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FRUGIVORY BY PHYLLOSTOMIDAE BATS IN A MONTANE ATLANTIC FOREST, SOUTHEASTERN MINAS GERAIS, BRAZIL

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Abstract. The study was carried out at Parque Estadual do Ibitipoca, in southeastern Minas Gerais State, Brazil. The aim was to verify which fruits are most important in the diet of Phyllostomidae bats between two areas of Ombrophilous Dense Forest: Mata de Grota and Mata Grande. Bats were captured with mist nets and their diet was studied by analysis of fecal samples. In total, 400 captures were obtained, of which the Phyllostomidae family represented 98%. The most abundant species were *Sturnira lilium* (59.9%), *Platyrrhinus lineatus* (11.3%), *Artibeus lituratus* (8.7%) and *Carollia perspicillata* (7.6%). From the 126 fecal samples, 14 plant species were found; the most commonly consumed ones were *Solanum swartzianum* (31.1% of samples), *Ficus mexiae* (23.5%), *Solanum pseudoquina* (9.2%) and *Dyssochroma viridiflorum* (8.4%). There was no difference in seed richness between the Mata de Grota and Mata Grande, but there was a great difference in the diversity of seeds in these areas. In Mata de Grota, the consumption of *F. mexiae* was more pronounced, whereas *S. swartzianum* was consumed more significantly in the Mata Grande than the Mata de Grota. In S*turnira lilium*, 71.8% of the diet was composed of Solanaceae seeds, and this plant family also predominated in the diet of *C. perspicillata* (53.8%). *Ficus mexiae* was the plant species consumed by the largest number of bats and was an exclusive item in the diets of *A. lituratus*, *A. fimbriatus* and *Platyrrhinus recifinus*, and predominated in the diet of *P. lineatus*. Solanaceae seeds occurred more frequently compared with other plant families. The consumption of large amounts of *F. mexiae* in several months throughout the year suggests that some species move to the park in these periods in search of this feeding resource.

Key words: Atlantic Forest, bat-plant interactions, seed dispersal, Serra da Mantiqueira.

INTRODUCTION

In tropical regions, approximately 90% of plants produce fruits with zoochoric syndrome (Fleming 1979) and 50% to 75% of tree species produce fleshy fruits adapted for bird or mammal consumption (Howe & Smallwood 1982). Among several mammal groups, the ecological importance of frugivory is highlighted in the Order Chiroptera (Kunz *et al.* 2011) given the large variety of fruits consumed by them (Fabián *et al.* 2008). In chiropterochoric fruits some traits, such as fleshy pulp, strong odor, green color when mature, persistence, and accessibility in the plant foliage are important (van der Pijl 1972).

Among Chiroptera species, frugivory is predominant in the Phyllostomidae family. In this family, Carolliinae, Phyllostominae and Stenodermatinae are the most representative subfamilies regarding fruit consumption (Fabián *et al.* 2008). The other bat families feed on fruits only occasionally (Lobova *et al.* 2009). In Brazil 189 plants have been recorded as a food resource for bat fauna (Fabián *et al.* 2008), and 33 species of bats consume the fruits of 90 plant species (Sette 2012).

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The species richness of chiropterochoric plants is important to maintain a diversified bat community throughout the year (Passos *et al.* 2003). For Fleming & Kress (2011), the preservation of interactions between bats and plants, as well as the habitats where this occurs, is essential to preserve the ecological and evolutionary dynamics of tropical forests. Furthermore, data from studies concerning bat-plant interactions are essential in developing conservation strategies (Passos *et al.* 2003). According to Brusco & Tozato (2009), bats are the main dispersers of seeds in the Atlantic Rainforest, which demonstrates the importance of these mammals and the need to investigate frugivory from different points of view.

There are few studies on the diet of frugivorous bats in montane areas (Giannini 1999, Mello *et al.* 2008). In the Atlantic Rainforest, a number of preserved forest remnants are located in high-altitude sites. This study aimed to describe the fruit consumption by Phyllostomidae bats, as well as the most important fruits in their diets in montane areas of the Atlantic Rainforest of the Parque Estadual do Ibitipoca, Minas Gerais State. The major interactions that exist in two areas of Ombrophilous Dense Forest inside the park were also confirmed.

