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Bat assemblage in agricultural landscapes: comparison between native forest fragment and alley cropping system

Assembleia de morcegos em paisagens agrícolas: comparação entre fragmento de floresta nativa e sistema de cultivo em aleias

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ABSTRACT

Agroforestry systems are known to reduce impacts of traditional agriculture due to their capacity of decreasing deforestation and maintain biological diversity. This study investigated bat abundance, richness and diversity in an alley cropping system in São Paulo state, comparing bat assemblage to an adjacent forest fragment. Captures occurred in two distinct periods and the sampling effort of 1,296m^2/h was applied for each site. From thirteen species captured in the fragment (n=109), in which *C. perspicillata*, *A. lituratus* and *S. lilium* were the most abundant, only two (*A. lituratus* and *S. lilium*) were recorded at the alley cropping (n=7). Shannon diversity was also significantly lower for the alley cropping (H'= 0.60), when compared to the forest fragment (H'= 2.02). Contrary to our expectations, the alley cropping system studied here does not support bat richness and diversity, as accomplished by other agroforestry complexes. The results also reinforce the importance of considering wildlife while managing agricultural landscapes and establishing agroforestry systems.
Keywords: bat richness, diversity, agroforestry, wildlife conservation.

RESUMO

Sistemas agroflorestais são conhecidos por reduzirem os impactos da agricultura tradicional devido à sua capacidade de diminuir desmatamentos e manter a diversidade biológica. Este estudo investigou a abundância, riqueza e diversidade de morcegos em um sistema de cultivo em aleias no Estado de São Paulo, comparando a assembleia de morcegos com um fragmento florestal adjacente. As capturas ocorreram em dois períodos distintos, e o esforço de amostragem aplicado para cada área foi de 1,296m^2/h. Das 13 espécies capturadas no fragmento (n=109), onde *C. perspicillata*, *A. lituratus* e *S. lilium* foram as mais abundantes, apenas duas (*A. lituratus* e *S. lilium*) foram registradas no cultivo em aleias (n=7). A diversidade de Shannon também foi significativamente menor no sistema de aleias (H'= 0.60), quando comparada com o fragmento florestal (H'= 2.02). Contrária as nossas expectativas, o sistema de cultivo em aleias estudado aqui não suporta a riqueza e diversidade de morcegos, como realizado por outros complexos agroflorestais. Os resultados também reforçam a importância de se considerar a fauna no manejo de paisagens agrícolas e estabelecimento de sistemas agroflorestais.
Palavras-chave: riqueza de morcegos, diversidade, agrofloresta, conservação da fauna.

INTRODUCTION

The demand for agricultural products has driven tropical forests around the world to a drastically reduction of its original vegetation (Gibbs et al., 2010). Despite the known impacts of converting natural ecosystems into agricultural lands, losses of native vegetation are expected to increase on tropical forests of Africa and South America in the future (Laurance et al., 2014). In this scenario, agricultural expansion is one of the major causes of deforestation in the Brazilian Atlantic Forest, currently with only 12.4% remaining of its original area (SOS Mata Atlântica and INPE, 2018).

The remnants of Atlantic Forest in Brazil are located along the coastal region and in the interior side of the country as fragments isolated by agricultural fields (SOS Mata Atlântica and INPE, 2018). Among the most discussed impacts of agriculture on natural ecosystems, forest fragmentation is a central issue because it affects biodiversity dynamics and restricts natural populations to increasingly smaller habitats (Chiarello, 2000). As these fragments are the only suitable habitat available for wildlife in agricultural matrices, their management plays an essential role on biodiversity conservation (Chiarello, 2000; Ripperger et al., 2015).

The efforts to increase biodiversity conservation, reduce deforestation and maintain a sustainable food production have brought alternative ways of agricultural practices. Among these, the agroforestry systems are the most ecologically related to the natural forests because it combines feasible agricultural production to native perennial woody plants (Swaminathan, 1987). Some benefits of agroforestry to biodiversity include habitat provision and increased connectivity between landscapes (Harvey et al., 2006), maintenance of species richness and diversity (Bhagwat et al., 2008; Harvey and Villalobos, 2007; Moraes-Ornellas and Ornellas, 2009), and reduction of deforestation pressure to give rise to agriculture (Bhagwat et al., 2008).

