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CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA E RECURSOS NATURAIS

LUCAS ANDREI CAMPOS-SILVA

FACTORS AFFECTING BIRD FAUNA IN PATCHES OF URBAN PRIVATE FORESTS IN SOUTHEASTERN BRAZIL

São Carlos
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Dissertação apresentada ao Programa de Pós-Graduação em Ecologia e Recursos Naturais, para obtenção do título de Mestre em Ecologia e Recursos Naturais.

Orientação: Prof. Dr. Augusto João Piratelli

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"Se vi mais longe
foi por estar de pé
sobre ombros de gigantes"
(Isaac Newton)

"If I have seen further
it is by standing
on the shoulders of giants"
(Isaac Newton)

ÍNDICE

Fatores que afetam a avifauna em áreas de florestas privadas urbanas no Sudeste do Brasil

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Resumo Geral

A ecologia urbana tem recebido recente atenção na literatura científica. Mas, muitos estudos são conduzidos em áreas públicas. Muitos loteamentos fechados têm sido criados nas cidades Neotropicais, frequentemente incluindo manchas de vegetação nativa. Fragmentos de vegetação nativa abrigam uma notável biodiversidade urbana e áreas privadas podem ser geridas, juntas com parques públicos, para oferecerem sítios adequados a avifauna urbana. Ainda assim, pouco é conhecido sobre a importância dessas manchas de vegetação nativa para a conservação de aves. Aqui nos caracterizamos a composição da avifauna de manchas de vegetação e analisamos os efeitos de um conjunto de características de variáveis biológicas e da paisagem sobre a avifauna. Realizamos este estudo em Sorocaba (Brasil) em 28 fragmentos de florestas particulares de 17 loteamentos fechados, de setembro de 2016 a setembro de 2017. Amostramos a avifauna por meio de 46 pontos fixos (um a seis por loteamentos fechados) e avaliamos 16 variáveis do ambiente (14 locais – estrutura da vegetação – e dois da paisagem) e áreas de 10mx10m. Registramos 72 espécies, principalmente especialistas em hábitats e dieta (58%). Essas florestas abrigam muitas espécies dependentes e independentes de florestas (65% de todas as espécies amostradas). Oito variáveis locais afetaram a riqueza, diversidade, abundância, guildas tróficas e dependência florestal. Porcentagem de cobertura florestal influenciou na abundância, guildas tróficas e dependência florestal. Assim, manchas particulares de vegetação podem ser relevantes refúgios a avifauna urbana e o manejo apropriado podem incrementar seu papel na manutenção de uma avifauna mais especializada.

Introdução Geral

Atualmente mais da metade da população mundial vive nas cidades (Aronson et al. 2014, United Nations 2014). O processo de urbanização ocasiona mudanças na estrutura das comunidades biológicas, transformando a sua composição e diversidade implicando, em geral, em homogeneização (McKinney 2006; Cruz et al. 2013; Sacco et al. 2013; Myczko et al. 2014), ocasionando a perda de biodiversidade, de funções e serviços ecossistêmicas (Kremen and Ostfeld 2005).

As aves respondem de formas distintas ao processo de urbanização, evitando, tolerando ou explorando áreas urbanizadas (Caula et al. 2008; Shochat et al. 2010; Evans et al. 2015; Rayner et al. 2015; Seress and Liker 2015; Piratelli et al. 2017; Murgui and Hedblom 2017). Cerca de 20% das espécies de aves do mundo são encontradas dentro do ecossistema urbano, e a literatura referente a como elas respondem ao processo de urbanização em termos de riqueza, diversidade, abundância e comportamento é ampla (Proppe et al. 2013; Aronson et al. 2014; Sengupta et al. 2014; Barth et al. 2015; Seress and Liker 2015; Sol et al. 2017). Estudos realizados principalmente em áreas verdes têm revelado quais são as relações aves-habitat dentro das cidades (Barth et al. 2015; Seress and Liker 2015; Murgui and Hedblom 2017).

