Euglossine bee communities in small forest fragments of the Atlantic Forest, Rio de Janeiro state, southeastern Brazil (Hymenoptera, Apidae)

Willian Moura de Aguiar[1,2] & Maria Cristina Gaglianone[2]

[1]Laboratório de Estudos Ambientais, Programa de Pós-Graduação em Modelagem em Ciências da Terra e do Ambiente, Universidade Estadual de Feira de Santana. BR 116, Km 03, Campus Universitário, Feira de Santana-BA, 44031–460. wmag26@yahoo.com.br
[2]Laboratório de Ciências Ambientais, Programa de Pós-Graduação em Ecologia e Recursos Naturais, Universidade Estadual do Norte Fluminense Darcy Ribeiro. Av. Alberto Lamego, 2000, Parque Califórnia, Campos dos Goytacazes-RJ, 28013–602. mcrisgag@uenf.br

ABSTRACT. Euglossine bee communities in small forest fragments of the Atlantic Forest, Rio de Janeiro state, southeastern Brazil (Hymenoptera, Apidae). Euglossine bees are important pollinators in forests and agricultural areas. Although the structure of their communities is critically affected by anthropogenic disturbances, little is known about these bees in small forest fragments. The objectives of this study were to analyze the composition, abundance, and diversity of euglossine bee species in nine small fragments of different phytophysiognomies of the Atlantic Forest in southeastern Brazil, and to identify the environmental variables that may be related to the species composition of these communities. Males were sampled quarterly from May 2007 to May 2009 with aromatic traps containing methyl cinnamate, vanillin, eucalyptol, benzyl acetate, and methyl salicylate. A total of 1558 males, belonging to 10 species and three genera of Euglossina were collected. The richness ranged from five to seven species per fragment. *Euglossa cordata, E. securigera, Eulaema nigrita e E. cingulata* were common to all fragments studied. The diversity differed significantly among areas, ranging from H' = 1.04 to H' = 1.65. The precipitation, phytophysiognomy, and altitude had the highest relative importance over the species composition variation. The results presented in this study demonstrate that small forest fragments are able to support populations of euglossine bee species, most of which are widely distributed and reportedly tolerant to open and/or disturbed areas and suggest that the conservation of such areas is important, particularly in areas that are regenerating and in regions with agricultural matrices where these bees can act as important pollinators.

KEYWORDS. Chemical baits; fragmentation; loss habitat; orchid bees; solitary bees.

RESUMO. Comunidade de abelhas Euglossina em pequenos fragmentos de Mata Atlântica no estado do Rio de Janeiro, sudeste do Brasil (Hymenoptera, Apidae). Abelhas Euglossina são importantes polinizadores nas florestas e em áreas agrícolas. Embora a estrutura dessas comunidades seja criticamente afetada por perturbações antrópicas, pouco é conhecido a respeito destas abelhas em pequenos fragmentos florestais. Os objetivos deste estudo foram analisar a composição, abundância e diversidade de espécies em nove pequenos fragmentos florestais de diferentes fitofisionomias no sudeste do Brasil, e identificar as possíveis variáveis ambientais que podem estar relacionadas à composição de espécies de Euglossina. Os machos foram amostrados trimestralmente de maio/07 a maio/09 com o auxílio de armadilhas aromáticas contendo cinamato de metila, vanilina, eucaliptol, acetato de benzila e salicilato de metila. Foram amostrados 1558 machos de três gêneros e 10 espécies. A riqueza variou de cinco a sete espécies por fragmento. *Euglossa cordata*, *E. securigera*, *Eulaema cingulata* e *E. nigrita* foram comuns a todos os fragmentos estudados. A diversidade diferiu significativamente entre as áreas estudadas, variando de H' = 1.04 até H' = 1.65. A precipitação, o tipo fitofisionômico e a altitude tiveram alta importância relativa sobre a variação da composição de espécies. Os resultados apresentados neste estudo demonstram que pequenos fragmentos podem suportar populações de abelhas Euglossina que, em sua maioria, são amplamente distribuídas e supostamente tolerantes a ambientes abertos e perturbados e sugerem que a conservação dessas áreas pode ser de grande importância, principalmente em regiões em processo de regeneração e com matrizes agrícolas, onde essas abelhas podem atuar como polinizadores.

PALAVRAS-CHAVE. Abelhas de orquídeas; abelhas solitárias; fragmentação; iscas aromáticas; perda de habitat.

The Atlantic Forest comprises different ecosystems of great ecological importance and is considered one of the principal conservation hotspots due to its high level of endemism and elevated number of threatened species (Myers *et al.* 2000). The Atlantic Forest has been subjected to constant aggression since the colonial period, and particularly from the 1960s to the 1980s with the recent period of expansion of agriculture and industrialization happened in Brazil (Rizzini 1979; Fundação SOS Mata Atlântica & INPE 2008). Today less than 8% of the forest's original area has been preserved (Fundação SOS Mata Atlântica/INPE 2011) and most of the remaining forests, especially in areas of intense agriculture, are less than 10 ha, isolated, highly disturbed, little studied, and unprotected (Rocha *et al.* 2003).

Environmental changes caused by anthropic activities, particularly the fragmentation and habitat loss, are considered the main cause of the decline of pollinators (Aizen & Feinsinger 2003; Fahrig 2003; Goulson *et al.* 2008; Winfree *et al.* 2009; Potts *et al.* 2010). Insects, more specifically bees, are the principal pollinators of native and cultivated plants. Alterations in the environment such as the fragmentation and habitat loss promote consequences among pollinators that are still not fully understood (Potts *et al.* 2010).