MATERIAL AND METHODS

Study site. The Parque Estadual do Ibitipoca (PEI) (1488 ha; 1200-1784 m altitude) is located in the Serra da Mantiqueira, in an Atlantic Rainforest in southeastern Minas Gerais (21°42'S, 43°54'W) (Figure 1), in the municipalities of Lima Duarte, Santa Rita de Ibitipoca, and Bias Fortes. The climate is mesothermal highland tropical, with dry cold winters and rainy summers (Herrmann 2006). Grasslands cover 50% and forests 32% of the PEI area (Herrmann 2006).

We selected two areas of Montane Ombrophilous Dense Forest (Veloso *et al.* 1991) interspaced with grasslands. The first area, known as Mata de Grota (15 ha, 1300 m altitude), developed on rocks crev-

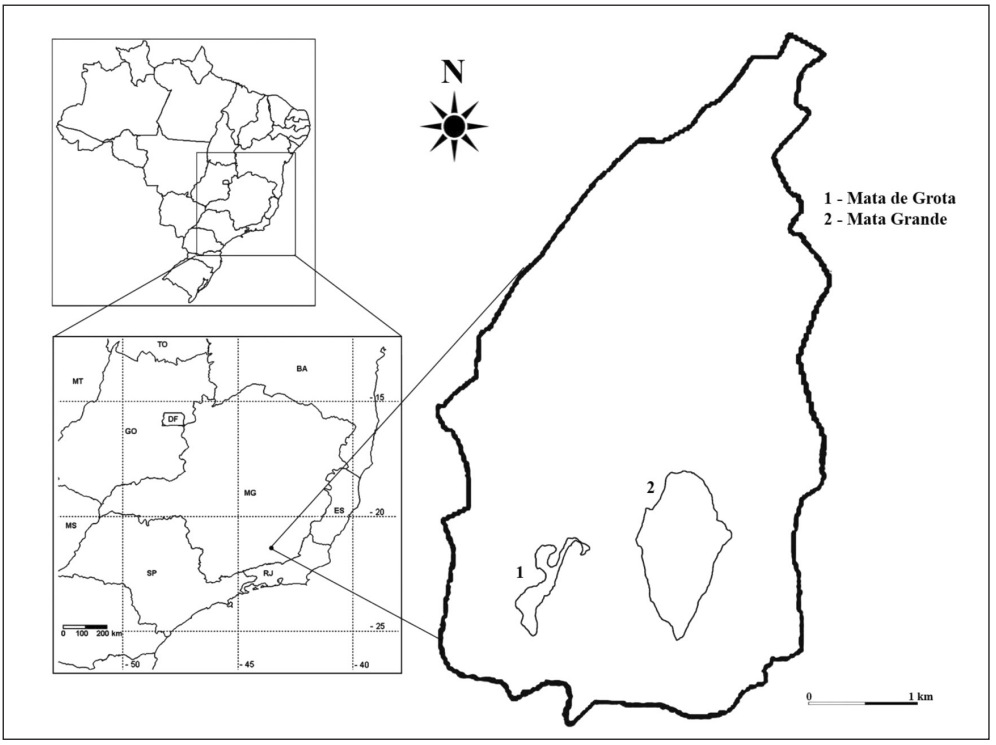

FIG. 1. Location of the Parque Estadual do Ibitipoca. The highlighted areas are the sampled Ombrophilous Dense Forests: 1. Mata de Grota, 2. Mata Grande.