Têm sido sugerido e amplamente pesquisado fatores que podem atuar na influência da composição da avifauna urbana entre eles: (1) alimentação suplementar oferecida pelo ser humano, (2) presença de predadores não nativos, (3) estrutura e composição florística e (4) presença e tamanho de manchas de vegetação nativas (Beninde et al. 2015; Huang et al. 2015; Lepczyk et al. 2017). Em geral, a densidade de espécies esta negativamente relacionada com a cobertura urbana, e a presença de fragmentos naturais remanescentes favorece a diversidade e riqueza de aves (Caula et al. 2008; Ryder et al. 2010; Strohbach et al. 2013; Aronson et al. 2014; Sengupta et al. 2014; Beninde et al. 2015; Rayner et al. 2015; Seress and Liker 2015). Assim, a presença de áreas naturais dentro do ambiente urbano é importante para a conservação das aves (Strohbach et al. 2013; Beninde et al. 2015). No geral, essas áreas fazem parte das chamadas áreas verdes, as quais são compostas por formações mais naturais como parques, praças, jardins e reservas, situando-se em um mosaico de áreas particulares e públicas (Taylor and Hochuli 2017). Elas são contrastantes em termos de estrutura, variando em tamanho e características de vegetação (Taylor and Hochuli 2017).

Estudos sobre aves urbanas em geral são desenvolvidos nestas áreas verdes, especialmente nas públicas (Lerman and Warren 2011; Shwartz et al. 2013; Paker et al. 2014; Barth et al. 2015). Porém, há uma grande lacuna de conhecimento a respeito da importância de áreas naturais encontradas em áreas privadas, especialmente formações florestais mais extensas e complexas e seu papel na conservação da diversidade biológica das cidades. As áreas particulares mais estudadas são os jardins residenciais (Goddard et al. 2010, 2013; van Heezik et al. 2012; Cerra and Crain 2016).

Como a diversidade e a riqueza de aves estão geralmente relacionada com a estrutura da vegetação nativa, a redução de remanescentes florestais no ecossistema urbano acarreta redução drástica de certas espécies, especialmente as mais especializadas como as florestais (Chace and Walsh 2006; Partecke et al. 2006; Evans et al. 2009; Strohbach et al. 2013; Barth et al. 2015). Áreas privadas compreendem as maiores proporções das paisagens nas cidades (Dickinson et al. 2010), e a manutenção da vegetação nativa é essencial para a conservação da avifauna especializada dentro do ecossistema urbano (Ferenc et al. 2014). No Brasil, 53% da vegetação nativa está localizada em propriedades privadas, mantendo muitos representantes das aves residentes (Soares-Filho et al 2014).

Entender os padrões de composição das espécies e quais são os atributos do habitat que influenciam na avifauna dentro do ecossistema urbano não apenas nas áreas verdes públicas, mas sim também nas áreas particulares é muito importante para o planejamento sustentável das cidades e conservação dos recursos naturais (Fontana et al. 2011; Aronson et al. 2014; Ferenc et al. 2014), sobretudo nos dias atuais, quando há altas taxa de conversão do uso da terra e consequentemente perda acelerada de áreas nativas dentro das cidades (Fontana et al. 2011; Barth et al. 2015).

Aqui nós amostramos a avifauna urbana em manchas de vegetação nativa privadas. Nós visamos detectar variáveis locais e da paisagem que podem determinar a avifauna nessas áreas, focando em seus atributos ecológicos. Esses dados podem preencher a lacuna de conhecimento relacionado a avifauna urbana e assim, subsidiar medidas de políticas públicas visando a conservação da biodiversidade nas cidades.

Artigos Produzidos

Este estudo gerou um artigo científico, nomeado "*Factors affecting bird fauna in patches of urban private forests in Southeastern Brazil*", que foi submetido à revista *Urban Ecosystems*, submissão que é solicitada na norma regimental atual do Curso de Pós-Graduação em Ecologia e Recursos Naturais da Universidade Federal de São Carlos. Este trabalho está formato segundo as normas exigidas pela revista.

