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THE EFFECT OF THE SURROUNDING MATRIX ON BIRD COMMUNITIES IN FRAGMENTS OF THE BRAZILIAN ATLANTIC FOREST

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Abstract · Despite being one of the most diverse biomes in the world, the Atlantic Forest is currently restricted to small isolated fragments and, therefore, the majority of its fauna is declining or threatened. This is mainly due to habitat loss, edge effects, and other patch-level negative effects. Here we study whether the type of matrix surrounding Atlantic forest fragments affects patterns of bird diversity. We hypothesize that fragments in contact with a matrix dominated by *Eucalyptus* plantations would have more diverse bird communities compared to matrices dominated by pastures. We assessed the richness, abundance, and functional diversity of birds at the edge and in the interior of fragments of Atlantic Forest surrounded by pastures and by plantations of *Eucalyptus* trees. Even though all the studied fragments showed relatively low values of species richness, those surrounded by the *Eucalyptus* matrix had higher species richness and evenness at the edge of the fragments compared to those surrounded by pasture. Furthermore, the bird community in contact with the *Eucalyptus* matrix had higher functional diversity and higher abundance of bird groups generally sensitive to disturbances. Our data illustrate the importance of the matrix composition surrounding fragments. While replacing Atlantic forests with *Eucalyptus* plantations will lead to a reduction in bird diversity, our data suggest that nevertheless *Eucalyptus* plantations can buffer edge effects for forest birds compared to more abrupt transitions, such as with pastures.

Resumo · Efeito da matriz envolvente sobre comunidades de pássaros em fragmentos da Mata Atlântica do Brasil
Apesar de ser um dos biomas mais ricos em biodiversidade do mundo, a Mata Atlântica encontra-se majoritariamente restrita a pequenos fragmentos isolados e, portanto, grande parte de sua fauna está em declínio e sob risco de extinção. Isso se deve principalmente à perda de habitat, efeitos de borda e outros efeitos negativos relacionados a fragmentação. Nossa hipótese é que fragmentos florestais em contato com uma matriz formada principalmente por eucalipto apresentariam comunidades de aves mais diversas quanto à riqueza e papéis funcionais. Avaliamos a riqueza, abundância e diversidade funcional de aves na borda e no interior de fragmentos de Mata Atlântica cercadas por pastagens e por eucaliptos. Apesar de todos os fragmentos terem apresentado baixos valores de riqueza de espécies, aqueles cercados por uma matriz de eucalipto apresentam maior riqueza e uniformidade de espécies na borda comparado com fragmentos circundados por pasto. Além disso, a comunidade em contato com a matriz de eucalipto apresentou maior diversidade funcional e maior abundância de grupos geralmente sensíveis a distúrbios. Nossos dados ilustram a importância da composição da matriz em torno dos fragmentos. Embora a substituição da Mata Atlântica por plantações de eucaliptos leve a uma redução significativa da diversidade de aves, nossos dados sugerem que as plantações de eucalipto podem amortecer os efeitos de borda para as aves florestais nos fragmentos, em comparação com transições mais abruptas, como as pastagens.

Key words: Brazil · Ecology · Edge effect · Eucalyptus · Pasture · Species richness

INTRODUCTION

One of the main processes that causes the loss of global biodiversity is human modification of natural habitats (Houghton 1994, Myers et al. 2000). Animal and plant communities suffer from decreases on habitat availability and the effects of changes on biotic and abiotic variables caused by surrounding matrices (Andrén & Angelstam 1988, Andrén 1994, Bhakti et al. 2018). These effects – known as edge effects – are perceived throughout the interface between the natural environment and the novel surrounding matrix. The edge effect has been extensively investigated as an important effect on species that remain in fragments of native vegetation (e.g., Saunders et al. 1991, Murcia 1995, Lidicker 1999, Laurance et al. 2002, Ries et al. 2004, Harper et al. 2005, Ferrante et al. 2017). The edge effect, when it affects forests, is characterized by enhanced solar light levels, higher intensity and frequency of winds, and greater variation of humidity and temperature (Matlack 1993, Chen et al. 1995,

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Oliveira et al. 2004). Birds respond in different ways to edge effects (Gascon et al. 1999, Prevedello & Vieira 2010), which results in changes in abundance and diversity of species that either prefer the edge or the interior of remaining habitats (Murcia 1995, Lidicker 1999, Harper et al. 2005).