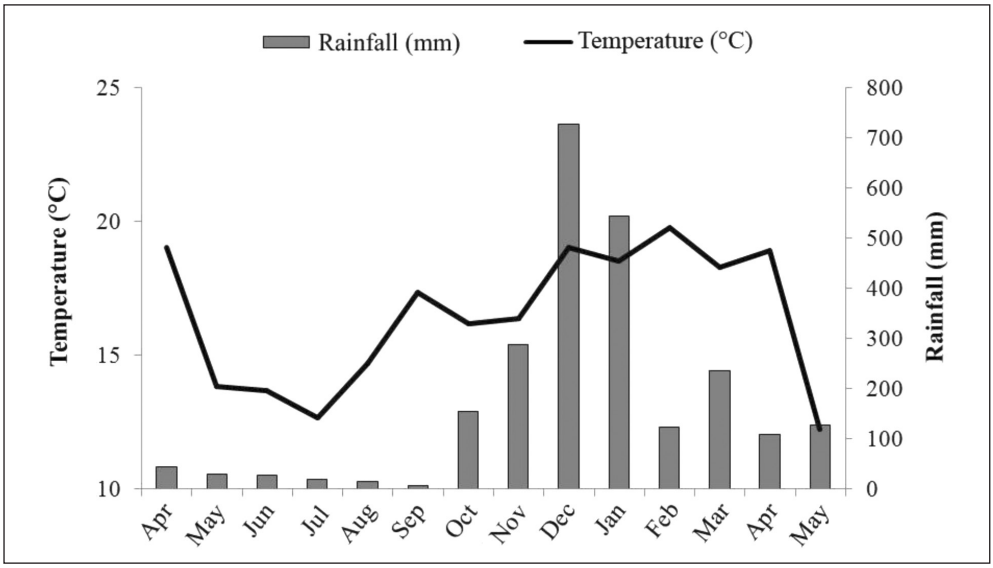

FIG. 2. Ombrothermic diagram relating to the months of study in the Parque Estadual do Ibitipoca (April 2011 to May 2012). The values represent the mean monthly temperature and the total monthly rainfall. Data provided by the Instituto Estadual de Florestas.

ices, with decayed material that fell from higher areas of the PEI, resulting in the development of tall vegetation (Dias *et al.* 2002). It is connected with semideciduous forests located outside the PEI boundaries. The second area, known as Mata Grande (94 ha, 1400 m altitude), is the main forest remnant in the PEI. It consists of a 17-m canopy with emergent trees to 25 m and several clearings (Rodela 1998).

Climatic data were obtained from the climate station in the PEI. The temperature varied from 5.3°C to 36.8°C, with mean of 19.9°C. The highest rainfall occurred between October 2011 and May 2012, and December 2011 was the wettest month (726.9 mm). The lowest rainfall value (7.5 mm) was recorded in September 2011 (Figure 2).

Capture of bats. Bat captures were carried out twice-monthly for 14 months from April 2011 to May 2012, with two nights of sampling in each month, except in April 2011 (three nights by area) and January 2012 (two nights in the Mata de Grota and one in the Mata Grande). In total, bats were sampled throughout 57 sampling nights, 26 in the Mata Grande and 31 in the Mata de Grota. Nights that had a dark moon were preferred and the interval between sampling visits was 15 days. Eight to ten mist nets (2.5 × 9 m × 36 mm) were used each night, installed 30 cm above the ground. The total capture effort (*cf.* Straube & Bianconi 2002) was 62 171.25 m^2h (34 503.75 m^2h^{-1} Mata de Grota and 27 667.5 m^2h^{-1} Mata Grande). The nets were opened at 18:00 h, remained open for six hours and were monitored every 15 minutes. Captured bats were kept for 1 hour in sterilized cotton bags, to collect feces. After this, bats were screened and fitted with collars color-coded for identification (Esbérard & Daemon 1999) and were then released in the same capture locations. Two individuals of each species were collected and deposited as voucher specimens in the Chiroptera collection of the Universidade Federal de Juiz de Fora.

Data analyses. Individual fecal samples were stored in tubes containing 70% alcohol and numbered according to the bat capture numbers. The collected material was screened in the laboratory under a stereo microscope to separate seeds, which were then washed and dried in an oven for 24 h prior to identification. To help identify these seeds, fruits were collected at the study sites. Voucher material was deposited in the Herbarium Leopoldo Krieger of the Universidade Federal de Juiz de Fora. From each

plant, seeds were removed from fruits, were dried and deposited in a collection of seed for comparison with fecal samples. Seed identification was performed with the aid of literature (Lorenzi 1998, Almeida *et al.* 2005, Lobova *et al.* 2009) and via consultations with experts.