Research Paper

Factors affecting bird fauna in patches of urban private forests in Southeastern Brazil

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Abstract Urban ecology has received attention in the recent scientific literature, but most studies are conducted in public areas. Many private closed gated communities have been created in Neotropical cities, often including patches of native vegetation. Fragments of native vegetation shelter a noteworthy urban biodiversity, and private areas could be managed together to public parks to offer friendly sites for urban avifauna. Yet, little is known about the importance of these private forests for bird conservation. Here we characterized the bird-fauna composition in patches of native private forests and analyzed the effects of a set of biological and environmental characteristics on birds. We performed this study in Sorocaba (Brazil) in 28 patches of private forests in 17 closed gated communities, from September 2016 to September 2017. We sampled bird fauna through 46 fixed-points counts (one to six per gated communities) and evaluated 16 environmental variables (14 local - vegetation structure - and two of the landscape) in plots of 10mx10m. We recorded 72 species of birds, mostly diet- and habitat specialists (58%). These private forests harbor many forest dependent/semi depend species (65% of all sampled species). Eight local variables have affected the species richness, diversity, abundance, trophic guilds, and forest dependence. Percentage of forest cover has influenced abundance, trophic guilds and forest dependence. Yet, patches of private native vegetation may be relevant refuges to urban birds, and proper management may enhance their role in maintaining a more specialized bird fauna.

Keywords Birds, Brazil, habitat heterogeneity, Neotropical, private forest areas, urban ecology

Introduction

More than half of the world's human population currently lives in urban setlemments (Aronson et al. 2014; United Nations 2014). Urbanization is the anthropic process that gradually converts uninhabited native landscapes into areas with sporadic or permanent human presence (Marzluff 2001). The process of urbanization drives shifts in the structure of biological communities, affecting their composition and diversity, often resulting in losses of biodiversity and ecosystem functions and services (Kremen and Ostfeld 2005) and implying in homogenization (McKinney 2006; Cruz et al. 2013; Sacco et al. 2013; Myczko et al. 2014).

Nearly 20% of the world's bird species are found within urban settlements, and a broad scientific literature explain how they respond to the process of urbanization on richness, diversity, abundance, and behavior (Proppe et al. 2013; Aronson et al. 2014; Sengupta et al. 2014; Barth et al. 2015; Seress and Liker 2015; Sol et al. 2017). Birds respond by different ways to the urbanization process, avoiding, tolerating or exploring urbanized areas (Marzluff 2001; Caula et al. 2008; Shochat et al. 2010; Evans et al. 2015; Rayner et al. 2015; Seress and Liker 2015; Piratelli et al. 2017; Murgui and Hedblom 2017). Research carried out mainly in green areas have clarified the relations bird-habitat within the cities (Barth et al. 2015; Seress and Liker 2015; Murgui and Hedblom 2017), addressing the main factors that can positive or negatively influence the composition of urban avifauna (*e.g*. supplementary feeding offered by humans, presence of non-native predators, plant structure and composition and presence and size of native vegetation patches) (Marzluff 2001; Beninde et al. 2015; Huang et al. 2015; Lepczyk et al. 2017). Green areas are composed by patches of native vegetation, contrasting in structure and varying in size and vegetation characteristics (Taylor and Hochuli 2017) along a mosaic of private and public lands. They emphasizing not only natural value but also anthropic characteristics such as parks, squares, gardens and reserves (Taylor and Hochuli 2017).

Habitat heterogeneity is a key factor driving species richness by creating habitat physical conditions, and allowing higher niche specialization (MacArthur and MacArthur 1961; Huang et al. 2015). The urbanization process influences habitat heterogeneity causing losses of local structures (*e.g*. reduction in the number of tree species, standing dead trees, richness of shrubs) thereby affecting bird fauna (Carbó-Ramírez and Zuria 2011; Myczko et al. 2014; Paker et al. 2014). Examples of this influence are shifts of more by less specialized trophic guilds (*e.g*. replacement of canopy and trunk-twig insectivores by ground insectivores) (Bessinger and Osborne 1982).

Species density is usually negatively related to paved cover, and the presence of remainings of native vegetation favors bird diversity and richness (Caula et al. 2008; Ryder et al. 2010; Strohbach et al. 2013; Aronson et al. 2014; Sengupta et al. 2014; Beninde et al. 2015; Rayner et al. 2015; Seress and Liker 2015). Yet, the presence of native patches into the urban matrix is important for bird conservation (Strohbach et al. 2013; Beninde et al. 2015).Studies on urban birds usually are carried out on these green areas, mainly in public ones (Lerman and Warren 2011; Shwartz et al. 2013; Paker et al. 2014; Barth et al. 2015). Yet, the relevance of native vegetation in private areas is still poorly known, specifically the more extensive and complex forest fragments and their role on biological conservation in cityscapes. As bird diversity and richness usually are related to the structure of native vegetation, the reduction of forest remnants leads to a dramatic reduction of target species, as the more habitat- and diet specializers and forest dependents (Chace and Walsh 2006; Partecke et al. 2006; Evans et al. 2009; Strohbach et al. 2013; Barth et al. 2015).