In this scenario, the alley cropping system is an agroforestry that consists of arable crops grown in the alleyways between spaced rows of seasonal woody plants (Kang and Wilson, 1987). Studies have related this system to a range of ecological benefits including biomass production (Holzmueller and Jose, 2012), efficient soil fertility and management of water resources (Quinkenstein et al., 2009), benefits on carbon fixation (Silva et al., 2012), enhanced biological pest control (Faveta et al., 2014) and perch for birds crossing agricultural fields (Pereira, 2013).

Among important wildlife representatives, the bats are responsible for a range of ecosystem services as pollinators, seed dispersers and insect population suppressors (Kunz et al., 2011), including those of high economic value as agricultural pests (Brown et al., 2015; Cleveland et al., 2006). Despite the increased number of studies addressing bat richness and diversity in agroforestry (Castro-Luna and Galindo-González, 2012; Cortés-Delgado and Sosa, 2014; Faria et al., 2006; Harvey and Villalobos, 2007), there is no information about bats in alley cropping, and their presence in these areas has not yet been documented.

Thus, this study aimed to investigate bat fauna in an alley cropping system in São Paulo state (southeast Brazil), comparing the results to an adjacent native forest fragment, in order to assess the potential of this agroforestry in maintaining local bat richness and diversity. If the local alley cropping system works as other agroforestry practices, providing resources to maintain bat richness and diversity (Bhagwat et al., 2008; Faria et al., 2006; Harvey and Villalobos, 2007; Moraes-Ornellas and Ornellas, 2009), it is expected that bat species captured in the native forest fragment are also recorded around the agricultural areas.

MATERIAL AND METHODS

Study Area

The study was carried out in two sites located within the Federal University of São Carlos - Araras *campus* (22º18'36" S; 47º23'04" W) in southeast São Paulo (Figure 1A). The fragment of seasonal semideciduous Atlantic forest is a secondary forest with 12.7 ha area (Figure 1B). Its proximity to large agricultural fields has caused a high level of anthropic presence and occurrence of fires in the past. The climate is tropical with a hot and wet summer and a cold and dry winter (Kottek et al., 2006). The average annual temperature and precipitation is around 21.6 ºC and 1,422.8 mm, respectively (UFSCar, 2015).

