small-green areas ($p < 0.001$).

The interaction between type of forager and habitat was significant ($F_{(2.647,630)} = 14.97$; $p < 0.001$). Pairwise comparisons demonstrated that open-space foragers' general activity was higher at large-green areas and small-green areas compared to non-green areas ($p < 0.001$ for both comparisons). The activity of open-space foragers was also higher at the large-green areas compared to small-green areas, however this difference was not significant ($p = 0.061$). The same pattern was observed for edge-space foragers, but in this case all differences were statistically significant ($p < 0.001$ for all comparisons; Table 2).

Table 2
Mean values and standard deviation ($\pm$) of number of one-minute segments with sequences of echolocation calls per recording per habitat. Statistical difference among habitats for the open-space foragers is indicated by different capital letters and for edge-space foragers, by different lowercase letters. The two types of foragers were not compared to each other.

Habitat type	Open-space forager	edge-space forager
Non-green area	1.578($\pm$ 1.629)-A	0.018($\pm$ 0.214)-a
Small-green area	3.069($\pm$ 1.832)-B	0.7628($\pm$ 1.722)-b
Large-green area	3.370($\pm$ 1.739)-B	2.217($\pm$ 2.105)-c
Total(Average)	2.672($\pm$ 1.902)	1.000($\pm$ 1.819)

The effect size (*d*) of the difference of activity between non-green areas and large-green areas was higher for edge-space foragers than for open-space foragers ($z = 2.72$; $p = 0.006$). The same pattern was

observed when we compared small-green areas to large-green areas ($z = 4.24$; $p < 0.001$). However, there was no significant difference in effect size between the activity of open-space foragers and edge-space foragers in the comparison between non-green areas and small-green areas ($z = 1.79$; $p = 0.072$).

Feeding activity

We also observed a significant effect of non-green areas ($b = -0.398$; $t_{(416.453)} = 4.314$; $p < 0.001$) and small-green areas ($b = -0.218$; $t_{(416.453)} = 2.358$; $p = 0.019$) on feeding activity, indicating that the feeding activity varies among different areas. The pairwise comparisons demonstrated that feeding activity was higher at large-green areas compared to small-green areas ($p = 0.019$) and non-green areas ($p < 0.001$). However, feeding activity did not differ significantly between non-green areas and small-green areas ($p = 0.051$).

Interaction between forager and habitat type was statistically significant ($F_{(2,645)} = 4.407$; $p = 0.011$). We observed higher feeding activity of edge-space foragers in large-green areas compared to non-green areas ($p < 0.001$) and small-green areas ($p < 0.001$), but there was no difference between non-green areas and small-green areas ($p = 0.128$) for this group of bats. Regarding the open-space foragers we did not find statistical difference in feeding activity in any pairwise comparisons: non-green areas and small-green areas ($p = 0.120$), non-green areas and large-green areas ($p = 0.161$) and small-green areas and large-green areas ($p = 0.876$; Table 3).

Table 3
Mean values and standard deviation ($\pm$) of number of feeding buzzes. Statistical difference among habitats for the open-space foragers is indicated by different capital letters and for edge-space foragers, by different lowercase letters. The two types of foragers were not compared to each other.

Habitat	Open-space forager	edge-space forager
Non-green area	0.134(± 0.917)-A	0.000(± 0.000)-a
Small-green area	0.273(± 1.143)-A	0.157(± 0.677)-a
Large-green area	0.259(± 0.652)-A	0.495(± 1.730)-b
Total	0.222(± 0.927)	0.217(± 1.091)

Species identification

In total we analyzed 28 passes and identified 8 species belonging to 4 families: Molossidae, Vespertilionidae, Emballonuridae and Noctilionidae (Table 4). We also included *Noctilio leporinus* in the list of identified species even though it is a trawling bat, well known for fishing habits (Schnitzler et al 1994; Schnitzler and Kalko 2001) and not an insectivorous aerial species which is the focus of this work.

Table 4
List of identified species showing in which habitats they were registered.