Private areas comprise the largest proportions of the landscape in cities (Dickinson et al. 2010), and the maintenance of native vegetation is essential for conservation of specialized bird fauna within urban ecosystems (Ferenc et al. 2014). In Brazil, 53% of native vegetation are located in private properties, hosting many representatives of resident birds (Soares-Filho et al 2014). Ornithological studies in private urban green areas are often developed in gardens, isolated trees and orchards, which probably do not have the same forest structure of native forests (Akinnifesi et al. 2010; Goddard et al. 2010, 2013; van Heezik et al. 2012; Cerra and Crain 2016). To our knowledge, no study on birds has ever been developed in patches of urban private native forest in the Neotropics. Understanding patterns of species composition and identifying the attributes of habitat that influence bird fauna within the urban ecosystem, not only in public but also in private green areas, is relevant for sustainable city planning and conservation of natural resources (Fontana et al. 2011; Aronson et al. 2014; Ferenc et al. 2014). This has received more priority nowadays, when large areas of native ecosystems have been converted into anthropogenic landscapes, thus catalyzing losses of native vegetation within cities (Fontana et al. 2011; Barth et al. 2015).

Here we sampled urban bird fauna in private patches of native vegetation. We aimed to detect local and landscape variables that can determine birdlife in these areas, focusing on their ecological attributes. These data may fill a gap in the knowledge of urban avifauna, and thus subsidize public policies aimed at biodiversity conservation in cityscapes.

Matherial and Methods

Study area

This study was carried out in the city of Sorocaba, southeastern Brazil (23°30'5.65"S; 47°27'9.46"W, Fig. 1). The city has ~ 650,000 inhabitants, and the predominant vegetation is the morphodomains of the Atlantic Forest and -less frequently - Cerrado (IBGE, 2017). The climate is subtropical with dry winters (temperatures below 18ºC) and hot summers (over 22ºC), with averages annual precipitation of 1311 mm and temperature of 22.1ºC (Alvares et al. 2013).

Sampling design and data collection

We studied 28 private patches of native forest vegetation located within the urban area of Sorocaba (Fig. 1). We excluded from our analyses non-forest native areas (*e.g.* native fields, flooded areas) because Sorocaba is located in the southeastern region of the state of São Paulo, where Atlantic Forest (prevailing forest areas) is the predominant vegetation. We also made this decision because most of the permanent protected areas in the Atlantic Forest is characterized by forest formations (Federal Law nº 12.651/2012, Brazil 2012). We excluded from our analyses non-forest anthropogenic areas such as squares, gardens and orchards.

All these native forest vegetation studied were located in the so-called "gated communities". We selected private forest patches of gated communities because in these areas we have control on a series of antropogenic effects, such as hunting, cattle trampling and predation by domestic animals. Gated communities are defined as walled or fenced residential areas governed and approved by Brazilian Federal Law 6.766/79 (Brazil 1979). They are areas having guardhouses and/or gates operated by private security agents that control access to lots and other open spaces. All gated communities must maintain at least 20% of their area to be designated as "green area", destined to leisure and human well-being, being able to promote the conservation of the local biodiversity (Resolution SMA-031, São Paulo 2009). This percentage varies according to the successional stage of the vegetation, maintaining characteristics of native vegetation and less anthropogenic effects (São Paulo 2009). The first gated community appeared in Brazil in the 1970s in the state of São Paulo, and expanded in number after the 1990s for the whole country; these new components of urban landscapes are generally found outside the central areas (Freitas 2008, Barros 2012; Silva et al. 2015).

All these private native forests were in 17 gated communities within a maximum limit of 8 km from the center of Sorocaba, representing ~60% of the local gated communities (Fig. 1c). These private forest patches vary greatly in extent and are generally found fragmented and in small size, ranging from 0.1 to 6.72 hectares. They have different levels of anthropization, thus varying in their local characteristics (Fig. 1c, Online Resource 1, Online Resource 2).