Bees belonging to the subtribe Euglossina (*sensu* Silveira *et al.* 2002) are important pollinators in tropical and subtropical forests (Dressler 1982; Roubik & Hanson 2004), where they may pollinate plants from more than 40 botanical families, including species of economic interest. Interaction with certain species is quite limited, as in the case of Orchidaceae, in which case approximately 700 species are exclusively dependent on these insects for their pollination (Dressler 1982; Mori & Boeke 1987; Maués 2002; Cameron 2004; Roubik & Hanson 2004).

Several studies have investigated the impact of fragmentation and habitat loss on euglossine bee communities (Becker *et al.* 1991; Morato 1994; Tonhasca *et al.* 2002; Sofia & Suzuki 2004; Brosi 2009; Ramalho *et al.* 2009; Nemésio & Silveira 2010). The results obtained in some of these studies suggested a negative effect of the fragmentation on populations of some species, which could lead to a decline of the abundance and species richness of these bees (Powell & Powell 1987; Morato 1994; Sofia & Suzuki 2004; Ramalho *et al.* 2009; Nemésio & Silveira 2010).

In recent decades, the results of a growing number of studies have demonstrated that the conservation value of small fragments must not be ignored (Tscharntke *et al.* 2002). Small forest fragments can increase landscape connectivity (Dunning *et al.* 1992) and provide the habitats for animal species (for example, birds: Fischer & Lindenmayer 2002; beetles: Estrada & Coates-Estrada 2002; butterflies: Benedick *et al.* 2006) and the maintenance of ecological services such as pollination (Bodin *et al.* 2006).

Studies dealing with the importance of forest fragments as sources of pollinators for agricultural crops demonstrate that these remaining forests provide such plantations with greater richness and abundance of pollinating agents, and increased pollination efficiency (Ricketts 2004; Chacoff & Aizen 2006; Benevides *et al.* 2009). Thus, the conservation of forest fragments should be encouraged in agricultural regions, especially in the Atlantic Forest, where the majority of fragments are found on small rural properties with diverse agricultural activities (Rocha *et al.* 2003; Fundação SOS Mata Atlântica & INPE 2008).

Despite the recognized importance of euglossine bees as pollinating agents, few studies (Tonhasca *et al.* 2002; Sofia & Suzuki 2004; Ramalho *et al.* 2009; Nemésio & Silveira 2010) have analyzed the euglossine bee community in small forest fragments under the domain of the Atlantic Forest. Therefore, the objectives of this work were to: 1) comparatively analyze the composition, abundance, and diversity of euglossine bee species in small fragments of different formations of the Atlantic Forest in northern Rio de Janeiro state, and 2) identify if abiotic variables (temperature, humidity, precipitation and altitude) and the phytophysiognomic type may be related to the species composition of these communities.

MATERIAL AND METHODS

Study areas. The study was carried out in nine forest fragments of less than 20 ha under Atlantic Forest domain with different phytophysiognomic formations in the northern and northeastern regions of Rio de Janeiro State, Brazil, in accordance with the classification of Veloso *et al.* (1991). Two fragments (F1 and F2) of seasonal semideciduous lowland forest (SSLF), located in São Francisco de Itabapoana; four fragments (F3, F4, F5 e F6) of submountainous semideciduous seasonal forest (SSSF), in the municipality of São José de Ubá, and three fragments (F7, F8 e F9) of dense mountainous ombrophilous forest (DMOF), in Trajano de Moraes were selected. The distance between the fragments studied varied from 0.05 to 135 km (Fig. 1). All fragments are composed of secondary forest vegetation and are located on private properties, with the exception of two studied areas, which are located on the grounds of the Municipal Forest Unit of Trajano de Moraes (F7 and F8). The study areas present distinct local characteristics, such as altitude, matrix around, and phytophysiognomy (Table I).

In the SSLF and SSSF region the climate, according to the Köppen classification, is Aw, with elevated temperatures, rainy summers, and dry winters. In the DMOF region the climate is classified as Cwa, with a moderately humid climate, dry winters, and hot summers (Fig. 2).

Sampling protocol. Euglossine males were sampled every three months between 9:00 AM and 3:00 PM from May 2007 to May 2009, totaling 60 sampling hours in 10 days in each area. The captures were realized with aromatic traps containing the following baits as attractants: methyl cinnamate, vanillin, eucalyptol, benzyl acetate, and methyl salicylate, as utilized by Aguiar & Gaglianone (2008a) and Ramalho *et al.* (2009). Baits were applied to cotton balls inside the traps, which were placed 1.5m from the soil with a minimum distance of 2m between each attractant. Captured specimens were deposited in the Zoology Collection of the Environmental Sciences Laboratory of the Universidade Estadual do Norte Fluminense.

Taxonomic identification was performed through comparisons with previously identified material in the above collection, based on taxonomic keys and publications, and by the specialist Dr. Gabriel A.R. Melo (Universidade Federal do Paraná). Taxonomic decisions were based on classification adopted in Moure's Bee Catalogue (Moure *et al.* 2008).

Data analysis. Species diversity, dominance, and uniformity in species-abundance distribution were calculated, respectively, with the Shannon-Wiener Diversity Index, Berger-Parker Index, and Pielou Index (Magurran 2004).