For each bat species, we calculated the frequency of occurrence of each seed species based on the number of fecal samples where a seed species was present. The diversity of fruit species consumed by bats in the PEI was estimated using Simpson's Index of Diversity (1-D) for the whole sampling area and for each area individually; the differences between areas was inferred through bootstrap values. The Simpson Index was appropriate for our data as it provides a good estimation of diversity even for small sample sizes (Magurran 2004). The G-test was used to test for differences in the frequency of occurrence of seed species between areas. Statistical analyses were performed using PAST 2.15 and BioEstat 5.0 software (Hammer *et al.* 2001, Ayres *et al.* 2007).

RESULTS

In total, 400 captures were made, of which 48 were recaptures, and Phyllostomidae represented 98% (N = 392) of the total samples. Considering only captures, the most abundant species was *Sturnira lilium* (E. Geoffroy, 1810) with 59.9% (N = 206), followed by *Platyrrhinus lineatus* (E. Geoffroy, 1810) with 11.3% (N = 39), *Artibeus lituratus* (Olfers, 1818) with 8.7% (N = 30) and *Carollia perspicillata* (Linnaeus, 1758) with 7.6% (N = 26). The other Phyllostomidae species represented 12.5% (Table 1).

The number of fecal samples obtained from Phyllostomidae bats was 126, containing 14 seed species, five of which were identified to genus level, and insect fragments (Table 2). The seeds were mainly from *Solanum swartzianum* Roem. & Schult. (Solanaceae) (31.1%), *S. pseudoquina* A.St.-Hil. (9.2%), *Dyssochroma viridiflorum* (Sims) Miers (Solanaceae) (8.4%), and *Ficus mexiae* Standl. (Moraceae) (3.5%).

Of the total fruit species consumed by the bats, 12 were found in the Mata de Grota and eight in Mata Grande, but species richness did not differ (p = 0.6) between sites. However there was a pronounced difference (p = 0.006) in bat fruit diversity between Mata de Grota (1-D = 0.8257) and Mata Grande (1-D = 0.6361). In Mata Grande, Solanaceae species were the most common fruit in the diet of Phyllostomidae, occurring in 80% of samples, with *S. swartzianum* as the most common species (57.7%). In Mata de Grota, Solanaceae was found in 50% of fecal samples, but the commonest species was *F. mexiae* (29%) (Figure 3). The consumption of *F. mexiae* in Mata de Grota was higher than expected

TABLE 1. Number of captures (followed by percentages) of Phyllostomidae bats in the two forests Mata de Grota and Mata Grande, in the Parque Estadual do Ibitipoca.

Subfamily	Mata de Grota	Mata Grande	Total
Glossophaginae			
Anoura caudifer (E. Geoffroy, 1818)	12 (4)	-	12* (3.1)
Carolliinae			
Carollia perspicillata (Linnaeus, 1758)	28 (9.3)	7 (8.3)	35* (9.1)
Stenodermatinae			
Artibeus fimbriatus Gray, 1838	2 (0,7)	-	2 (0.5)
Artibeus lituratus (Olfers, 1818)	23(7.6)	7 (8.3)	30 (7.8)
Chiroderma doriae Thomas 1891	3 (1)	-	3 (0.8)
Pygoderma bilabiatum (Wagner, 1843)	1 (0.3)	-	1 (0.3)
Platyrrhinus lineatus (E. Geoffroy 1810)	40 (13.3)	1 (1.2)	41* (10.6)
Platyrrhinus recifinus (Thomas, 1901)	8 (2.7)	-	8 (2.1)
Sturnira lilium (E. Geoffroy, 1810)	173 (57.5)	69 (82.1)	242* (62.9)
Vampyressa pusilla (Wagner, 1843)	11 (3.7)	-	11 (2.9)
Total	301	84	385

TABLE 2. Frequency of occurrence of fruits and insect fragments found in fecal samples of Phyllostomidae bats captured in the Parque Estadual do Ibitipoca. Numbers in bold on the left represent the frequency in the samples from Mata de Grota, numbers in italics on the right the frequency at Mata Grande.

