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Original investigation

Feeding and social activity of insectivorous bats in a complex landscape: The importance of gallery forests and karst areas

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ABSTRACT

Worldwide, increasing human activity, such as agriculture and mining, and decreased landscape complexity, are negatively affecting numerous mammal species. For example, bat communities are becoming threatened in many locations mostly due to the loss of their preferred roosting and foraging habitats. Brazilian landscapes and their associated bat communities are no exception, with the situation being further exacerbated by recently adopted permissive environmental laws that have resulted in reduced biodiversity protection and conservation. Therefore, there is an urgent need to understand how landscape and environmental variables relate to bat activities in Brazil in order to support efforts for their conservation. We used acoustic monitoring data to investigate differences in foraging and social activity of insectivorous bats among four habitat types in a heterogeneous landscape in the Cerrado-Atlantic forest ecotone in southeastern Brazil. We also sampled insect availability and measured temperature at the same sites. Our results showed increased social activity and a greater number of species emitting social calls in karst, and increased feeding activity with a greater number of species emitting feeding buzzes in gallery forest. We also found a positive influence of both temperature and insect abundance on foraging and social activity. Our study provides new insights regarding habitat use by bats in a heterogeneous landscape, and demonstrates the importance of preserving different habitats in heterogeneous landscapes for the conservation of bat species and the ecological functions they perform.

Introduction

Globally, numerous mammal species are negatively affected by increased human activity, such as agriculture and mining (Duarte et al., 2015; Wickramasinghe et al., 2004). These activities result in land cover changes that create inhospitable habitats for native species (Dorresteijn et al., 2015; Foley et al., 2005). Furthermore, the structural complexity of landscapes is decreasing worldwide, with profound negative effects on resource availability (*e.g.*, food, shelter) for mammal species (Bazzaz, 1975; Tews et al., 2004). For example, although bats generally have a high capacity for displacement, bat communities are becoming threatened in many locations mostly due to the loss of their preferred roosting and foraging habitats (Furey and Racey, 2016; Muylaert et al., 2016).

Although the scientific community is already aware of the ongoing massive loss of biodiversity (Ceballos et al., 2015), some countries are facing legislative changes that will actually reduce the protection and conservation of biodiversity, as is the case for Brazil (Sparovek et al., 2012). In 2012, the promulgation of Brazil's new Forest Code (Law 12.651, 2012) severely modified the conservation requirements for private properties, reducing the amount of area to be protected or restored and providing amnesty for past illegal deforestation (Soares-Filho et al., 2014). Moreover, a new Brazilian federal law recently reduced the range of legal protection of caves and karst areas, eliminating the previous mandatory protection of all cave sites and replacing it with minor protection of only those considered as most relevant (Brasil, 2009). As a result, these areas have become more susceptible to degradation from economic activities such as mining (Ferreira et al., 2014). Both of these

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legal changes, together with several others at the state level, as well as the continuous reduction of human and financial support of the environmental conservation authorities, have the potential to negatively affect Brazilian bat communities in important ways because many species rely on natural areas outside of conservation units (Bernard et al., 2011). Therefore, there is an urgent need to understand how landscape and environmental variables relate to bat activities in Brazil in order to support efforts for their conservation.

Habitat selection by bats for foraging, roosting and swarming, among other uses, is typically related to microclimatic conditions, vegetation structure, and resource availability, including distance to water and roosting sites (Ford et al., 2006; Rainho et al., 2010; Rainho and Palmeirim, 2011; Schnitzler and Kalko, 2001; Torquetti et al., 2017). For example, in general, sites with rivers and lakes with good water quality are expected to have greater activity of insectivorous bats from different ecomorphological guilds (Barros et al., 2014; Ramos-Pereira et al., 2010). Temperature in particular influences bats in a variety of ways, including their selection of shelter (Torquetti et al., 2017) and when and where to forage (e.g. the use of open habitats during periods of high temperatures (O'Donnell, 2000).

Griffin (1944) introduced a novel method for studying spatial distribution and habitat use by bats through the interpretation of echolocation calls. This technique allows the characterization of bat activities using their different echolocation calls (Gillam and Fenton, 2016). Among the types of calls that have been related to specific bat activities are two well-defined behavioral signatures that are associated with feeding and social activities (Budenz et al., 2009; Schnitzler and Kalko, 2001): feeding buzzes and social calls. Feeding buzzes are terminal phases of calls emitted only when pursuing prey and are characterized by a sudden decrease in interpulse interval and call frequency modulation (FM), followed by a pause (Schnitzler and Kalko, 2001). Social calls are usually composed of isolated or irregularly emitted pulses, and are often multi-harmonic and low in frequency. As the name suggests, social calls are associated with social interactions, including courtship, learning, aggregation, group coordination and agonistic interactions (Budenz et al., 2009; Downs and Racey, 2007).