The characteristics of the surrounding matrix are especially important for those communities stuck in isolated fragments (Prevedello & Vieira 2010, Watling et al. 2011). In general, the edge effect is stronger when the ecological differences between edge and adjacent habitat are greater (Ries et al. 2004). Therefore, monoculture forest plantations apparently provide more favorable conditions for native forest species than agricultural land uses (Barlow et al. 2007, Brockerhoff et al. 2008). However, the role of silviculture of introduced/exotic plants in conserving biodiversity is controversial. Although monocultures hold some native species of birds and allow movement among fragments (e.g., Castellon & Sieving 2006, Hansbauer et al. 2008), they present a low biodiversity when compared to native habitats (Barlow et al. 2007, Brockerhoff et al. 2008, Bremer & Farley 2010).

The effect of different types of matrices on communities within fragmented habitats is poorly understood, particularly in the Atlantic Forest. In general, some monocultures, such as *Eucalyptus* plantations, seem to act as minimizers of the edge effects that are more prominent in open matrices (Engel & Nassur 1995). Our objective was to investigate biodiversity patterns in forest fragments surrounded by pasture and *Eucalyptus* to understand what were the effects of those matrices on bird communities within fragments of Atlantic forest. We hypothesized that forest birds would benefit from a matrix of *Eucalyptus* compared to fragments surrounded by matrices of pasture. We predicted that the diversity within fragments surrounded by *Eucalyptus* would be greater than those surrounded by open pastures. Specifically, we expected for *Eucalyptus*-surrounded fragments: i) greater species richness, ii) higher dominance of few species, and iii) greater functional diversity of birds, particularly groups sensible to fragmentation, such as large frugivorous forest species.

METHODS

Study area. This study was conducted in fragments of forest around Rio Doce State Park (RDSP, 19°29´24”–19°48´18”S and 42°28´18”–42°38´30”W), the largest remaining extension of Atlantic Forest of Minas Gerais State, Brazil. RDSP is composed by 360 km^2 of semi-deciduous seasonal tropical forest (Veloso et al. 1991). Due to high levels of fragmentation, the native vegetation outside the Park is restricted to fragments surrounded by pasture and silviculture, mostly *Eucalyptus* (Fonseca 1997). We chose eight fragments with at least 200 meters of distance between center and edge to minimize the edge effect. All fragments are composed of Atlantic semi-deciduous forests and are characterized by the presence of a canopy of approximately 15 meters and undergrowth. Four fragments were surrounded by *Eucalyptus* with a light understory vegetation and four surrounded by pasture. We collected data regarding richness and abundance of bird species within fragments. The fragments surrounded by pastures had a mean size of 56 ha (SD = 13 ha), while the fragments in contact with *Eucalyptus* had an average size of 57 ha (SD = 15 ha).

Bird sampling. Between September and November 2014, we sampled the bird community of each fragment through the technique of point counts. At this season, birds are most active in the study area due to reproductive behavior (Sick 1997). We recorded birds sighted or heard within a 30 m-radius over 15 minutes. Flying birds were not counted, except in cases where territorial displays or foraging maneuvers in the understory occurred, as in the case of members of the family Trochilidae. This methodology is considered useful for sampling small fragments, as it allows greater reliability on the position of the birds to the observer (Anjos et al. 2010). We chose six points distant at least 150 m from each other in each fragment. Three points were positioned 30 m away from the edge so that it was possible to detect species that frequent the edge (edge points). Three points were distant 200 m from the matrix toward the center of the fragment so that it was possible to detect the species that frequent the interior (interior points). We repeated the sampling three times at each point on different consecutive months. To avoid any effect of time on the sample, the order of points was altered. Thus, points that were made in the early morning on the first sample, were sampled at the end of the morning in the second sample. To allow the movement of researchers between points, three transects were opened connecting the points in the interior and in the edge of the fragments. Thus, the movement between points took on average 10 minutes. Observations initiated soon after sunrise and lasted no longer than 02:30 hours.

Data analysis. We quantified species richness across four groups: interior points and edge points of fragments with pasture as the closest matrix (PI and PB, respectively), and with *Eucalyptus* as the closest matrix (EI and EB, respectively). To test whether the species richness of fragments was similar, we used a two-way ANOVA test. In addition, we calculated the relative abundance of species in the four groups by dividing the total number of individuals of a species recorded in each set of points by the total number of individuals of all species recorded for all groups. Subsequently the results were multiplied by 100 to present data as percentages. To evaluate the similarity of species between groups (PI, PB, EI, and EB), we calculated the Jaccard index (Jaccard 1901) using the program PAST (Paleontological Statistics; Hammer et al. 2003). This index considers the relationship between the number of shared species and the total number of species found when comparing two samples. Thus, this analysis uses binary data and therefore disregards the weight of abundance among communities. To include abundance in the analysis of similarities, we also calculated the Bray- Curtis similarity index (Bray & Curtis 1957). The results were presented by dissimilarity dendrograms created by UPMGA connection method ("unweighted Pair Group Method with Arithmetic") with the aid of the procedures available in the “vegan” package (Oksanen et al. 2013) of R software, version 3.0.2 (2013).