Food item	*Bat species**																Total
	AC	*Ac*	Af	*Af*	Al	*Al*	Cp	*Cp*	Pl	*Pl*	Pr	*Pr*	Sl	*Sl*	Vp	*Vp*	
	N=2		*N=1*		*N=7*		*N=13*		*N=13*		*N=2*		*N=85*		*N=3*		
Araceae																	
Philodendron sp.							2		1								3
Hypericaceae																	
Vismia brasiliensis Choisy							1						1				2
Melastomataceae																	
Miconia sp.								*1*						*1*			2
Moraceae																	
Ficus mexiae Standl.			1		7				12		2		5	*1*			28
Ficus sp.															1	*1*	2
Piperaceae																	
Piper richardiifolium Kunth								*1*					1				2
Piper sp.													6		1		7
Solanaceae																	
Dyssochroma viridiflorum (Sims) Miers							3						7				10
Solanum granuloso-leprosum Dunal													3				3
Solanum mauritianum Scop.							2						2	*2*			6
Solanum pseudoquina A. St.-Hil.								*1*					8	*2*			11
Solanum swartzianum Roem. &Schult.							1						20	*16*			37
Solanum sp.														*1*			1
Urticaceae																	
Cecropia glaziovii Snethl.								*1*					4				5
Insects	2												4	*1*			7
Total	2	*0*	1	*0*	7	*0*	9	*4*	13	*0*	2	*0*	61	*24*	2	*1*	126

* The bat species were abbreviated as: Ac = *Anoura caudifer*; Af = *Artibeus fimbriatus*; Al = *Artibeus lituratus*; Cp = *Carollia perspicillata*; Pl = *Platirrhynus lineatus*; Pr = *Platirrhynus recifinus*; Pb = *Pygoderma bilabiatum*; Sl = *Sturnira lilium*; Vp = *Vampyressa pusilla*.

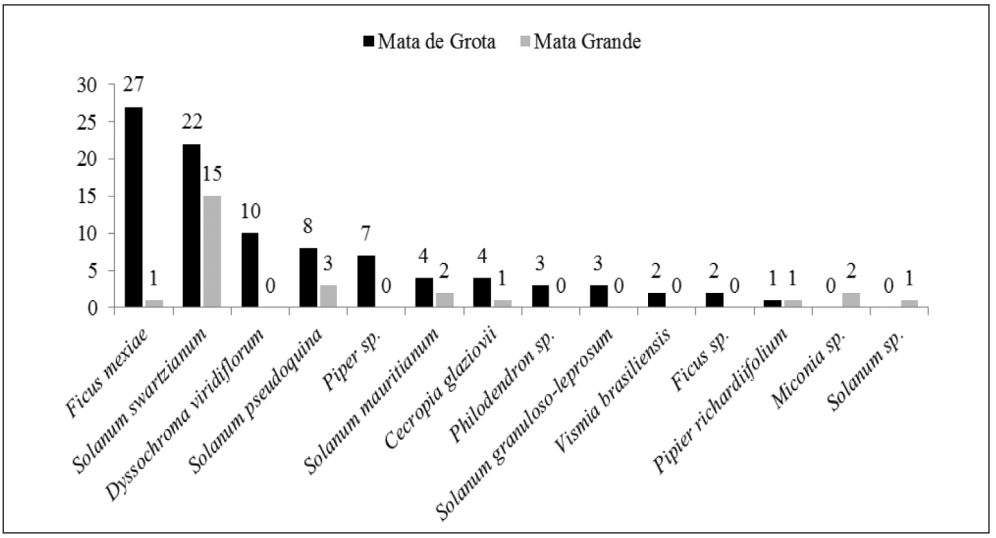

FIG. 3. Frequency of occurrence of fruits consumed by Phyllostomidae bats in the areas of Mata de Grota and Mata Grande in the Parque Estadual do Ibitipoca

(G^2 = 9.7397, g.l. = 1, p = 0.0018). In contrast, the consumption of *S. swartzianum* was associated with Mata Grande (G^2 = 10.5431, g.l = 1, p = 0.0012).