We carried out bird censuses and sampled the environmental variables from September 2016 to September 2017. For sampling bird communities, we performed 10-minutes fixed point counts (FP) (20-meters limited) from dawn to four hours later. We did not record birds that were flying above the canopy. We included species of open areas as long as they were under the canopy cover. We sampled a total of 46 point counts, settled proportionally to the respective size of each private forest patch, varying in total from one to six. The point counts were the sample units. Each point was georeferenced; respecting the minimum distance of 200 meters each other to reduce an overestimation of the abundance of species. We performed two data collecting in each fixed point count, both in the rainy and in the dry season, totaling 92 samples.

We proceed bird species identification according to Del Hoyo et al. (2016). We also categorized birds according to their regional threatened status (São Paulo 2014). The species were also considered in terms of forest-dependence (Becker et al. 2013; Santos-Junior et al. 2016), as independent (I); semi-dependent (S), and dependent (D) (Online Resource 3).

We clustered bird species into trophic groups according to their main food itens and microhabitats (Wilman et al. 2014; Del Hoyo et al. 2016; as open-areas insectivores (Ia), canopy insectivores (Ic), foliage-gleaner insectivores (If), understory insectivores (Is), trunk- twig insectivores (It), aerial insectivores (Iv), nectarivores-insectivores (Ne), carnivores (Ca), nectarivores (Ne), large frugivores (body mass over 80g) (Fg), small frugivores (body mass less than 80g) (Fp), open areas granivores (Ga), forest edge granivores (Gb), omnivores (On) and piscivores (Pi). We also separated the trophic guilds in terms of specialists or generalists. The specialists were those species considered specialized to some type of resource, stratum or specific environment (*e.g*. Fg, Fp, Gb, Ic, If, It), whereas the generalists were those species belonging to the opportunistic trophic guilds, which use a great variety resources, strata or environments (*e.g*. Ga, Ia, Iv e On) (Melo 2017).

Environmental Variables

In order to characterize the environmental complexity (habitat heterogeneity) in each point count, we sampled 14 local variables only in the rain season, in plots of 10x10m in the same days of bird data collecting. We also sampled two landscape characteristics (Table 1, Table 2).We choose these two variables because they are known to affect the urban bird fauna (Strohbach et al. 2013; Ferenc et al. 2014; Beninde et al. 2015; Chang and Lee 2016). These measurements were obtained using the area measurement function of Google Pro 2017 software and the maps were produced using QGis software (Version 2.18.5).

Data analysis

In order to compare the bird communities from different sites, we used the Point Abundance index (IPA), Pielou's evenness index (J'), Margalef's richness index (D') and Shannon-Wiener's diversity index (H). We calculated the IPA from the sum of the contacts of each species in each point count divided by the total amount of point counts (92 samples) x 100.

We evaluated the relationships between explanatory environmental variables and species abundance data, richness, diversity and equitability, trophic guilds and forest dependence (dependent variables) through redundancy analysis. In order to make a more accurate analysis, we separate the variables into spatial and local, which were analyzed separately. The redundancy analysis (RDA) is a multiple linear regression followed by a principal component analysis (PCA) performed through the adjusted values table, in which the response variable is a matrix of species composition which is explained by a matrix of predictive variables (Boccard et al. 2011). The RDA is a linear method and therefore all data on species abundance, trophic guilds and forest dependency were standardized through Hellinger's transformation (Peres-Neto et al. 2006). In order to avoid overestimating the quantities of explanatory variances (Type 1 error), we used the double criterion for the selection of explanatory variables (Blanchet et al. 2008).

We used the selection criterion which presents functions for the selection of the best explanatory variables "Best" means that they are the variables that better explain most of the variance of the values Boccard et al (2011). To achieve this goal, we first use the "Vegan's ordistep ( )" function from the R Studio Vegan package. In this function, the significance of the F statistic together with all the explanatory variables is tested by permutation tests, with the most significant explanatory variables (based on p values) being selected. In case of a tie, we use as selection criterion the variables with lower values of "Aikake Information Criterion (AIC)". The process continues until no more significant variable can enter the model. This process was carried out in order to find out which explanatory variables influenced in: a) abundance; b) richness, diversity, and equitability; c) trophic guilds d) forest dependency. Point counts located within the same gated communities were considered as pseudoreplic, and each point count was analyzed separately in the RDAs.