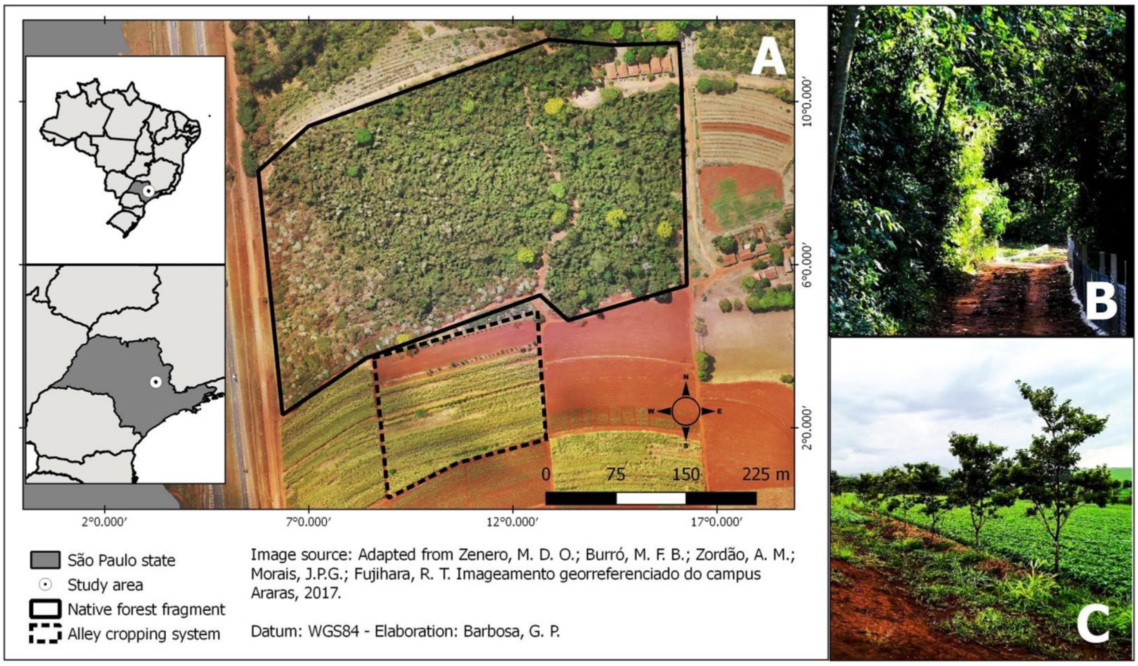

Figure 1. Study sites located within the Federal University of São Carlos – Araras *campus* in São Paulo state, southeast Brazil. (A) Solid and dashed lines denote the native forest fragment and the alley cropping system, respectively. (B) Sampling trail inside the native forest fragment and (C) sampling corridor along the alley cropping system.

The alley cropping site consists of native woody species planted in rows forming four alleys with 150 m long, established at different distances from each other, being 30, 40, 50 and 60 m, respectively (Figure 1C). Each alley is divided in three segments of 50 m, where ten seedlings of Brazilian fern tree (*Schizolobium parahyba*) (Vell.) S. F. Blake, ten seedlings of cedar tree (*Cedrela fissilis* Vell) and ten seedlings of yellow trumpet tree (*Handroanthus serratifolius*) (Vahl) S. O. Grose were planted, spaced 5 m from one another. The 120 tree individuals occupy 600 m of alleys in a 20,250 m^2 of sugar cane and soy bean cropping area.

The alley cropping system was established in 2008 as part of a study that evaluates the technical viability of sugar cane (*Saccharum* spp.) in agroforestry (Pereira, 2013). The species planted on the alleys are pioneering plants native to the Brazilian Atlantic Forest (Yamamoto et al., 2007), and chosen due to their use in the recovery of degraded areas and possibility of logging in a long term management system (Pereira, 2013). In general, these plant species are large trees with flowers pollinated by insects and seeds dispersed by the wind (Yamamoto et al., 2007). The only study addressing wildlife in this site until now was performed by Pereira (2013), describing the potential of this system as perch for bird species crossing agricultural fields.

Data Sampling and Analysis

Bat sampling was conducted in two periods: from December 2009 to August 2010 (1° year), and from January to October 2015 (2° year). The alley cropping was about one year old at the first period, the trees were about 1.5 m in size and the sugar cane was the current culture at the site. At the second period, the alley was about six years old, the trees ranging from 3 to 5 m in size and soy bean was the culture at this time. The time interval between periods was randomly chose and followed normal procedure of sugar cane and soy bean crop rotation.

Both sites were visited four times per period, once per season (Spring: 22/09-21/12; Summer: 21/12-20/03; Fall: 20/03-21/06; Winter: 21/06-22/09). All fieldwork was made considering the moon cycle to avoid influences of lunar phobia in bat activity and capture (Morrison, 1978). For each sampling night, six mist-nets (9 X 2 m) were set at understory level, along corridors in the alley cropping and in a trail within the native forest fragment. The nets were opened at sunset and remained for three

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consecutive hours, being checked every 15 minutes. Sampling effort was calculated according to Straube and Bianconi (2002).

Captured bats were visually inspected, sexed, had their mass and right forearm measured and were released in the same place they were trapped. Field identification was based on the keys produced by Gardner (2008) and Reis et al. (2013). All research reported in this manuscript is under the licenses provided by the Biodiversity Authorization and Information System (SISBIO- 48180-1), and the Committee on Ethics in the Use of Animals (CEUA/UFSCar – 7159160615).

Bat species richness was estimated by Jackknife-1, using the software EstimateS 9.1 (Colwell, 2013). Shannon-Wiener diversity (H'), and similarity indexes of Jaccard (SJ) and Sorensen (SO) were calculated according to Krebs (1999). Accumulation curves based on abundance were constructed to assess species richness and to compare bat assemblage between the sites and study periods.