Studies using feeding buzzes and social calls are still rare (Estrada-Villegas et al., 2010; Fenton, 2003; Hintze et al., 2016a; Knörnschild et al., 2012), although the knowledge of bat preferences for foraging and social interactions are key to the conservation of these mammals and the ecosystem services they provide (Kunz et al., 2011). Some studies, especially in temperate areas, have begun to show how habitat type and heterogeneity (Mendes et al., 2017), climatic conditions (Meyer et al., 2016), and food availability (Coleman and Barclay, 2013) influence insectivorous bat activity and feeding. However, there remains a need to evaluate the influence of these factors in complex Neotropical landscapes. In fact, few studies have evaluated feeding and social activity of insectivorous bats within the same landscape, and these are restricted to a few species in temperate regions (Downs and Racey, 2007).

In this work, we used acoustic monitoring to investigate the spatial distribution of two behavioral signatures of insectivorous bats in a heterogeneous landscape of a CerradoAtlantic Forest transition zone in southeastern Brazil. Specifically, we tested the hypothesis that insectivorous bats use different habitats for distinct purposes. We predicted that there would be: (i) more feeding activity and a higher number of species foraging in areas of gallery forest, since this habitat type has waterbodies that potentiate foraging activity (Hintze et al., 2016a; Marques et al., 2016); and (ii) more social calls and a higher number of species socializing in karst outcrops, since these areas are usually used as swarming sites and for underground roosts (Avila-Flores and Medellín, 2004). We also tested the hypothesis that temperature affects foraging and social activities, and that foraging behavior can be explained by food availability. We predicted there would be: (i) a positive relationship between feeding activity and temperature; and (ii) a positive relationship between bat feeding activity and richness and abundance of flying insects.

Methods

Study area

We conducted the study in the Serra do Cipó National Park and in the Morro da Pedreira Environmental Protection Area, two of the largest protected areas in southeastern Brazil, together comprising 131,769 ha with elevations varying between 750 and 1200 m. These areas are part of the transition zone between the largest karst system in Latin America, known as the Sistema Bambuí (Auler, 2002), and the Serra do Espinhaço Complex, a mountain range very rich in iron, manganese, bauxite and gold (Fig. 1). Both protected areas possess a predominance of campos rupestres (rocky grasslands) (Fig1, Photo A; Silveira et al., 2016), but also have areas of cerrado *sensu stricto* (Fig. 1, Photo C) and gallery forest (Fig. 1, Photo D). We also studied a site located 1 km outside the Morro da Pedreira boundary.

There are limestone outcrops in the western portion of Morro da Pedreira, at the border of the Bambuí karst complex (Auler, 2002), which usually form karst areas (Fig. 1, Photo B). This type of habitat is important for bats mainly because it provides daytime refugia (Kunz et al., 2011) in the form of caves and crevices (Furey and Racey, 2016). We sampled three distinct karst outcrops, which together contain more than 100 natural cavities. Campos rupestres are easily recognizable habitats, consisting of shrubs and sparse small trees located among rocky terrain and quartzitic outcrops. Small bodies of water are commonly found in these habitats (Benites et al., 2007). Gallery forests have a closer resemblance to the Atlantic Forest biome than the other habitat types of the study and occur as narrow well-defined strips (no more than 100 m wide) along streams with tall tree cover with canopies reaching up to 20 m to 30 m. The trees in this region are mostly evergreen, with water available throughout the year. Finally, cerrado *sensu stricto* (hereafter referred to as cerrado) is a typical Brazilian savanna and is defined as a habitat that includes a large proportion of grassland with abundant medium-sized trees and shrubby and herbaceous plant species (Eiten, 1982).

The climatic regime of the region is Tropical Altitudinal (Alvares et al., 2013) with markedly dry and cold winters, and hot and wet summers. The mean annual temperature is around 22° C and the mean annual rainfall is 1500 mm (Rocha et al., 2016). The rainy season typically occurs between November and April, but during 2014 and 2015, the period of the present study, the Brazilian southeast experienced a severe drought, with the first rains not occurring until January 2015, and lasting until the middle of June of the same year (Coelho et al., 2016; Nobre et al., 2016).

Acoustic data collection

In each of the four habitat types (campos rupestres, cerrado, gallery forest, and karst), we defined eight sampling sites located at least 1 km apart, with the exception of two sites in the karst area, which were only 450 m apart (due to the small size of the karst outcrop), and a campos rupestres site and a gallery forest site 650 m apart. We acoustically sampled each of the 32 sites on different nights. In each site we established three 100-m linear transects separated by 50–100 meters. We established three sampling stations spaced 50 m apart along each transect (start, middle and