Most ecological studies only use species richness to compare communities, but this approach assumes functional redundancy among species, when two or more species exert similar functional roles in the environment (Lawton & Brown 1993). To address this problem, we performed an evaluation based on functional diversity patterns of bird species. We calculated the functional diversity to evaluate the communi-

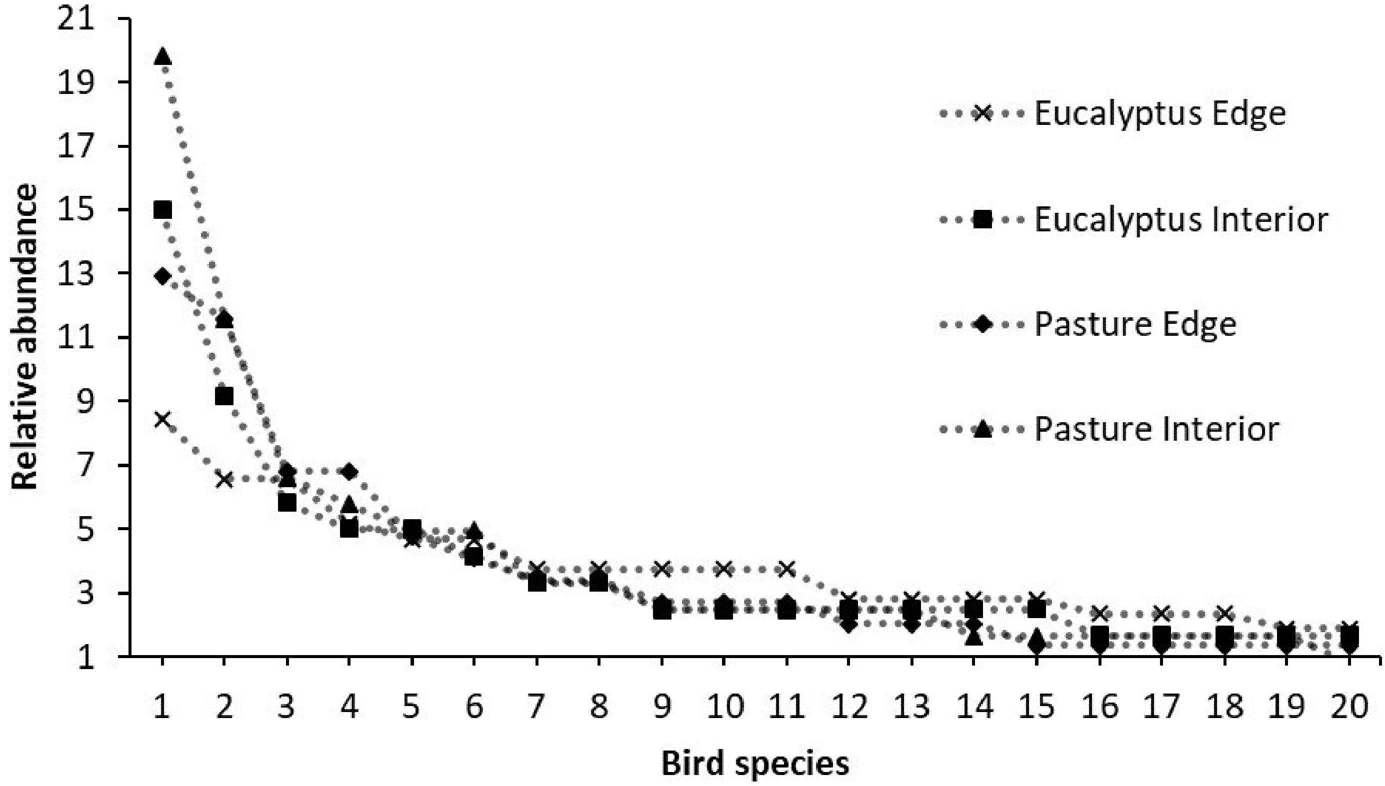

Figure 1. Ranking of relative abundance for the twenty most abundant species of each group of birds for Atlantic forest fragments in Minas Gerais state, Brazil, 2014.

ties based on the number of functions that species perform in their environments, following Petchey & Gaston (2002, 2006). Functional groups have been defined as a set of species that exhibit similar responses to the environment or similar effects on the main ecosystem processes (Gitay & Noble 1997). Thus, the analyses were aimed to select well-known characteristics of birds studied and that could be influenced by the matrix closest to the fragment. We assumed that the matrix affected food availability, nesting-site availability and vegetation structure, which could directly influence foraging sites. This process would result in assemblages composed of species with different diet, nesting strategy and use of foraging strata. These variables were used to calculate the functional diversity (Petchey & Gaston 2002), performed using the "spicy" package (Kembel et al. 2008) of R software.