The equitability of the species distribution in the study areas were analyzed with the Rank-Abundance Plot, whereby species' relative abundances were plotted in decreasing order (Whittaker 1965) and the difference between the curves obtained for the different areas was analyzed with the Kolmogorov-Smirnov Test (Magurran 2004).

The frequency of occurrence (FO) and dominance (D) were calculated according to Bodenheimer (1955) for each species sampled: FO = (number of samples with the species/ number of samples)* 100. When FO $\geqslant$ 50%, the species is considered very frequent (vf), when FO < 50% and $\geqslant$ 25%, the species is frequent (f), when FO < 25%, the species is labeled infrequent (in). Dominance was calculated as: D = (Abundance of species i/total abundance)* 100. When D $\geqslant$ 5%, the species is considered dominant (d), when

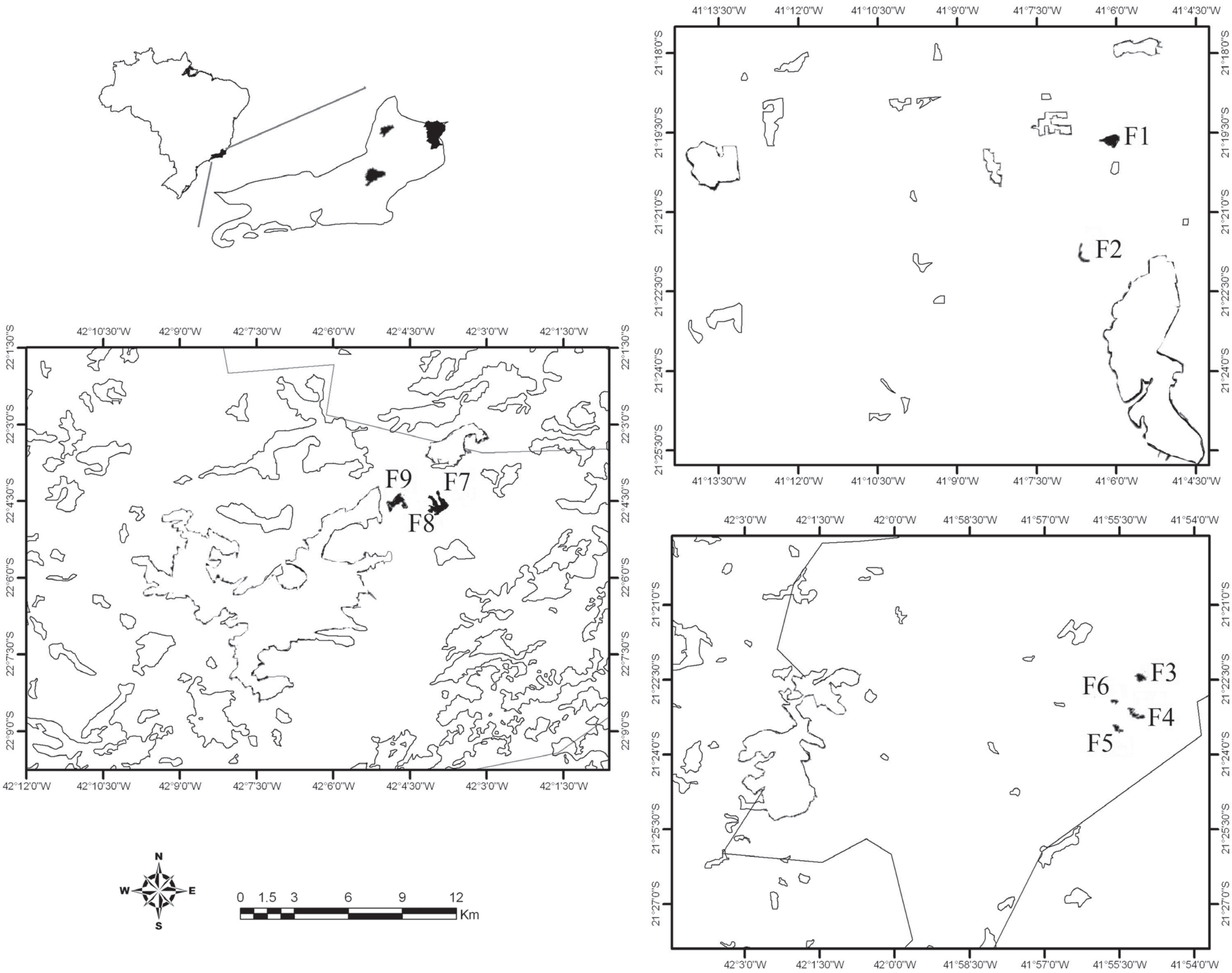

Fig. 1. Location of the nine small forest fragments studied for the Euglossine bee communities in Rio de Janeiro state, southeastern Brazil, from May/2007 to May/2009. Black areas indicate fragments studied, outlined areas indicate fragments nearby.

Table I. Location of the study areas, phytophysiognomic type, fragment sizes, altitude, and type of matrix surrounding each forest fragment. SFI: São Francisco de Itabapoana, RJ, SJU: São José de Ubá-RJ and TRJ: Trajano de Moraes, RJ. SSLF: seasonal semideciduous lowland forest; SSSF: submountain semideciduous seasonal forest and DMOF: dense mountainous ombrophilous forest.

