HABITAT AND SPECIES SEGREGATION OF STRIGIFORMES IN THE BRAZILIAN ATLANTIC FOREST

HÁBITAT Y SEGREGACIÓN DE ESPECIES DE STRIGIFORMES EN EL BOSQUE ATLÁNTICO BRASILEÑO

Rafael Martos-Martins[1]* & Reginaldo José Donatelli[2]

[1]São Paulo State University (UNESP), Post-graduate Program in Zoology, Bioscience Institute, Botucatu, São Paulo, Brazil
[2]São Paulo State University (UNESP), Biological Sciences Department, School of Sciences, Bauru, São Paulo, Brazil
***rafael.martos@yahoo.com.br**

ABSTRACT: The order Strigiformes contains approximately 250 owl species distributed worldwide, and the majority of them live in forests. Although basic information is available on many owls, few have been studied in-depth; consequently, little is known about the role of vegetation in their lives. This study aimed to investigate Strigiformes in a fragment of the Atlantic Forest using point count surveys conducted from January 2018 to December 2019. Twelve points were sampled for 30 min/month, totaling 144 h. Data on vegetation structure were collected for analysis. The numbers of individuals and species were then estimated. Twenty-six individuals of four species were recorded: 12 *Strix virgata*, 6 *Pulsatrix koeniswaldiana*, 5 *Megascops atricapilla*, and 3 *Megascops choliba*. *Strix virgata* was associated with sites with typical mature forest characteristics, although it tolerated variation in some parameters (e.g., average canopy height). *Pulsatrix koeniswaldiana* was a generalist in terms of habitat characteristics, even when using edge areas. *Megascops choliba* was scarce within the sampled area and seemed to avoid mature forest. *Megascops atricapilla* occurred from sites with a lower canopy to more mature forest areas. Altogether, this study highlighted the importance of conserving forest fragments in the Atlantic Forest, which harbors considerable biodiversity, especially of owls.

KEYWORDS: *biodiversity conservation, birds, Brazilian Atlantic rainforest, species segregation*

RESUMEN: El Orden Strigiformes contiene aproximadamente 250 especies de búhos distribuidas en el mundo, y la mayoría viven en bosques. Aunque se dispone de información básica sobre muchos búhos, pocos han sido estudiados en profundidad; en consecuencia, se sabe poco sobre el papel que juega la vegetación en sus vidas. Este estudio tuvo como objetivo investigar las especies de Strigiformes en un fragmento de la Mata Atlántica. Los recuentos de puntos se realizaron desde enero de 2018 hasta diciembre de 2019; se muestrearon doce puntos durante 30 min/mes, totalizando 144 h. Se recopilaron datos sobre la estructura de la vegetación para su análisis. Luego se estimó el número y las especies presentes. Se registraron 26 individuos de 4 especies: 12 *Strix virgata*, 6 *Pulsatrix koeniswaldiana*, 5 *Megascops atricapilla* y 3 *Megascops choliba*. *Strix virgata* se asoció a sitios de características típicas de bosques maduros, aunque tuvo tolerancia en la variación de algunos parámetros (p. ej., altura media del dosel). *Pulsatrix koeniswaldiana* fue generalista en las características del hábitat, incluso cuando utilizó áreas de borde. *Megascops choliba* fue escaso dentro del área de muestreo y pareció evitar el bosque maduro. *Megascops atricapilla* se asoció desde sitios con un dosel más bajo hasta áreas de bosques más maduros. En conjunto, este estudio destacó la importancia de conservar fragmentos de bosque en el Bosque Atlántico, que alberga una biodiversidad considerable, especialmente de búhos.

PALABRAS CLAVE: *aves, conservación de la biodiversidad, segregación de especies, selva tropical atlántica brasileña*

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The Order Strigiformes is comprised of approximately 250 species distributed worldwide (König and Weick 2008, Gill et al. 2022). Approximately 95% of Strigiformes live in forests (König and Weick 2008). In addition, approximately 80% of the world's Strigiformes can be found in the tropics (Marks et al. 1999); Brazil is home to 26 owl species (Pacheco et al. 2021). Strigiformes are bioindicators of environmental quality, and their conservation, along with forest fragments, is necessary to maintain the biodiversity of tropical forests (Terborgh 1992, Motta-Junior et al. 2004). Although knowledge about Neotropical owls has advanced in recent decades (Esclarski et al. 2011, Fink et al. 2012, Menq and Anjos 2015, Enríquez 2017, Claudino et al. 2018), studies that analyze the owl community, especially in forest environments, are still important.