We classified species according to the items included in the diet, nesting strategy and foraging stratum based on Sick (1997) and Lopes et al. (2005). For diet, we avoided classifying species as specialists or generalist. Instead, birds were classified as: i) carnivorous (feed on live vertebrates or parts of them, excluding rotting meat); ii) insectivorous (consume insects and other arthropods); nectarivores (consuming floral nectar); granivores (feed on grain); frugivorous (feed on fruits or parts of them); carrion-eaters (feed on rotting meat); piscivores (feed on fish); and folivores (feed on leaves, especially sprouts).

RESULTS

We recorded 78 species of birds and a total of 601 individuals. In fragments surrounded by pasture, we found 58 different species and a total of 268 individuals, of which 48 species and 147 individuals were detected in the edge, and 40 species and 120 individuals in the interior of the fragments. In fragments surrounded by *Eucalyptus*, we found 56 different species and a total of 333 individuals, with 49 species and 213 individuals detected in the edge, and 42 species and 120 individuals in the interior.

Species richness was similar among fragments independent of the habitat of closest matrix ($F_{1,44}$ = 2.24 P = 0.141). However, points in the edge of fragments surrounded by *Eucalyptus* presented higher species richness ($F_{1,44}$ = 11.87, P = 0.001) than in the edge of pastures.

The ranking of relative abundance (Figure 1) showed that the points in the interior of fragments surrounded by *Eucalyptus*, points in the edge of fragments surrounded by pasture, and points in the interior of fragments surrounded by pasture had few species that dominate the community (species with the highest abundance were *Thamnophilus ambiguus* 15.0 %; *Pheugopedius genibarbis* 12.9%; *Thamnophilus ambiguus* 19.8%, respectively). However, points in the edge of fragments surrounded by *Eucalyptus* had greater homogeneity, with the most abundant species, *Thamnophilus ambiguus*, representing only 8.5 %.

We found more similarity in the species composition in groups of points surrounded by the same matrix than among other groups of points (Table 1). However, when abundance was taken into consideration, we observed the highest similarity for points in the edge of *Eucalyptus* and in the interior of pasture (Table 1). Points in the edge of pasture and edge of *Eucalyptus* and interior of *Eucalyptus* and edge of *Eucalyptus* had intermediate similarities. Points in the interior of pasture and edge of pasture, edge of pasture and interior of *Eucalyptus*, and interior of pasture and interior of *Eucalyptus* had the higher dissimilarities.

The functional diversity was higher for points in the edge of fragments near *Eucalyptus* and pasture, and lower for points in the interior of fragments near *Eucalyptus* and pas-

Table 1. Jaccard and Bray-Curtis indices of similarity and functional diversity of birds for Atlantic forest fragments in Minas Gerais state, Brazil, 2014. EI – Points in the interior of fragments surrounded by *Eucalyptus*; PI – Points in the interior of fragments surrounded by pasture; EB - Points in the edge of fragments surrounded by *Eucalyptus*; PB - Points in the edge of fragments surrounded by pasture.

	Jaccard-Index				Bray-Curtis-Index			
	EI	EB	PI	PB	EI	EB	PI	PB
EI		0.52	0.44	0.45		0.56	0.61	0.63
EB	0.52		0.39	0.47	0.56		0.47	0.55
PI	0.44	0.39		0.52	0.61	0.47		0.62
PB	0.45	0.47	0.52		0.63	0.55	0.62	

ture. The individual assessment of feeding guilds showed a greater overall richness of birds including insects and/or fruits in their diet (Table 1). However, the difference between *Eucalyptus* and pasture was higher because of a greater proportion of birds that consumed insects and smaller proportion that ate fruit in the pasture. In all environments, bird species that build closed or cup nests and were vegetation foragers dominated the assemblages (Table 2).