Areas	Municipality	Coordinates	Size (ha)	Phytophysiognomy	Altitude (m)	Matrix
F1	SFI	21º19'36"S 41º06'04"W	16.0	SSLF	40	Sugarcane, coconut, mango, manioc, and passionfruit
F2	SFI	21º21'53"S 41º06'04"W	5.5	SSLF	16	Pasture and sugarcane
F3	SJU	21º23'30"S 41º55'30"W	4.0	SSSF	200	Pasture, tomato, and bell pepper
F4	SJU	21º22'31"S 41º55'04"W	7.6	SSSF	250	Pasture
F5	SJU	21º22'53"S 41º55'37"W	2.0	SSSF	200	Pasture, tomato, eggplant, and cucumber
F6	SJU	21º23'10"S 41º55'15"W	6.6	SSSF	200	Pasture and tomato
F7	TRJ	22 º04'20"S 42º03'56"W	14.0	DMOF	710	Pasture and urban area
F8	TRJ	22º04'37"S 42º04'00"W	12.0	DMOF	740	Pasture, eucalyptus, and urban area
F9	TRJ	22°04'31"S 42°04'42"W	18.0	DMOF	825	Pasture, eucalyptus, peach, kaki, and banana

D < 5% and ⩾ 2.5%, the species is accessory (a), and when D < 2.5%, the species is occasional (oc). When analyzed together, these indices have been used to group the species into three categories (Ct): vf + d = common species, in + oc = rare species, and other combinations = intermediate species (adapted from Palma 1975).

To compare the diversity index among the euglossine bee community the estimated Shannon-Wiener were transformed

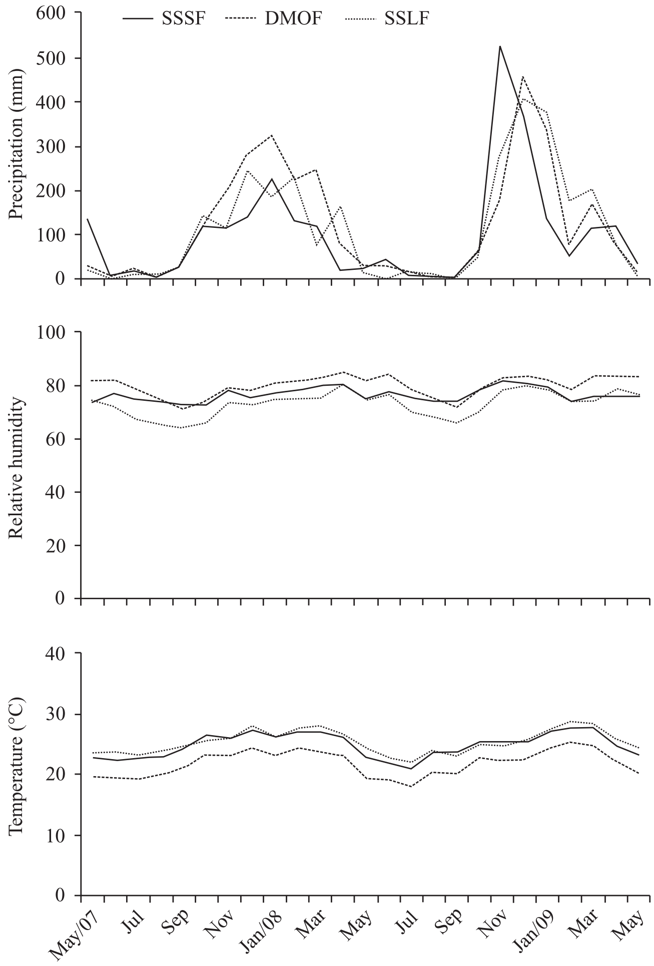

Fig. 2. Climate data from May/2007 to May/2009 for the three regions studied (source: INMET- National Meteorological Institute).

to exponential of the Shannon-Wiener index: exp(H'). In addition, the Jackknife procedure was performed to estimate the Shannon-Wiener index, resulting in a confidence interval of 95%. These intervals were compared and non-overlapping intervals were considered significantly different (Zahl 1977). Estimates were performed using the program SPADE (Species Prediction and Diversity Estimation) (Chao & Shen 2005).

The rarefaction curve for species richness was expressed as a function of 1000 randomization, as described by Magurran (2004). This analysis was performed with EcoSim 7 software (Gotelli & Entsminger 2004). Curves were obtained by plotting the values simulated by EcoSim on the software Past 1.91.

The Software EstimateS 8.0 (Colwell 2006) was employed for calculating the non-parametric richness estimators (Chao1, Jack1 and Bootstrap) to confirm the sample sufficiency.

The ordenation among the communities of euglossine bees in the study areas was performed by using Detrended Correspondence Analysis (DCA), from the matrix of abundance of individuals in each forest fragment sampled. The DCA was employed because it is commonly applied to represent patterns of gradual replacement of species along environmental gradients (Ter Braak 1995). Later, the first two axes of DCA were used to check the relationship with precipitation, humidity, temperature and altitude of each area studied by Pearson's linear correlation. The axes of the DCA have also been used to investigate the relationship with the vegetational type using analysis of variance (ANOVA).

Spearman´s correlation was conducted among abiotic (temperature, humidity, precipitation and elevation) and biotic (vegetation type) variables and the abundance of each species to verify the relation of the patterns of abundance in each fragment studied. These analyzes were performed with the aid of software Statistica 8.0.