The Atlantic Forest, in Brazil, is a global hotspot and one of the most threatened areas on the planet (Fundação SOS Mata Atlântica 2022). The original cover was of 1 309 736 km^2, today only 12.4% of its area remain in many fragments (most of them < 50 hectares) (Fundação SOS Mata Atlântica 2022). Among the 1971 bird species native to Brazil (Pacheco et al. 2021), approximately 992 are found in the Atlantic Forest (Pinto et al. 2012, Fundação SOS Mata Atlântica 2022). The majority of Strigiformes species occur in this biome, with a few species exclusive to the Amazon region and others associated with non-forest environments (Sick 1997). However, little is known about which vegetation components influence the occurrence of Strigiformes in this forest (Amaral 2007, Motta-Junior and Braga 2012).

The aim of this study was to survey the Strigiformes inhabiting a fragment of seasonal semi-deciduous forest (the Atlantic Forest in the interior of the State of São Paulo) and to describe the characteristics of the vegetation structure associated with each species and report, if it occurs, a possible segregation between the sampled species.

METHODS

Study area

This study was conducted in the State of São Paulo, Brazil, at the Caetetus Ecological Station (EECa) (22°20'S and 22°30'S, 49°40'W and 49°45'W), which has an area of 2179 ha (Tabanez et al. 2005) (Fig. 1A and B). Forest formation at the EECa is characterized as seasonal semi-deciduous (IBGE 1988). The climate of the region is mesothermic with dry winters, the dry season extends from April to September, and the rainy season from October to March (Tabanez et al. 2005). Around the station there are plantations of different crops (e.g., coffee, soy, sorghum and eucalyptus), which alternate during the year.

Survey of Strigiformes

Strigiformes were monthly sampled between January 2018 and December 2019 using point count methodology associated with the playback technique (Fuller and Mosher 1987, Mosher et al. 1990, Bibby et al. 1992, Andersen 2008). Twelve points, each 800 m apart, were selected (Fig. 1C). The points were demarcated on pre-existing trails: 9 points on the 8 km-long Jeep trail, 2 on the 2 km-long Lake trail, and 1 on the access trail to the Jeep and Lake trails. Each point was sampled in randomly order for 30 min each month. Monthly samplings were made, whenever possible, on two consecutive nights with a crescent or full moon, always starting after sunset and lasting 3 h, with six points sampled each night, totaling 144 h in the two years of sampling (6h / point / year).

Vocalizations (typical call and song obtained from sound data-base WikiAves 2022) of owl species that can occur at the site were emitted, using a 5W portable speaker, at each sampling point to maximize detection. The list of species that can occur in the study area was based on distribution maps (Sick

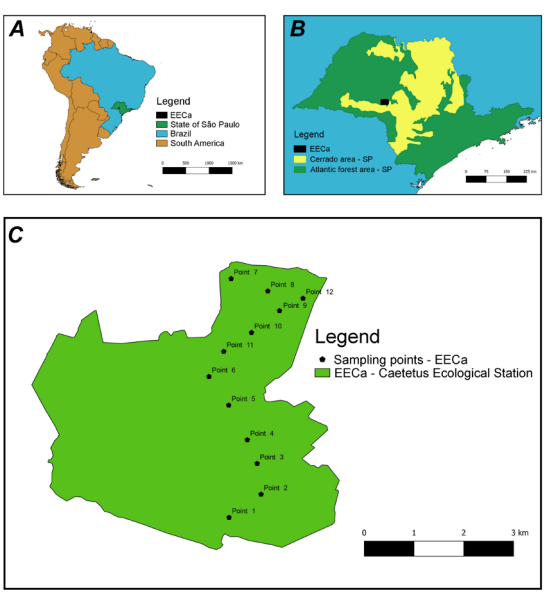

Figure 1. A) Map of South America, highlighting Brazil and the State of São Paulo; **B)** Location of the Caetetus Ecological Station in the State of São Paulo, Brazil; and **C)** Map of Caetetus Ecological Station and the distribution of selected sampling points.