Family	Species	Occurrence		
		Non-green Area	Small-green area	Large-green area
Molossidae	<i>Eumops glaucinus</i>	x	x	x
	<i>Molossus rufus</i>		x	
	<i>Nyctinomops laticaudatus</i>		x	x
	<i>Molossus molossus</i>	x	x	x
	<i>Promops centralis</i>			x
Embalonuridae	<i>Peropteryx trinitatis</i>		x	x
Noctilionidae	<i>Noctilio leporinus</i>		x	
Vespertilionidae	<i>Myotis nigricans</i>	x	x	x

Through visual inspection of the remaining bat passes, we could easily recognize most of the calls we considered as open-space foraging species as being from the genus *Molossus*, whereas all edge-space foragers clearly belonged to the genus *Myotis*. Among the species we identified, we considered as open-space foragers the following taxa: *Molossus molossus*, *M. rufus*, *Nyctinomops laticaudatus*, *Eumops glaucinus*, *Promops centralis* and *Peropteryx trinitatis*. *Myotis nigricans* was the only species we classified as edge-space forager among the identified species. An example of a typical pulse of each identified species is shown in Figure 1. Table 4 shows the relation of identified species per family we found in each habitat.

Discussion

As expected, even small green areas presented higher bat activity compared to urban sites in the studied area. Furthermore, the number of species we found in the green areas were noticeably greater than in non-green areas. Similarly, other studies have demonstrated the preference of Neotropical bats for vegetated areas in an urban matrix, as in Mexico City (Avila-Flores and Fenton 2005) and in the metropolitan area of Recife Northeast of Brazil; Araujo and Bernard 2016).

Almost all bat calls recorded in the urban sites were emitted by open-space foraging species, mostly belonging to the genus *Molossus*. This effect of species richness reduction and dominance of a few open-space adapted species in urban area was also observed in Mexico City (Avila-Flores and Fenton 2005), in Panama City (Jung and Kalko 2011), in San Francisco (Krauel and Lebuhn 2016) and in Sydney (Threlfall et al. 2011). The predominance of open-space bats in cities can be attributed to their faster and

more energetically efficient flight compared to the bats adapted to edge spaces (Norberg and Rayner 1987). This more energetically efficient flight would make open-space bats well adapted to urban areas since it would allow them to fly over greater distances to search for sparsely distributed food patches or roosts within cities (Avila-Flores and Fenton 2005; Russo and Ancillotto 2015; Krauel and Lebuhn 2016).

However, despite being well adapted to urban environments, we recorded significant larger general activity of open-space foragers in the green areas compared to the non-green areas. Moreover, although the effect size of the difference in activity between large-green areas compared to the other areas was indeed higher for edge-space foragers, contrary to our expectations, the effect sizes of the two types of foragers did not differ in the comparison between small and non-green areas. Still, we found some of the open-space foraging species, such as *N. laticaudatus* and *P. trinitatis*, only in the green areas. These results indicate that open-space bats do benefit from green urban areas, even though they do not seem to show a preference for the large parks as edge-space bats do.

Nonetheless, our results contrast with those found by Araujo and Bernard (2016). These authors compared the bat activity of several families inside and outside green areas in the Metropolitan Region of Recife, Northeastern Brazil. The authors obtained more recordings from molossids, which were the majority of open-space foragers we registered in our study, outside green areas than inside them. A possible explanation for these contrasting results could be a difference between the recorded species in the two areas. *Molossus sp.* was the predominant group of molossids recorded in our study, but we do not know the predominant genus or species of molossids recorded in Recife, since Araujo and Bernard (2016) identified the calls at family level only. Even though molossids are typical open-space foragers (except for the genus *Molossops*, Jung and Kalko 2011; Jung et al. 2014), there is high morphological and behavioral heterogeneity among molossid species, which could lead to differences in adaptability to urban environment among these animals (Jung and Threlfall 2016). Besides a potential variation in bat species, differences in roost availability related to differences in vegetation and urban settlement characteristics could have also contributed for the different results obtained (Duchamp and Swihart 2008; Russo and Ancillotto 2015). The dissimilarity between the two studies exemplifies how the impact of urbanization can vary regionally and highlights the need of more studies in different areas.

The presence of vegetation has been pointed out as the main factor of sustainability to insect population (Avila-Flores and Fenton 2005; Russo and Ancillotto 2015). It consists in a potential explanation for the greater general bat activity we found in the green areas and the greater edge-space forager activity in the large-green areas. However, since in our study the open-space foraging bats did not show difference in feeding activity among the habitats, at least for this group the preference for vegetated habitats do not seem to be related to a greater abundance of insects in these areas. An alternative explanation is that the vegetation would provide greater availability of roost sites (Duchamp and Swihart 2008; Basham and Banks 2011; Coleman and Barclay 2012). Moreover, the competition with urban birds could reduce the availability of roost sites out of green areas (Basham and Banks 2011).