RESULTS

Euglossine bee community in the small fragments. During the study period 1,558 male euglossine bees belonging to three genera and ten species were sampled in the nine forest fragments (Table II). The forest fragments with the highest abundance of bees were F5 (316 individuals), followed by F4, F6, and F3 (264, 243, 212 individuals, respectively), all fragments in submountainous semideciduous seasonal forest areas (SSSF). The fragments of dense mountainous ombrophilous forest (DMOF), however, presented the lowest abundance of bees (F9, 92 individuals; F8, 75, and F7, 68). In the fragments of semideciduous seasonal lowland forest (SSLF), the abundances were intermediate when compared with the other areas studied (F1, 159 individuals and F2, 129) (Table II).

Species richness varied from five to seven in each fragment (Table II). *Euglossa cordata* (Linnaeus, 1758), *Euglossa securigera* Dressler, 1982, *Eulaema cingulata* (Fabricius, 1804), and *Eulaema nigrita* Lepeletier, 1841 were common to all fragments studied. On the other hand, *Euglossa annectans* Dressler, 1982 only occurred in fragments F7 and F9, *Euglossa pleosticta* Dressler, 1982 in fragment F8, and *Eulaema atleticana* Nemésio, 2009 in F1. Individuals of *Euglossa despecta* Moure, 1968 were restricted to fragments of SSSF and *Eulaema atleticana* to fragment F1. *Exaerete smaragdina* (Guérin, 1844) was not sampled in DMOF fragments (Table II).

Eulaema nigrita was dominant in all seasonal semideciduous lowland forest and dense mountainous ombrofilous forest fragments, representing between 40% and 59% of the individuals sampled; *Euglossa cordata* was dominant in all SSSF fragments, where it was represented by 26% to 39% of the individuals (Table II). The euglossine bee communities presented uniformity varying between J = 0.68 and J = 0.82 in the fragments studied (Table II).

The diversity of species differed significantly among the studied areas, ranging from H' = 1.04 in F2 to H' = 1.65 in F4. The lowest diversity values were observed for the communities of the SSLF fragments and the highest values in the SSSF fragments (Table III).

Table II. Composition, total abundance, richness, diversity, uniformity, and dominance (D), of the Euglossina species sampled trimesterally between May 2007 and May 2009 in nine fragments of Atlantic Forest in the Rio de Janeiro state, southeastern Brazil. SSLF- semideciduous seasonal lowland forest, SSSF- submountain semideciduous seasonal forest, and DMOF- dense mountainous ombrophilous forest. Ct: Category: C = common species, I = intermediate species, and R = rare species.

Species	Study Areas													Total
	SSLF			SSSF					DMOF					
	F1	F2	Ct	F3	F4	F5	F6	Ct	F7	F8	F9	Ct		
Euglossa annectans Dressler	0	0	–	0	0	0	0	–	3	0	11	C		14
E. cordata (L.)	61	39	C	72	72	83	93	C	3	5	5	C		433
E. despecta Moure	0	0	–	1	3	3	1	R	0	0	0	–		8
E. fimbriata Rebêlo & Moure	0	0	–	9	36	44	18	C	0	4	1	R		112
E. pleosticta Dressler	0	0	–	0	0	0	0	–	0	1	0	R		1
E. securigera Dressler	1	2	R	55	37	76	42	C	8	17	8	C		246
Eulaema atleticana Nemésio	1	0	R	0	0	0	0	–	0	0	0	–		1
E. cingulata (Fabricius)	19	7	C	26	55	26	25	C	22	18	23	C		221
E. nigrita Lepeletier	67	76	C	49	60	82	62	C	32	30	44	C		502
Exaerete smaragdina (Guérin)	10	5	C	0	1	2	2	R	0	0	0	–		20
Abundance	159	129		212	264	316	243		68	75	92			1558
Richness	6	5		6	7	7	7		5	6	6			10
Diversity (H')	1.25	1.04		1.49	1.65	1.61	1.52		1.28	1.48	1.418			1.61
Uniformity (J)	0.68	0.64		0.80	0.80	0.82	0.78		0.78	0.80	0.77			0.70
Dominance (D)	0.42	0.59		0.3	0.3	0.26	0.39		0.47	0.40	0.48			0.33

Table III. Comparison of species diversity of euglossine bees in nine small forest fragments in the Rio de Janeiro state, southeastern Brazil. Diversity was calculated from the exponential [exp (H')] and estimated (H') Shannon-Wiener index. LL CI95% = lower limit of the confidence interval; UL CI95% = upper limit of the confidence interval. The overwrite lowercase letters to the estimated H' indicated differences between the areas studied.

Areas	Exp. H'	H' estimated	LL CI 95%	UL CI 95%
F4	5.21	1.65[a]	1.58	1.71
F5	5.00	1.61[ab]	1.55	1.67
F6	4.59	1.52[abc]	1.43	1.61
F3	4.42	1.49[bc]	1.41	1.57
F8	4.4	1.48[abcd]	1.3	1.66
F9	4.08	1.41[abcd]	1.23	1.58
F7	3.59	1.28[cde]	1.09	1.47
F1	3.48	1.25[de]	1.12	1.37
F2	2.83	1.04[e]	0.88	1.19

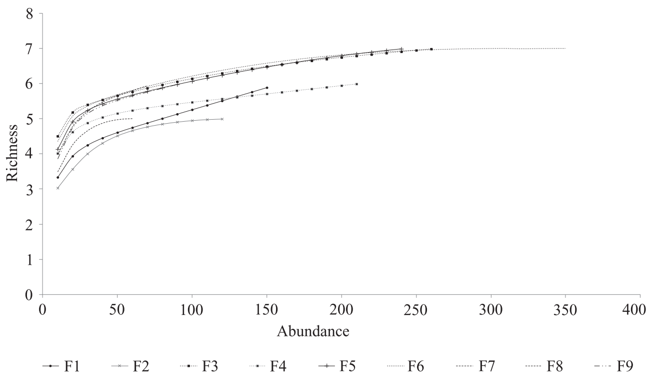

Fig. 3. Rarefaction curves with 1,000 simulations for species richness for nine small forest fragments of the Atlantic Forest, Rio de Janeiro state, southeastern Brazil.