The highest number of fecal samples was obtained from *S. lilium* (N = 85), followed by *C. perspicillata* (N = 13) and *P. lineatus* (N = 13), while the remaining species did not exceed seven samples each (Table 2). *Sturnira lilium* consumed 12 fruit species, in addition to insect fragments, which were found in five samples. Seeds were found in 94.1% of samples (N = 80) from *S. lillium*, most of which were from the family Solanaceae, occurring in 71.8% (N = 61) of the samples. The consumption of Solanaceae by *S. lilium* was higher in Mata Grande than in Mata de Grota (G^2 = 4.1358, g.l. = 1, p = 0.0420), and the frequencies of occurrence in each area were 90.9% and 70.7% respectively. *Carollia perspicillata* consumed nine seed species, also predominantly Solanaceae. The second most consumed plant species was *F. mexiae*, which was found in 28 fecal samples and consumed mostly by *P. lineatus*, *A. fimbriatus* and *S. lillium*. *Vampyressa pusilla* consumed *Ficus* and one species of the genus *Piper* (Table 2). Solanaceae seeds were found in samples in all months except October 2011. Other plant families occurred sporadically (Table 3).

TABLE 3. Monthly plant families observed in fecal samples of Phyllostomidae bats in the Parque Estadual do Ibitipoca.

Family	2011								2012					
	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Araceae						X								X
Hypericaceae	X													
Melastomataceae	X												X	
Moraceae	X	X	X											X
Piperaceae	X													
Solanaceae	X	X	X	X	X	X	X		X	X	X	X	X	X
Urticaceae									X				X	

DISCUSSION

In Mata de Grota, a large number of plants belonging to the Solanaceae, Piperaceae, Moraceae and Urticaceae families (personal observation) were observed, whose fruits are widely consumed by bats (Lobova *et al.* 2009). Areas with a greater occurrence of these plant families provide a higher food supply for frugivorous bats (Muscarella & Fleming 2007). Thus the scenario observed in Mata de Grota can explain the higher diversity of Phyllostomidae bats in this area compared with Mata Grande, where the Lauraceae, Melastomataceae and Rubiacaeae families dominated (Carvalho *et al.* 2000), whose fruits are rarely consumed by bats (Lobova *et al.* 2009).

Some fruits had high consumption by bats in the PEI. *Ficus mexiae* was the only recorded species of the genus *Ficus* (R.C. Forzza *et al.*, unpublished data), and its higher consumption in the Mata de Grota might be due to its intense fruiting in the months with highest capture rates, as well as to the high activity of frugivorous bats in these tree canopies. With regard to the Solanaceae, there was a predominance of fruits from this family in the diet of *S. lilium*, as described in other studies (Passos *et al.* 2003, Fabián *et al.* 2008, Lobova *et al.* 2009), mainly at high altitude (Giannini 1999, Mello *et al.* 2008). Despite the high abundance of *S. lilium* in Mata de Grota, Solanaceae was proportionally more represented in the diet of this bat species in Mata Grande. This difference might be related to the availability of food, since in Mata Grande *S. swartzianum* was consumed only by *S. lilium*, suggesting that the plant is an important food resource for this bat species in Mata Grande. The exclusive consumption of *S. swartzianum* by *S. lilium* was also observed by Passos *et al.* (2003) in an Atlantic Forest area in São Paulo State. However, in Mata de Grota one fecal sample of *C. perspicillata* contained *S. swartzianum*.

According to Herrera *et al.* (2002), insect consumption by frugivorous bats is associated with protein supply in periods of low fruiting, but this consumption might also be related to insects that are associated with the fruits when the bats feed on them. However there are a few records of insect consumption by *S. lilium* (Herrera *et al.* 2001). In studies by Mello *et al.* (2008), *S. lilium* showed an entirely frugivorous diet, though in the PEI five samples from *S. lilium* contained insects.