RESULTS AND DISCUSSION

A sampling effort of 1,296 m^2/h was attained for each study site, in which a total of 109 bats belonging to 13 species were captured (Table 1). The family Phyllostomidae dominated the assemblage, accounting for eight species (89.9%), followed by Verpertilionidae bats with five species (10.1%). Frugivorous and insectivorous bats were the most common feeding guild, with five species (38.5%) each. Two species of nectarivorous bats (15.4%) and one species of omnivorous (7.7%) were also captured (Table 1).

Phyllostomidae make up a large family in Brazil with 92 species (Nogueira et al., 2014), and in São Paulo state with 37 species (Garbino, 2016). Their high presence has been described in several studies addressing local bat assemblages, including secondary forests (Tavoloni, 2006), urban areas (Teixeira and Rocha, 2013) and experimental fields (Sato et al., 2015). However, despite their dominance, the high abundance of Phyllostomidae in our study might also have been influenced by the sampling method used (understory mist-nets), which facilitates their capture in detriment of other common

Table 1. Bat species captured in a native forest fragment and an alley cropping system in Araras, SP, Brazil. Trophic guild classification followed Kalko et al. (1996), as aerial insectivore (AI), frugivore (F) nectarivore (N) and omnivore (O).

Species	Trophic	1° Year		2° Year		Total	Total	Total
	guild	Native	Alley	Native	Alley	Native	Alley	Study
Family Phyllostomidae								
Subfamily Carolliinae								
Carollia perspicillata (Linnaeus, 1758)	F	6	-	32	-	38	0	38
Subfamily Stenodermatinae								
Sturnira lilium (E. Geoffroy, 1810)	F	3	5	28	-	31	5	36
Artibeus lituratus (Olfers, 1818)	F	8	2	2	-	10	2	12
Platyrrhinus lineatus (E. Geoffroy, 1810)	F	2	-	-	-	2	0	2
*Artibeus fimbriatus*Gray, 1838	F	1	-	-	-	1	0	1
Subfamily Glossophaginae								
Anoura caudifer (E. Geoffroy, 1818)	N	2	-	5	-	7	0	7
Glossophaga soricina (Pallas, 1766)	N	1	-	-	-	1	0	1
Subfamily Phyllostominae								
Phyllostomus hastatus (Pallas, 1767)	O	1	-	-	-	1	0	1
Family Vespertilionidae								
Subfamily Vespertilioninae								
Eptesicus diminutus Osgood, 1915	AI	3	-	-	-	3	0	3
Histiotus velatus (I. Geoffroy, 1824)	AI	-	-	3	-	3	0	3
Subfamily Myotinae								
Myotis albescens (E. Geoffroy, 1806)	AI	-	-	1	-	1	0	1
Myotis nigricans (Schinz, 1821)	AI	1	-	1	-	2	0	2
Myotis riparius Handley, 1960	AI	-	-	2	-	2	0	2
Total number of individuals		28	7	74	0	102	7	109
Total number of species		10	2	8	0	13	2	13

bat families (Fleming, 1986). This is also confirmed as insectivorous bats, well known to consume and control pest insect populations in a range of agrossystems (Brown et al., 2015; Cleveland et al., 2006), were not captured at the studied alley cropping.

The most common species was *Carollia perspicillata* (34.9%), followed by *Sturnira lilium* (33.0%), *Artibeus lituratus* (11.0%) and *Anoura caudifer* (6.4%). The remaining nine species each composed less than 5% of all captures, of which four species were represented by a single capture. Despite the ability to diversify their diet, the increased number of *C. perspicillata* and *S. lilium* in this study might have been led by the high food availability along the year, since these bats feed mostly on pioneer species as *Piper* sp. and *Solanum* sp., respectively (Martins et al., 2014; Tavoloni, 2006). Although the study area has no botanical survey to the moment, such plants are easily found inside the native forest fragment and on its edges.

A total of 13 species (Jackknife1=18.2) were recorded in the native forest fragment, accounting for ten species on the 1° year and eight species on the 2 ° year. A prevalence of *A. lituratus* (28.6%) and *C. perspicillata* (21.4%) was found in the 1° year, while the 2° year showed an increase in *C. perspicillata* (43.2%) and *S. lilium* (37.8%) abundances (Figure 2). Despite the differences among both periods, studies have shown no niche overlap between *A. lituratus* and *C. perspicillata* (Tavoloni, 2006). Besides interspecific relation of these bats to some pioneer plants (Tavoloni, 2006; Martins et al., 2014), food availability during the sampling period may also explain this pattern found in abundances.