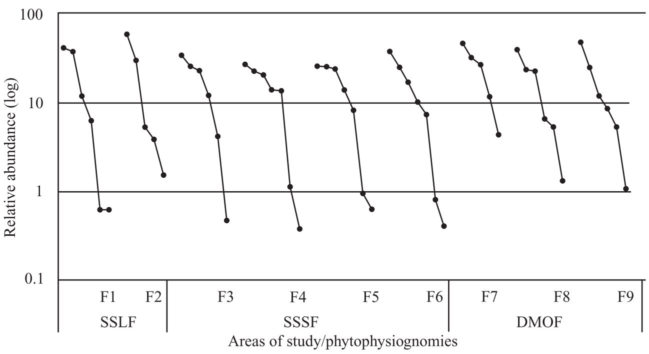

Fig. 4. Species importance (Rank-abundance plot, Whittaker [1965]) according to relative abundance of euglossine bees attracted to aromatic baits between May/2007 and May/2009 in nine small forest fragments of the Atlantic Forest, Rio de Janeiro state, southeastern Brazil.

The rarefaction curves for the nine fragments analyzed demonstrated sampling sufficiency for almost all the areas, with the exceptions of F1 and F6 (Fig. 3), which is confirmed by richness estimators (Table IV). The values of the richness curves indicated no significant difference in the number of euglossine species among the nine small forest fragments studied (Fig. 3).

The curves obtained for species importance (Rank-Abundance Plot) did not present significant difference compared with all the fragments (according to the Kolmogorov-Smirnov Test, $p > 0.05$) (Fig. 4). In general, observations showed that most species were represented by more than 10% of the individuals in each area resulting in higher number of common species than rare or intermediate species (Table II).

Table IV. Richness estimators for the euglossine bees in nine small forest fragments in the Rio de Janeiro state, southeastern Brazil, between May 2007 and May 2009.

Richness estimator	SSLF		SSSF				DMOF		
	F1	F2	F3	F4	F5	F6	F7	F8	F9
Jack1	7.8 ± (1.2)	5.9 ± (0.9)	6.9 ± (0.9)	6.0 ± (0)	7.9 ± (0.9)	8.8 ± (1.8)	6.9 ± (0.9)	5.0 ± (0)	6.9 ± (0.9)
Chao1	7.0 ± (2.2)	5.0 ± (0)	6.0 ± (0.5)	6.0 ± (0)	7.0 ± (0)	7.0 ± (0.3)	6.0 ± (0.5)	5.0 ± (0)	6.0 ± (0.5)
Bootstrap	6.7 ± (0)	5.5 ± (0)	6.3 ± (0)	6.1 ± (0)	7.4 ± (0)	7.7 ± (0)	6.4 ± (0)	5.2 ± (0)	6.4 ± (0)

The ordination methods (Detrended Correspondence Analysis) among the euglossine bee communities studied resulted in three groups that coincide with the phytophysiognomies analyzed (Fig. 5). The eigenvalue in the axes 1 and 2 were, respectively, 0.16 and 0.11. The variance percentage explained by the axes 1 was 45.27% and by axes 2 was 31.76%.

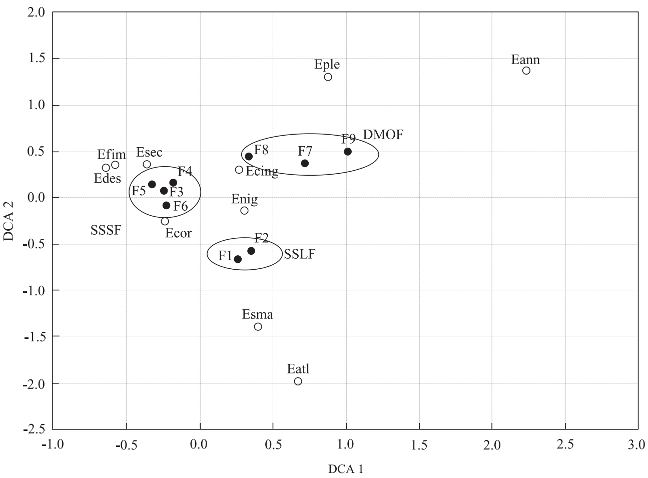

Fig. 5. Diagram of Detrended Correspondence Analysis (DCA) for areas and for species sampled in small forest fragments of the Atlantic Forest, Rio de Janeiro state, southeastern Brazil. Eann: *Euglossa annectans*, Ecor: *Euglossa cordata*, Edes: *Euglossa despecta*, Efim: *Euglossa fimbriata*, Eple: *Euglossa pleosticta*, Eatl: *Eulaema atleticana*, Ecing: *Eulaema cingulata*, Enig: *Eulaema nigrita* e Esma: *Exaerete smaragdina*.