Bats of the genus *Carollia* consumed mainly fruits of the genus *Piper* (Marinho-Filho 1991, Lopez & Vaughan 2007), though in Ibitipoca *C. perspicillata* fed more on Solanaceae fruits, with those of the genus *Solanum* being the most consumed (30.8%), though those of *Dyssochroma viridiflorum* had the highest occurrence (23.1%). This fruit also occurred in fecal samples of *S. lilium* (8.8%) but at a lower frequency. The species *C. perspicillata* and *S. lilium* play an important role in the seed dispersal of *D. viridiflorum* (Sazima *et al.* 2003, Verçoza *et al.* 2012). Furthermore, the number of Solanaceae fruits chosen in Mata de Grota was clearly higher than that of Piperaceae (personal observation). In this area, more *C. perspicillata* individuals were captured, therefore more fecal samples derived from these bats. The abundance of Solanaceae species in this area probably contributed to the fact that the diet observed for *C. perspicillata* in the PEI was different from the pattern observed at other sites, where this species consumed more Piperaceae fruits (Marinho-Filho 1991, Lima & Reis 2004). In studies on the variation in the diet of *C. perspicillata*, Mello *et al.* (2004) observed that when *Piper* is not consumed, fruits of *Solanum* predominate in the diet of *C. perspicillata*. Further studies on the diet of *C. perspicillata* and its relationship with other bat species might clarify the relationship between their feeding habits and the resources present in the PEI.

The species *P. lineatus* was mainly captured in Mata de Grota (92.8%), where it consumed almost only *F. mexiae*, and the importance of fruits of the genus *Ficus* in the diet of *P. lineatus* has been observed in other studies (Muller & Reis 1992, Sartore & Reis 2012). This bat was captured only in April and May 2011 and 2012, which are periods of intense *F. mexiae* fruiting. Thus the occurrence of *P. lineatus* in the PEI appears to be associated with the fruiting period of *F. mexiae*. Due to the remarkable abundance of these fruits they also represented 92% of *P. lineatus* diet.

In several studies, *A. lituratus* is commonly associated with the high consumption of *Ficus* (Muller & Reis 1992, Passos & Graciolli 2004, Sartore & Reis 2012). This was corroborated by data obtained at the PEI, since the fecal samples of this species only contained seeds of *F. mexiae* and captures occurred concomitantly with the fruiting period of this plant. However, according to Galetti & Morellato (1994) and Passos & Graciolli (2004), *A. lituratus*

becomes more generalist in the absence of its preferred food item, which was corroborated by Novaes & Nobre (2009) who confirmed that when *A. lituratus* did not find its preferred food item it fed on alternative food resources such as exotic fruits and leaves in urban areas. In the PEI, *A. lituratus* was captured mainly next to fruit-bearing *F. mexiae* inidviduals, suggesting that the population of this species is present mainly in areas where the fruits of such plant species are available.

Seed dispersal by bats is an important ecological mechanism in forest restoration (Muscarella & Fleming 2007). According to Campassi (2006), zoochoric plant species present in remnants of the Ombrophilous Dense Forest, such as those in the sampled areas of the PEI, are mostly dispersed by birds, whereas mammals dominate as seed dispersers in deciduous forests. In addition to the low proportion of plant species dispersed by mammals in the Ombrophilous Forest, little-known or uncommon feeding habits were recorded in the PEI. Due to the shortage of studies relating to the feeding habits of frugivorous bats from montane forests, it is possible that several interactions among bats and plants remain unknown. The data presented here for the PEI suggest an important relationship between Phyllostomidae frugivorous bats and plant composition in the altitudinal Atlantic Rainforest. Therefore further studies should be carried out in these remnants, to increase not only our knowledge about bat diversity but also its influence on forest restoration and maintenance of the vegetation in these areas.

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APPENDIX 1. Voucher specimens deposited in the Chiroptera collection of Universidade Federal de Juiz de Fora.

Anoura caudifer UFJF/DCN – 441, UFJF/DCN – 454; *Carollia perspicillata* UFJF/DCN – 412; *Artibeus fimbriatus* UFJF/DCN – 368; *Artibeus lituratus* UFJF/DCN – 83; *Chiroderma doriae* UFJF/DCN – 372, UFJF/DCN – 373; *Pygoderma bilabiatum* UFJF/DCN – 437; *Platyrrhinus recifinus* UFJF/DCN – 382; *Sturnira lilium* UFJF/DCN – 442; *Vampyressa pusilla* UFJF/DCN – 385, UFJF/DCN – 387.