1997, König and Weick 2008) and records from citizen science data (WikiAves 2022). To avoid inhibiting the smaller species, vocalizations were emitted in the order of species with the lowest body mass to the highest (Mosher et al. 1990). The order of emission of the vocalizations includes *Glaucidium brasilianum, Aegolius harrisii, Megascops choliba, Megascops atricapilla, Strix virgata, Strix hylophila, Strix huhula, Asio stygius, Asio clamator, Pulsatrix koeniswaldiana, Pulsatrix perspicillata*, and *Bubo virginianus.*

After each playback (1 minute), we waited for 1.5 minutes for each owl species, thus respecting a probable period of lethargy (Mosher et al. 1990), after, we emitted the next owl species playback. For the record of species occurrence, at each point, spontaneous and in response to playback (response to the species' own vocalization or of other species) auditory contacts and visual contacts were considered.

Evaluation of habitat vegetation structure

During 2019, the 12 sampling points were evaluated to describe habitat use. At each point, two 10 × 10 m plots (Durigan 2003) were demarcated, one on each side of the trail, totaling 200 m² area at each sampling point for analysis.

The Amaral (2007) and Menq and Anjos (2015) same parameters were utilized to analyze vegetation structure components: 1) average canopy height (ACH) - in meters – using Ribeiro (2011) formula; 2) number of trees with cavities (CAV); 3) fallen trees (FT); 4) presence of clearing (CLE); 5) presence of climbing plants (CLI); 6) presence of shrubs (SHR); and 7) presence of leaf litter (LIT). The last four variables were visually classified as absent, present in up to 10%, or present in more than 10% of the area. Individual trees were classified by perimeter at chest height (PER): 50–90 cm (PER1), 91–150 cm (PER2), 151–210 cm (PER3), and > 210 cm (PER4). Finally, to reduce bias the same researchers (Martos-Martins) obtained all parameters.

Analyses of owl surveys

We listed the species at each point and overall. As Strigiformes are territorial, we considered that the contacts made at the same point during the sampling period were with the same individuals (Bibby et al. 1992, Marks et al. 1999). Therefore, we only identified more than one owl per sampling point when two or more individuals were recorded simultaneously. The species accumulation curve was created using the non-parametric Jackknife 1 richness estimator to assess whether the sampling effort was satisfactory, using the EstimateS (Colwell 2009) and R Core Team (2019) programs with the '*vegan*' package (Oksanen et al. 2011).

The frequency of occurrence (FO) [(n / N) * 100, where n = the number of months where the species was recorded and N = Total months of sampling (24)] of each species was analyzed using data from the point count. The index calculation followed Vielliard and Silva (1990). Species with a FO of 0.1–24.9% were classified as rare (R), 25–49.9% as uncommon (UN), 50–74.9% as common (C), and 75–100% as very common (VC).

Analysis of vegetation structure and distribution patterns of Strigiformes

Canonical Correspondence Analysis (Ter Braak 1986) (CCA) using the "*vegan"* package of R program (Oksanen et al. 2011) was performed to determine whether the selected vegetation structure variables influenced the occurrence of Strigiformes. Vegetation

Table 1. Strigiformes of Caetetus Ecological Station: popular names, number of contacts, F.O% - frequency of occurrence; Status: R - rare, UN - uncommon, C - common, and VC - very common, and Location: sampling points where the species was recorded.

Species	Popular name	Contacts	FO%	Status	Location
Strigiformes					
Strigidae					
Megascops choliba	Tropical Screech Owl	6	20.83%	R	7, 11, 12
Megascops atricapilla	Black-capped Screech Owl	8	16.67%	R	1, 2, 3, 5, 6
Pulsatrix koeniswaldiana	Tawny-browed Owl	33	66.67%	C	3, 4, 5, 6, 7, 11
Strix virgata	Mottled Owl	57	95.83%	VC	1, 2, 3, 7, 8, 9, 10, 12

structure components and presence or absence of Strigiformes species data, at each point, were used for this analysis.

Composition of species and potential segregation

After finishing owl sampling, the data was analyzed to verify possible segregation in the distribution of species at the sampling points. For this analysis we consider that some species, due to their size, exercise dominance in this competition, when two or more occur in the same sampling point (territory). We define the dominant species territory as where a larger species (*P. koeniswaldiana* or *S. virgata*) was recorded alone or associated with another smaller species (*Megascops*).

RESULTS

Owl surveys

Four Strigiformes species were recorded during 24 months of sampling. A total of 104 contacts were made (Table 1), of which 57 were with *Strix virgata* (54.81%), 33 (31.73%) with *Pulsatrix koeniswaldiana*, 8 (7.7%) with *Megascops atricapilla*, and 6 (5.76%) with *Megascops choliba*.