It is important to highlight the existence of lakes in some of the green sites we monitored that might have also contributed for the greater bat activity in these areas. Bodies of water are often associated with high bat activity (Macswiney et al. 2009; Krauel and Labuhn 2016; Ancillotto et al. 2019; Gili et al. 2020). These habitats are important source of drinkable water and are frequently used as feeding areas, since the space above water bodies are often rich in insects (Macswiney et al. 2009; Salvarina 2016; Ancillotto et al. 2019).

We should also mention that the green areas monitored in our study are not totally natural environments. In all the parks we visited there are typically urban structures, such as buildings and artificial lights, which can also be explored by bats (Russo and Ancillotto 2015). In some nights, we could observe individuals from *Myotis spp.* flying around streetlamps. Many bat species hunt for prey attracted by artificial light (Gaisler et al. 1998; Avila-Flores and Fenton 2005; Jung and Kalko 2010), although some species may be averse to urban lights (Lewanzik and Voigt 2017). Therefore, even though our results indicate that edge-space species, such as *Myotis sp.*, are not well represented in urban environments, they still might explore and profit from man-made structures if these are close to vegetation.

In our study, we identified four species that were not captured by Oprea et al. (2009), who compared urban parks, tree-lined streets and non-tree lined streets in the city of Vitoria using mist nets. The species are *E. glaucinus*, *P. centralis*, *P. trinitatis* and *N. leporinus*. Some individuals of *Noctilio spp.* were observed by those authors but they could not capture and identify them at species level. Although the two studies used different methods to sample bat species, which favor the sampling of different groups (Phyllostomids in the case of mist nets and aerial insectivorous in the case of acoustic monitoring), both studies found more species inside the parks than outside them.

Amongst the identified species, we should highlight the identification of *P. centralis* and *P. trinitatis*, which represent the first records for these species in the state of Espírito Santo. *P. centralis* was previously thought to be restricted to Central America and northern, western and central regions of South America (reviewed in Hintze et al. 2019). However, the distribution range of *P. centralis* was recently revised by Hintze et al. (2019) based on acoustic surveys conducted throughout parts of Brazil including the present study. Modeling the species' potential distribution, the authors found that *P. centralis* has a much wider distribution in South America than previously thought. *P. trinitatis* is known to occur in Trinidad and Tobago, Aruba, Venezuela, French Guiana, Guiana and north, northeast and central-west regions of Brazil (dos Santos et al 2016). Our findings represent the very first record of the species for the Southeast Region of Brazil and for the Atlantic Forest biome (dos Santos et al 2016). This illustrates the importance of acoustical surveys to complement traditional capture methods in order to have a better picture of the real distribution of bat species, potentially contributing for more effective conservation plans.

Urbanization is considered a major driving force of biodiversity loss and biological homogenization (Paucharda et al. 2006). This effect can be attenuated by parks and discontinuous woodland patches existing within city limits (Cornelis and Hermý 2004; Alvey 2006; Nielsen et al. 2014; Gili et al. 2020). This is not only true for bats, but also for other taxa, such as birds (Fernández-Juricic and Jokimäki 2001;

White et al. 2005). For example, urban parks of 10-35 ha contain most of the bird species recorded in several cities in Europe (Fernández-Juricic and Jokimäki 2001). With respect to bats our results indicate that even small parks (< 5 ha) can be of great value for preserving species richness.

The study of the traits that are selected by urban environments is an important issue for biologists (Fernández-Juricic and Jokimäki 2001; van der Ree and McCarthy 2005; Lowry et al. 2013; Jung and Threlfall 2016, 2018; Santini et al. 2019). In the case of insectivorous bats, our study supports the idea that species which are adapted to hunt in open space are more likely to persist in urban environments. However, since we found some open-space adapted species only in large-green areas, other characteristics, such as specialized food and roost requirements, must be involved (Jung and Threlfall 2018). More studies about the ecology and behavior of each species are necessary to have a better knowledge of their environmental requirements that aid or prevent them from surviving in urban landscapes.

Declarations

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- Conflicts of interest – There are no conflicts of interest.
- Availability of data and material – Data available on request from the authors. The data that support the findings of this study are available from the corresponding author, Márcio H. Almeida, upon reasonable request.
- Code availability – Not applicable.
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Figures

Figure 1

Sonogram showing the echolocation pulses of the bat species recorded in the study area. The names of the species are abbreviated (see Table 4 for the complete name of the species). The real pulse intervals are not represented