We performed all the analyzes and graphics in the software R 3.2.3 (R Development Core Team 2015), through the vegan packages (diversity analysis and redundancy analysis (Oksanen et al. 2016). For the calculation of area measurements and percentages, we used the free version of Google Earth Pro, after checking in the field.

Results

Bird fauna composition and environmental complexity

We recorded 72 species of birds, mostly diet- and habitat specialist (58%), from 12 orders and 27 families (Online Resource 4). None of the species is threatened with extinction. This total of species represents 26% of the bird species of the city of Sorocaba (Piratelli et al., 2014). The most abundant were two generalist species, Sayaca Tanager (*Thraupis sayaca*) (IPA=94.6) and Pale-breasted Thrush (*Turdus leucomelas*) (IPA=70.7) (Online Resource 5). We recorded 11 trophic guilds, prevailing omnivorous species (n = 11) and foliage-gleaner insectivores (n = 13). Most species are forest-related species (65%), being 47% (n=34) semi-dependents, 18% (n=13) dependent and 35% (n=25) independent. We observed that 93.5% (n=43) of the point counts had values of equitability greater than 0.90 and therefore had a high uniformity of species abundance. Twelve (71%) of our studied gated communities had less than 20% of forest cover (Online Resource 6).

We verified that canopy and grass cover represented 6.15% of the variance of bird abundance (F = 1.4085, p = 0.021). The first axis of the RDA explained 67% of the values and the second axis, 32% of the variance (Fig. 2a). Canopy cover has a positive influence on the abundance of species semi-dependent of forests, *e.g*. Pale-breasted Thrush, Palm Tanager (*Thraupis palmarum*), Social Flycatcher (*Myiozetetes similis*), Green-barred Woodpecker (*Colaptes melanochloros*), White-tipped Dove (*Leptotila verreauxi*), Rufous-browed Peppershrike (*Cyclarhis gujanensis*) and Bananaquit (*Coereba flaveola*), and a forest-dependent (Golden-crowned Warbler, *Basileuterus culicivorus*). The percentage of private forest influenced 5% on the variation of species abundance (F = 1.9101, p = 0.005) (Fig. 2b). The abundance of several species had a relation with intermediate values of this explanatory variable (Fig. 2b).

The local variables percentage of herbaceous vegetation, tree richness and standing dead trees influenced in the variance of 17.5% of the data of values of bird ecological indexes (diversity, richness and equitability) (F = 2.9448, p = 0.041) (Fig. 3a). The first axis of the RDA explained 99% of the total variance. The bird species richness was positively related to the variables herb cover, tree richness and standing dead trees. Equitability was negatively related to all these variables (Fig. 3a). We observed that none of the landscape variables has significantly influenced the ecological indices of bird communities (F = 2.1853, p = 0.157, Fig. 3b).

We verified that the variables percentage of herbaceous cover, canopy cover and grass cover influenced significantly trophic guilds, being responsible for 16% of the total variance (F = 2.4874, p = 0.003). The first axis of the RDA explained 49% of the total variance and the second 32% (Fig. 4a). We verified that the canopy cover influenced positively the amount of edge granivorous and omnivorous species and negatively the generalist species as open-area gramnivores and insectivores, aerial insectivores and some carnivores (Fig. 4a). Grass cover positively influenced these same non- specialist trophic guilds previously reported. We verified that percentage of the forest cover has also significantly influenced the trophic guilds, being responsible for 6% of the total variance (F = 2.539, p = 0.01, Fig. 4b).

We found that more specialized guilds (*e.g*. insectivorous trunk climbers, foliage-gleaner insectivores, nectarivores-insectivores) and more forest species were more positively related to the percentage of the forest the forest cover (Fig. 4b).