A total of 26 individuals of 4 species, including *Strix virgata* (n=12), *Pulsatrix koeniswaldiana* (n=6), *Megascops atricapilla* (n=5), and *Megascops choliba* (n=3) were registered in the sample area. The species accumulation curve and Jackknife 1 richness estimator indicated that the sampling effort was sufficient to capture the species that occurred in the study area. The curve peaked in the 17th sampling and then stabilized (Fig. 2).

Analysis of vegetation structure and owl occurrence

CCA results show that the 18 environmental variables selected explain 92% variation in species composition at the sampling points (Fig. 3). The environmental variables most associated with owl presence were the measures of ACH (15.14, 19.04, 19.46, 19.54, 20.04, 20.74, 22.88, 23.88, and 24.58 m), CAV, FT, CLE (absent and up to 10%), CLI (absent and up to 10%), SHR (up to 10%), PER1 and PER2.

The analysis suggests that *Megascops choliba* associates with sites with an ACH between 19.04 and 20.04 m, CLI absent or covering up to 10% of the area, CLE absent or covering up to 10% of the area, and at least one FT. *Megascops atricapilla* associates with sites with an ACH between 15.14 and 24.58 m, SHR in up to 10% of the area, and sites with trees with a PER1. *Strix virgata* associates with sites with an ACH between 15.14 and 23.88 m, CAV, trees with a PER2, and CLI absent or in up to 10% of the area. *Pulsatrix koeniswaldiana* associates with sites with an ACH between 19.04 and 22.88 m, trees with PER1, CLE absent or up to 10% of the area, and FT.

Composition of species and potential segregation

Of the 12 sampling points, the dominant species *Strix virgata* and *Pulsatrix koeniswaldiana* were recorded, occurring at the same point, at only two (in point 3 and 7, only on one occasion in each), never together. These records were likely of individuals moving through the territory of the other species.

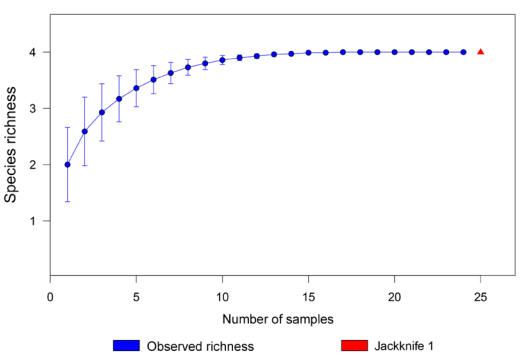

Figure 2. Species accumulation curve, randomized 1000 times and the non-parametric Jackknife 1 estimator of the Strigiformes species sampled in the Caetetus Ecological Station.

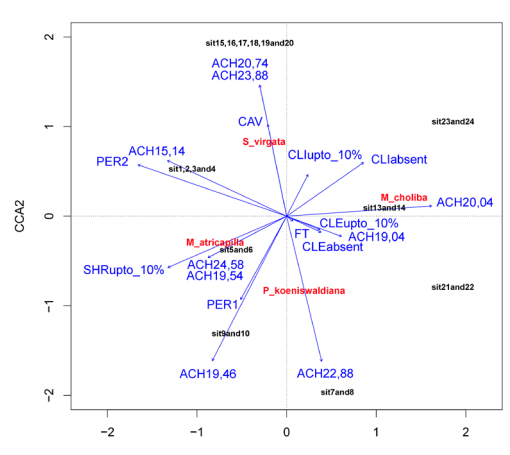

Figure 3. Canonical Correspondence Analysis (CCA) results showing the relationship between the recorded owl species and vegetation parameters in the Caetetus Ecological Station. Owls: M_choliba – *Megascops choliba*; M_atricapilla – *Megascops atricapilla*; P_koeniswaldiana – *Pulsatrix koeniswaldiana*, and S_virgata – *Strix virgata*. Vegetation variables: ACH - average canopy height; CAV - trees with cavity; FT - fallen trees; CLE - presence of clearing; CLI - presence of climbing plants; SHR- presence of shrubs and PER - perimeter at chest height of trees. The CCA1 axis represents 44.74% of this variation, while the CCA2 axis represents 42.56%.

Megascops species occurred at lower densities and were found in the dominant species territory. Despite the risk of being preyed upon by larger owls, competition between them may have been reduced, because *Megascops* owls occupy a mid-height and closer to ground forest part, while larger species tended to be close to the canopy. *Megascops* species were not found at the same sampling point.