The alley cropping accounted for only seven captures, with records for the species *S. lilium* (71.4%) and *A. lituratus* (28.6%) during the 1° year of sampling (Jackknife1=2). Applying the same efforts resulted in no bat captures during the 2 ° year of sampling, invalidating the expectation that the alley cropping could attract more bats in the second period of sampling, considering that the trees would be older and higher in size. These results are similar to those described by Suckow (2014) in a sugar cane field, where seven bats from the species *A. lituratus, A. fimbriatus, S. lilium* and *C. perspicillata* were captured.

Accumulation curves obtained for both areas and study periods corroborate with the richness estimated, where a higher number of species would be expected in the native forest fragment with a higher sampling effort (Figure 3). On the other hand, the accumulation curve obtained for the alley cropping system showed a small stabilization, representing that the effort applied to measure bat richness in this area was appropriate.

Despite not accounting for the effects of distinct agricultural crops on bat community in the present study, differences on alley cropping richness and abundance during both periods can be attributed to

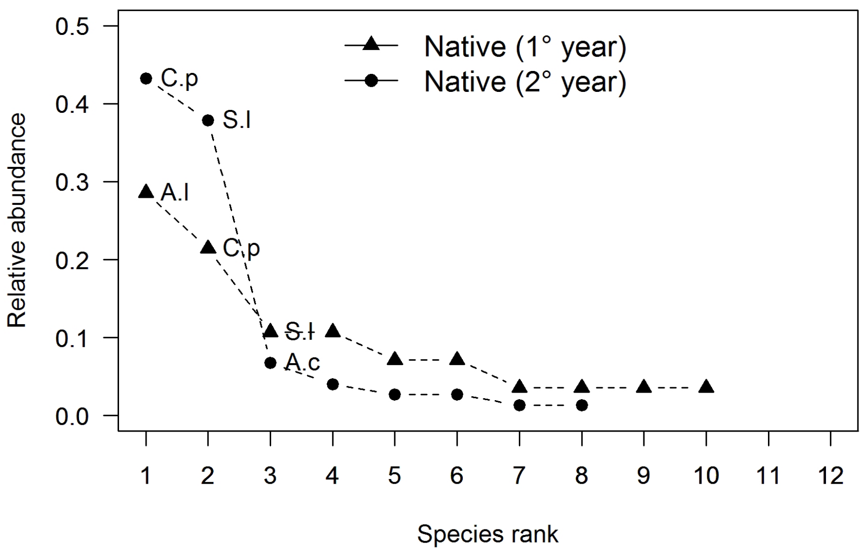

Figure 2. Relative abundance of bats captured in a native forest fragment in Araras, SP, Brazil. **C.p** = *Carollia perspicillata*, **S.l** = *Sturnira lilium*, **A.l** = *Artibeus lituratus*, **A.c** = *Anoura caudifer*.

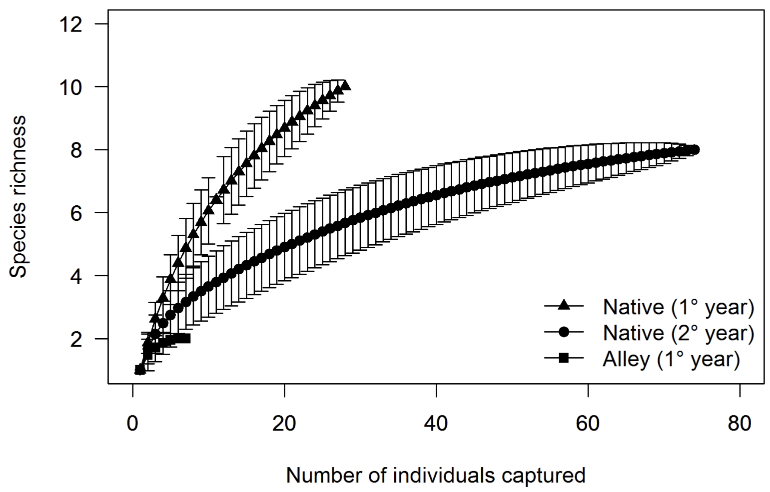

Figure 3. Individual-based species accumulation curve (100 randomizations) of bat assemblages carried out in a native forest fragment and an alley cropping system in Araras, SP, Brazil. Error bars show confidence interval (95%).