We found that the variables canopy height, grass cover and shrub density significantly influenced the number of species related to forest dependence, explaining 19% of the variances of these data (F = 3.2469, p = 0.006). The RDA 1 explained 66% of the variation and the second 32 %% (Fig. 5a). We verified that the response variables S and D were related to the explanatory variables canopy height and shrub density. We observed that the forest independent species were positively related to grass cover and negatively related to canopy height. Forest-dependent species were positively related to shrub density (Fig. 5a). The variable percentage of forest cover significantly influenced the dependent, semi-dependent and independent species of forests, accounting for 10% of the total variance (F = 4.4537, p = 0.008, Fig. 5b).

Discussion

Our studied private forests harbor a noteworthy part of the local bird fauna, mainly related to species that are forest-dependents. We also recorded many representatives of trophic groups typical from forest environments (*e.g*., insectivores of foliage, canopy insectivores, frugivores). Such composition emphasizes the importance of these sites as refuges for specialized bird fauna in the cities, since non-forest areas (*e.g*. squares and gardens) may not maintain the same proportion of specialists, due to the scarce forest structure of their habitats, restricting the amplitude of conditions and resources (Akinnifesi et al. 2010; Goddard et al. 2010, 2013; van Heezik et al. 2012; Cerra and Crain 2016). Thus, beyond public forest areas (*e.g*. parks and riparian forests) (Brummelhaus et al. 2012; Domínguez-López and Ortega-Álvarez 2014), private forests may also contribute to the conservation of forest species in cities.

We verified that both landscape and local characteristics influenced the composition of the urban bird fauna in the private forest patches. As in earlier studies, vegetation structure has influenced the composition of the urban birds, acting um an important driver of bird richness (Croci et al. 2008; Fontana et al. 2011; Ferenc et al. 2014; Schütz and Schulze 2015). The greater complexity of the forest environment may have influenced positively in a greater number of specialized trophic groups (insectivores of foliage, insectivorous trunk climbers, nectarivores-insectivores, large frugivores and forest edge granivores, Fig. 4a). Losses and reduction of forest cover imply in a decrease on more specializes guilds, dependent of more restrictive conditions (Schütz and Schulze 2015).

We found that many private forests patches have low structured understory, with richness and density of shrubs (Resource Online 1b). Shrub density positively influenced the amount of forest-dependent species (see Fig. 5a). They are important structural components of the understory, but their removal in urban forest areas is a common management practice, aiming to increase the recreational value, giving a pleasant and secure sensation to human inhabitants (Heyman 2010). Yet, such practice is very detrimental to more specialized bird fauna such as those of more specialized trophic guilds (*e.g*. insectivores of understory, insectivores trunk climbers) (Heyman 2010) and those that nest in shrubs. As stressed before, these private forests are manageable and an increase in the understory complexity is an important and essential alternative to the maintenance of this specific bird fauna.

The tree richness positively influenced the bird richness in these forest areas. An increment on the richness of native trees may increases the structural complexity and spatial heterogeneity, thus providing a greater range of conditions and resources to bird fauna (Ferenc et al. 2014). As these areas are manageable, and based on our findings, reforestation programs increasing the number of native tree species may be an important strategy to increase the bird fauna of these private forests (Croci et al. 2008; Ferenc et al. 2014), and thus of urban bird communities.

We observed a trend of a low number of standing dead trees, and this variable influenced the bird richness. Environmental resources such as standing dead trees are needed for more specialized species, and structures such as hollows in tree holes (found in dead trees) influence the richness of birds in the urban environment (Strohbach et al. 2013). Two species that had their abundance positively related to the number of this variable nest in tree holes, Lineated Woodpecker (*Dryocopus lineatus*) and Streaked Flycatcher (*Myiodynastes maculatus*), and the Lineated Woodpecker feeds on insects in these trunks. The number of standing dead trees is an important driver of bird richness (see Fig. 3a).

Canopy cover positively selected the abundance of species with more forest dependency (*e.g*. Green-barred Woodpecker, White-tipped Dove, Rufous-browed Peppershrike, Pale-breasted Thrush, Golden-crowned Warbler and Bananaquit, Fig. 2a). The increase of canopy cover positively influences the increase of forest birds richness by the fact that it increases the amplitude of resources and conditions necessary to maintain these species. Although we only studied forest areas, we also observed species typical of open areas. This may be explained by the low canopy cover, small fragments size and presence of grasses (Online Resource 1), which are common in many of our studied sites, being that the cover of grasses selected positively the abundance of more generalist species, mainly those from open areas (*e.g*. Smooth-billed Ani, *Crotophaga ani*; Eared Dove, *Zenaida auriculata*; Chalk-browed Mockingbird, *Mimus saturninus* and Blue-black Grassquit, *Volatinia jacarina*). In forest areas, the presence of grasses is related to areas with remarkable edge influence and lower coverage.