DISCUSSION

Owl survey

The species registered might appear low considering EECa is one of the largest forest remnants in the interior of the State of São Paulo. However, according to Gutiérrez et al. (2007) in a literature review, most owl assemblages contain 3 to 4 species. However, in neotropical forests, such as EECa, assemblages of 5 and 6 owl species can be found (Gutiérrez et al. 2007). In our study, the lower number of species may be related to the non-sampling of bordering and adjacent areas, this is because in bordering areas species that inhabit open, transitional and other phytophysiognomies areas can be recorded.

Among the recorded species, *M. atricapilla, S. virgata*, and *P. koeniswaldiana* are forest species and have some degree of sensitivity to human disturbances (Stotz et al. 1996, Sick 1997), while *M. choliba* are habitat generalist (Sick 1997). Studies on Strigiformes in South America, especially in Brazil, are scarce (but see, Borges et al. 2004, Amaral 2007, Zorzin et al. 2008, Esclarski et al. 2011, Fink et al. 2012, Menq and Delariva 2015, Menq and Anjos 2015, Claudino et al. 2018). Results of these studies are similar to ours in relation to owls that occur in inner forest areas. However, these studies were sampled in bordering and adjacent areas, which maximizes the chance of registering species that use other types of habitats, making these studies incomparable to ours.

Analysis of vegetation structure and owl occurrence

The results of our CCA showed that vegetation structure is an influential factor for owl occurrence. Thus, the vegetation structure is assumed to be a good indicator of where Strigiformes species use the resources present in their habitat (Block and Brennan 1993). Several components of vegetation structure have been shown to influence the occurrence of Strigiformes; for example, the study by Menq and Anjos (2015), shows similar results with this study, where owl species are associated with mature vegetation (high level of development) sites. These sites have structures that provide the owls with shelter and nesting sites such as cavities (Menq and Anjos 2015), and possibly a greater prey abundance. Smaller species such as *Megascops* have greater plasticity in terms of habitat, and *M. choliba* is associated with gaps or edge areas (Menq and Anjos 2015).

We found that *S. virgata* is associated with sites with characteristics of mature forests, although the results indicate a tolerance regarding the ACH and PER. *Strix virgata* inhabits forest interiors, is abundant in Neotropical forests and is tolerant of deforestation (Gerhardt et al. 1994, König and Weick 2008, Zorzin et al. 2008). This species requires natural cavities for reproduction (Gerhardt 2004). It is important to note that a nestling owl was recorded at point 9 in January 2018. Although the nest was not located, this finding confirms that the species reproduces at this site. The specie has a home range with a radius of approximately 260 m (Gerhardt et al. 1994), allows us to infer, as well as for each recorded species, that the records at different points, separated by 800 m, are different individuals.

Pulsatrix koeniswaldiana is a typical forest species that can also occur in degraded and marginal forests (König and Weick 2008, Zorzin et al. 2008), and, in this study, is generalist in terms of the characteristics of the habitat, tolerating immature forest (intermediate level of development) areas and even using edge areas (personal observation, outside the sampling period).

The analysis showed that *M. choliba* individuals were scarce within the EECa, as there were few contacts with the species. *Megascops choliba* seemed to avoid areas with a higher canopy, characteristic of mature forests, being distributed at points closer to the edges or at sites where the trail is wide. These results are consistent with those of Claudino et al. (2018), who found that *M. choliba* used more edges and cleared habitats.

Unlike *M. choliba*, *M. atricapilla* preferred the interior of the EECa, having a generalist pattern and occurring in areas with a lower canopy or mature forests with a higher canopy, which reflected the amplitude of the measurements of the trees at the site. Similar result to the one found by de Menq and Anjos (2015).

Composition of species and segregation

In this study, the potential occurrence of segregation between the recorded species was observed. *Strix virgata* and *P. koeniswaldiana* were the dominant spe-

cies and our results indicate that they seem to avoid occupying the same site. *Megascops* owls were not recorded at the same sampling point, with *M. choliba* being recorded at points closer to the edge or where the trail was wide, and *M. atricapilla* was recorded at points with dense vegetation. A possible explanation provided by Borges et al. (2004) is that habitat segregation may be associated with aggression and/or differential use of resources among congeneric species.

This study shows that vegetation structure is associated with the occurrence of owl species in a seasonal semideciduous forest fragments. It also identifies the vegetation characteristics that help to detect a possible site within a forest fragment where the reported species are more likely to occur. Thus, this study highlights the importance of conserving fragments in the interior of the State of São Paulo, which harbors a considerable general biodiversity, especially of the owls.

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