DISCUSSION

Our data showed that the *Eucalyptus* matrix seem to affect the number of species of birds as well as the relative abundance of these species in the edge of Atlantic forest fragments. Although species richness was similar among fragments independent of the surrounding matrix type, we found that points in the edge of fragments surrounded by *Eucalyptus* presented higher species richness than in the edge of pastures, corroborating our first prediction. Contrary to our second prediction, we found a greater evenness of species in points in the edge of fragments surrounded by *Eucalyptus*, which was different than is commonly found in natural communities, where there is usually high dominance by a few species. It is known that the abundance of species distributions affects the processes that determine the biological diversity of an assembly (Magurran 2004). This follows from the assumption that the abundance of a species reflects its success in competing for limited resources. Therefore, we infer that along the edge of the fragments in contact with *Eucalyptus*, resources may be available to the community so that all species benefit to the same extent. So presumably, the species that are less abundant in other locations have enough resources to compete equally in the edge, providing a balanced competition.

Evidence indicates that bird communities of a more specialized diet in South America, particularly in Brazil (e.g., comprising large frugivorous species), decline or disappear due to fragmentation, while more generalist species increase in richness and abundance, resulting in changes in the proportion of functional groups (Aleixo 2001, Anjos 2001, Marsden et al. 2001, Laurance et al. 2002, Sekercioglu 2012). In our study, because we surveyed altered fragments, both types of communities (frugivorous and omnivores) were characterized by an impoverished avifauna in relation to the richness of birds recorded for the region (Machado & Fonseca 2000). However, besides having a greater number of birds that include fruits in their diet, we noted the presence of some large frugivorous species in the edge of *Eucalyptus*, such as Red-ruffed Fruitcrow (*Pyroderus scutatus*), an endangered species in the state of Minas Gerais (Machado et al. 1998).

Our study suggests that different types of matrices surrounding forest fragments may affect bird community parameters. Moreover, the interface between *Eucalyptus* matrices and forest fragments can maintain higher functional diversity than pasture matrices and forest fragments, confirming our third prediction. However, one should take into consideration that *Eucalyptus* plantations are periodically cut and replanted, and therefore the edge effect is probably stronger in some phases of the restoration process. Although investigations on the effect of crops on forest biodiversity are still scarce, there is indication that the management practice of leaving lines of trees near fragments mitigates the edge effect, thus maintaining better conditions in the edge of the forest fragments (Nascimento et al. 2010). Moreover, it is possible that the traditional way of planting *Eucalyptus* in Brazil, consisting in cutting the entire *Eucalyptus* forests from five to six years after planting, may be a factor determining the greatest diversity. In this case, matrices of *Eucalyptus* would be acting minimizing the edge effect during the period of growth, reducing the disturbance in the edge and benefiting species of forest birds. However, when those matrices are cut, they leave the landscape vulnerable again and prone to varying levels of disturbance, benefiting open area species. The bird community would be shaped to present a greater range of guilds. However, in bird communities within fragments of Atlantic forest surrounded by pastures and constantly subject to the same conditions of disturbance, only a few guilds would benefit, thus dominating the bird community.

Table 2. Functional diversity index of birds and proportion of species for Atlantic forest fragments in Minas Gerais state, Brazil, 2014. EI – Points in the interior of fragments surrounded by *Eucalyptus*; PI - Points in the interior of fragments surrounded by pasture; EB - Points in the edge of fragments surrounded by *Eucalyptus*; PB - Points in the edge of fragments surrounded by pasture.

	Index of functional diversity	Feeding guilds (%)			Nesting (%)			Foraging stratum (%)	
		Insectivorous	Frugivorous	Others	Closed	Cup	Others	Vegetation	Others
EI	1.95	44	28	28	24	37	39	30	70
EB	2.19	47	29	24	28	37	35	24	76
PI	1.5	53	24	23	25	41	34	29	71
PB	2.0	52	23	25	24	41	35	20	80

Given the current situation of fragmentation of the Atlantic Forest, we suggest that future studies involving the effect of the matrix of on biodiversity in fragmented landscapes, should focus on the management of the matrix to maintain biodiversity, in particular for *Eucalyptus* forests. Approximately 50% of the wood production worldwide is represented by *Eucalyptus* forests (FAO 2007). As for 2012 in Brazil, the planting area of *Eucalyptus* reached 5.1 million hectares, with Minas Gerais state having the highest productivity, representing 22.4% of the total forest planted in Brazil (ABRAF 2013). In contrast, natural environments such as the Atlantic Forest, one of the hotspots of biodiversity in the world (Myers et al. 2000), are constantly deteriorating with approximately only 10% of its original area remaining (Morellato & Haddad 2000, Myers et al. 2000, Ribeiro et al. 2009). Of the 891 species of birds, including at least 223 endemics of this biome (Vale et al. 2018) ca. 8.5% (76 spp.) are classified as endangered (Copam 2010, IUCN 2019), which contributes to Brazil being the country with the highest number of endangered birds in the Neotropics (Collar et al. 1997).

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