The correlation between the first axes of the DCA and abiotic variables studied showed a significant negative influence of temperature (r = -0.719, p = 0.029), and positive of humidity and altitude (r = 0.852 and p = 0.003, r = 0.675 and p = 0.004, respectively). The second axis of DCA was significantly influenced negatively with temperature (r = -0.696, p = 0.037) and positively with precipitation and altitude (r = 0.964, p = 0.000; and r = 0.805, p = 0.000, respectively). ANOVA between the axes of the DCA and phytophysiognomies analyzed showed effect on the ordination of euglossine bee communities from the first (F2, 6 = 7.9935, p = 0.02032) and the second axis (F2, 6 = 59,975, p = 0.00011) of the DCA.

The correlations between the abundance of species and environmental variables analyzed revealed that *Euglossa annectans* has significant positive relationship with altitude (r = 0.69) and marginally with the other variables analyzed. Abundances of *Euglossa cordata*, *E. despecta*, *E. fimbriata*, *E. securigera* and *Eulaema cingulata* were negatively related to relative humidity (r = -0.94, -0.89, -0.72, -0.67 and -0.72, respectively) and had no relation with the other variables (Table V). On the other hand *Eulaema nigrita* and *Exaerete smaragdina* showed significant relationship with all variables analysed, except the humidity (Table V).

Table V. Spearman correlation between the abundance of euglossine species and abiotic variables observed in nine small forest fragments of the Atlantic Forest in the Rio de Janeiro state, southeastern Brazil, between May 2007 and May 2009.

Species	Abiotics variables			
	Temperature	Humididy	Precipitation	Altitude
Euglossa annectans	-0.66	0.66	0.66	0.69 *
E. cordata	0.51	-0.94**	-0.51	-0.52
E. despecta	0.18	-0.89**	-0.18	-0.17
E. fimbriata	-0.07	-0.72*	0.07	0.05
E. pleosticta	-0.44	0.44	0.44	0.35
E. securigera	-0.19	-0.67*	0.19	0.10
Eulaema atleticana	0.51	0.07	-0.51	-0.55
E. cingulata	-0.07	-0.72*	0.07	0.12
E. nigrita	0.83**	-0.61	-0.83**	-0.85**
Exaerete smaragdina	0.88**	-0.38	-0.88**	-0.88**

DISCUSSION

Species richness, expressed by rarefaction curves, demonstrated no significant differences among the nine fragments studied in the three phytophysiognomies. Nevertheless, species richness was lower than those registered in other studies of Atlantic Forest fragments. Those studies revealed 19 and 17 species (richness corrected according to the taxonomic changes indicated by Dr. Gabriel A.R. Melo) in dense sub-mountainous and lowland ombrophilous forest (Tonhasca *et al.* 2002; Ramalho *et al.* 2009, respectively), 14 species in fragments of sub-mountainous semideciduous seasonal forest (Nemésio & Silveira 2010), and 11 species in semideciduous seasonal lowland forest (Aguiar & Gaglianone 2008a). Species loss in small fragments has commonly been reported in studies on the effects of fragmentation on euglossine bee communities (Powell & Powell 1987; Sofia & Suzuki 2004; Ramalho *et al.* 2009). In small fragments of Atlantic Forest the low species richness relative to larger areas was also observed by Ramalho *et al.* (2009), who encountered 8 species in an area of 19 ha, a richness similar to that found in small fragments in urban areas (Bezerra & Martins 2001).

The dominance of *Eulaema nigrita* and *Euglossa cordata*, as observed in this study, was also registered in other Atlantic Forest fragments, both for well-preserved areas (Aguiar & Gaglianone 2008a; Ramalho *et al.* 2009) as well as disturbed ones (Viana *et al.* 2006; Ramalho *et al.* 2009). In small fragments, the high dominance of few species could be worrying, especially in light of susceptibility to a loss in habitat diversity which can lead to reduced resource availability (Connor & McCoy 1979). This factor frequently results in increased competition and rare species loss due to the consumption of food resources and/or offspring by dominant species (Schaffer *et al.* 1983; Roubik *et al.* 1986). On the other hand, dominant species are characterized as generalists in terms of food resources for their habit of visiting flowers of many different groups of plants (Winston 1987; Ramirez *et al.* 2002).

In the context of a global decline in pollinators (Potts *et al.* 2010), generalist species are extremely important for the pollination of native and cultivated plants (Ghazoul 2005; Gressler *et al.* 2006; Aguiar & Gaglianone 2008b; Benevides *et al.* 2009). Thus the conservation of these pollinators, even when associated with low species richness in small fragments, is important because it can ensure the pollination of many plant species, including those in surrounding agricultural areas. Benevides *et al.* (2009) observed increased richness in pollinators of *Passiflora edulis* f. *flavicarpa* DC (maracujá-amarelo), such as Centridini and Euglossina, in addition to *Xylocopa*, in cultivated areas near forest fragments. This result was related to bee dependency on nesting and feeding resources in forest areas. In the same way, Chacoff & Aizen (2006) observed that the abundance, richness, and frequency of flower visitors in orange plantations dropped significantly as distance from forest fragments increased. The authors considered remaining stands of forest as a source of flower visitors that may represent effective pollinators in agricultural areas. While agricultural areas may offer temporary sources of pollen and nectar (Steffan-Dewenter & Kuhn 2003), they do not furnish adequate habitats for nesting (Chacoff & Aizen 2006). This deficiency can be compensated with remaining forest areas that can supply year-round nesting and floral resources (Lagerlöf *et al.* 1992).