differences in sampling during sugar cane (1° year) and soy bean plantations (2 ° year). As habitat structure and heterogeneity plays a role on bat activity in agrosystems (Ripperger et al., 2015; Suckow, 2014), we believe that sugar cane plantations, due to its structural features, can provide a more suitable pathway to bats than soy bean. However, as already discussed above, differences here can also be attributed to the sampling method used, which creates a bias to the capturing of some bat species in detriment of others (Fleming, 1986).

Bat richness observed in the alley cropping was much lower than those recorded in other agroforestry systems. In a survey performed in a shaded coffee field in Bahia, Brazil, Faria et al. (2006) recorded 41 bat species, a significant higher richness when compared to a native forest (27 species) from the same study. In Costa Rica, Harvey and Villalobos (2007) reported 28 and 31 bat species in banana and cocoa agroforestry, respectively, overcoming the richness in a native forest (26 species). Both studies suggest that, in order to maintain bat richness, an agroforestry must contain structural features to provide resources and a suitable stratum that facilitates wildlife movement between cultures (Faria et al., 2006; Harvey and Villalobos, 2007). These features were not found at the alley system evaluated during both study periods, as the tree species planted are still young in age and size and do not offer food or roost resources to the bats. The results also suggest that the alley does not work as perch for the bats, as it does for birds that use the local alley cropping as a way to cross the agricultural fields (Pereira, 2013).

The native forest fragment during the 1° year showed an index of H’= 2.02, higher than the 2° year (H’= 1.35) and the alley cropping system (H’= 0.60). The index obtained in the 1° year is close to those from preserved forest areas in Brazil, as H’= 2.19 in Rio de Janeiro Botanical Garden (Esbérard, 2003). However, the index in the 2° year reflects better the bat diversity of forest fragments, as reported in Northwest Paraná (H’= 1.38) by Bianconi et al. (2004). A significantly low similarity between the native forest fragment and the alley cropping system during the 1° year was recorded (SJ = 0.20; SO = 0.33). Similar results were found between native forest and monoculture areas in Costa Rica (Harvey and Villalobos, 2007).

Although confirmed as beneficial to bird species (Pereira, 2013), the local alley cropping system, considering its tree species and currently structure already described, does not support the hypothesis of maintaining bat diversity in agricultural landscapes as described in other agroforestry systems (Faria et al., 2006; Harvey and Villalobos, 2007; Bhagwat et al., 2008). The results obtained here resemble those obtained for monocultures in other studies (Harvey and Villalobos, 2007; Suckow, 2014), which reinforces that, even though agroforestry practices are desirable from a biological conservation perspective (Swaminathan, 1987), these areas must account for different wildlife representatives when planned and constructed.

Lastly, we believe that the local alley cropping system could be improved in order to attract bats and other fauna than birds, by establishing a structural and floristic diversity that provides resources as fruits and roosts for wildlife. Studies based on diet of frugivorous bats, as performed by Tavoloni (2006), Martins et al. (2014) and others, can provide a valuable resource fund to design alley cropping systems and connect forest fragments among crop matrices. Castro-Luna and Galindo-González (2012) states that a higher abundance and diversity of bats are found in agroecosystems that have more fruit producing trees, suggesting that such strategy would benefit not only wildlife, but also the land owners and agricultural producers.

CONCLUSION

Despite its known ecological benefits, the alley cropping system within the Federal University of São Carlos – Araras *campus* in São Paulo, Brazil, does not support bat richness and diversity, as accomplished by other agroforestry complexes. Provided that, these results suggest the need of considering different wildlife dynamics while managing agricultural landscapes and establishing agroforestry systems, in order to increase the potential of these sites as biological diversity refuges. Results also reinforce the importance of increasing efforts to provide connection of natural forest fragments as they still work as source of food and refugee for local fauna. All things considered, future research is recommended in order to evaluate the benefits of alley cropping systems to other representatives of fauna, considering long term studies.

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