Our data suggest that small Atlantic Forest fragments possess limited Euglossina fauna, essentially species considered resistant to open, altered, and/or disturbed areas, such as *Euglossa cordata*, *Eulaema cingulata*, and *E. nigrita* (see Peruquetti *et al.*1999; Aguiar & Gaglianone 2008a; Ramalho *et al.* 2009). However, species considered more stringent like *Eulaema atleticana* and *Euglossa annectans* (Milet-Pinheiro & Schlindwein 2005; Nemésio 2009) were sampled in some of these small areas. The presence of these species highlights the importance of conserving these small fragments in order to preserve the diversity of euglossine bees.

The relative importance curve indicates that the most abundant species contributed with similar percentages when comparing with the species with lower abundances. This pattern is not commonly observed in euglossine bee communities. A large quantity of studies illustrate that the individual relative abundance can differ widely among species (Neves & Viana 1997; Peruquetti *et al.* 1999; Aguiar & Gaglianone 2008a; Ramalho *et al.* 2009), and the communities present few species that are clearly dominant and many species that are not common (Roubik & Hanson 2004). The relative abundance distribution pattern observed in this study is probably a reflection of rare species loss due to reduced areas. Species potentially less competitive or the most sensitive species to the effects of forest fragmentation probably could not survive in these small fragments. Similar results have been observed by Silva *et al.* (2009) in sandbank (*restinga)* areas in northeastern Maranhão State and by Nemésio & Silveira (2007) in the Mangabeira Park, an urban fragment in the city of Belo Horizonte-MG. This pattern indicates that only species tolerant of disturbed areas are able to inhabit these open areas and suggests that rarer or less abundant species may have become extinct in these fragments.

The loss of euglossine species in small forest fragments is most evident when comparing these results with studies of Aguiar (2011) in larger forest fragments better preserved in the same region and phytophysiognomies in the state of Rio de Janeiro. Aguiar (*op. cit.*) recorded in those areas a richness around 45% higher in seasonal semideciduous lowland forest (SSLF), about 40% higher in areas of seasonal semideciduous submontane forest (SSSF) and 55% higher in areas of dense mountainous ombrophile forest (DMOF), comparing with the small fragments. All these larger areas have more than 900 ha and are considered well preserved or in mature stage of regeneration (Dan *et al.* 2010, Nascimento, M.T. personal communication).

Detrended correspondence analysis (DCA) formed three groups, which coincide with the phytophysiognomies studied. The occurrence of *Euglossa annectans*, associated with higher altitudes and marginally with lower temperature and higher humidity and precipitation, demonstrates the habitat preference of this species, as observed in the region of DMOF. Other studies also showed the presence of this species at higher altitudes in the state of São Paulo (Garófalo *et al.* 1998) and Minas Gerais (Nemésio & Silveira 2007), however in southern Brazil it was also recorded in less elevated areas (Cortopassi-Laurino *et al.* 2009), but in mild temperatures, like those found in DMOF. The abundance pattern of *Euglossa securigera* and *E. fimbriata* and the occurrence of *E. despecta* only in SSSF resulted in the grouping of fragments of this phytophysiognomy in the performed analysis. Those species occurred in higher abundances in fragments with lower humidity. Gaglianone & Aguiar (2008a) observed that the same three species were highly abundant in the dry season in the region. This was pattern also observed by Silva & Rêbelo (1999) for *Euglossa securigera* in areas of Amazon rainforest in Maranhão state, confirming the relationship found in this study. However, this pattern differs of the areas of Atlantic Forest in southern Brazil, where *Euglossa fimbriata*, for example, has activity throughout the year without evident seasonal variations (Sofia *et al.* 2004). The third group is formed by the greater abundance of *Exaerete smaragdina* and the occurrence of *Eulaema atleticana* in the fragments of SSLF. These species showed a significant negative relationship with precipitation and altitude, and in contrast showed a positive relationship with temperature.

The performed analysis reinforced the role of phytophysiognomy as determinant in the composition, abundance and distribution patterns of the euglossine species. The reduced number of species encountered, mostly characterized by species of wide-ranging geographic distribution and resistance to the adverse conditions of the small fragments (boundary effect and resource reduction), may well have relevance in the alteration of community structure, leading to the high faunal similarity among distinct regions.

The environmental variables considered in the correlation analysis revealed that the humidity, temperature and altitude showed significant influence on the DCA axis 1, while the precipitation has not demonstrated this influence. In the second axis of DCA only the humidity showed no significant correlation. Environmental characteristics such as altitude, precipitation, and temperature may have influenced the occurrence of Euglossina (see Nemésio & Silveira 2007; Cortopassi-Laurino *et al.* 2009). According to Ramirez *et al.* (2002), altitude is one of the main factors that influences the geographical distribution of euglossine bees. Dias (2007) also showed significant differences in the euglossine bee species composition over an altitude gradient (50–2150 m), though richness and abundance were unaffected. In addition to these factors, resource availability, competition, and historical factors were cited by other authors as important players for determining euglossine bee richness and species composition (Rosenzweig 1995; Roubik & Hanson 2004; Souza *et al.* 2005; Silva *et al.* 2009).

Thus the results presented in this study demonstrate that small forest fragments, as the studied areas with up to 18ha, can support populations of euglossine bee species that are considered resistant to open and/or disturbed areas. Our results also indicate that the conservation of these small fragments has to be regarded important, especially in areas that are regenerating and in regions with agricultural matrices where these bees can function as important pollinators. The presence of these species in small fragments, however, offers no guarantee for their preservation since euglossine populations in small fragments may be represented by populations left over from large areas in past generations that are now on the road to extinction (Nemésio & Silveira 2007).

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