We detected only one large frugivorous species, Dusky-legged Guan (*Penelope obscura*). Large frugivorous require specific habitats and disappear from small fragments, and preserving areas of larger extension is indicated for the maintenance of more specialized species, as this one (Sodhi et al. 2011; Zaiden et al. 2015). Some of the sampled species are typical of riberbanks, beaches and shallow streams, *e.g*. Slaty-breasted Wood-rail (*Aramides saracura*), Black-crowned Night-heron (*Nycticorax nycticorax*), and Limpkinn (*Aramus guarauna*) (Online Resource 4). Many of the studied private forest patches have water resources, streams or lakes, yet they are protected by local legislation (federal law nº 12.651/2012), which provides for the protection of native vegetation, including permanent protected areas, found in surrounding water bodies (Brazil 2012). Thus, these areas not only may shelter forest birds but some open field and aquatic species.

In our study, the percentage of forest cover was a key factor affecting the bird fauna, since it has influenced almost all sampled response variables (abundance, trophic guilds and forest dependence). Landscape-related factors as the size of green areas have been reported as positive promoters of bird diversity in urban ecosystems (Strohbach et al. 2013; Ferenc et al. 2014; Beninde et al. 2015; Chang and Lee 2016). This is important to be stressed, since 71% (n = 12) of our studied gated communities had less than 20% of forest cover less (Online Resource 5). This is because "green areas" can be also be considered as those that are not necessarily forested such as squares and recreation areas (legally considered an institutional area, Resolution SMA-031, São Paulo 2009). As stressed before, this may have a negative impact on birds, because they have restriction on the availability of resources and conditions (Murgui and Hedblom 2017).

We verified that these patches of native private forests harbor a noteworthy part of the local bird fauna, mainly related to forest-related species and diet-and habitat specialist. We verified that set of local variables influenced many bird fauna attributes of these patches of native private forests as bird abundance (canopy and grass cover), ecological indexes (percentage of herbaceous vegetation, tree richness and standing dead trees), trophic guilds (herb cover, canopy cover and grass cover) and forest dependence (canopy height, grass cover and shrub density). Percentage of private forest influenced also attributes of this bird fauna (bird abundance, trophic guilds, forest dependence). Our data support that these patches of native private forests are relevant refuges to urban birds and that for the maintenance of more specialized birds, natural characteristics must be preserved. Our data, therefore, may subsidize measures of public policies aimed at protecting native vegetation of urban areas.

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Tables

Table 1 Local and landscape variables and forms of collection in private native vegetation patches studied of gated communities in the city of Sorocaba, São Paulo, Brazil.

Variable	Acronym	Method for measuring
Tree morphospecies richness	Tr.ric	Counting the total number of tree richness only at the morphospecific level. We consider tree individuals as defined by Gschwantner et al. (2009): species of perennial plant that typically forming a single self-supporting main stem and that has a definite crown.
Number of arboreal individuals	Tr.den	Counted number of arboreal individuals
Richness of shrubs	Sh.ric	Counted number total of shrubs morphospecies. We consider shrubs individuals as defined by Gschwantner et al. (2009): species of a perennial plant that does not form a single main stem and does not have a defined crown.
Shrub density	Sh.den	Counting the total number of shrubs individuals
Number of epiphytes	Ep	Counting the total number of epiphytes
Number of standing dead trees	Dea.tr	Counting the total number of standing dead trees
Percentage of soil cover per litter	Lit.co	We obtained these measurements using a square of PVC (0.5 x 0.5 m) subdivided in 4 separate sub-squares of 0.25 x 0.25 m. We placed the square in the soil five times in each point counts (in the center and in the four extremities of the 10x10m area), obtaining later the average of these variables. We visually estimated the percentage in each of the four sub-squares to cover the litter, grasses and herbaceous vegetation and later we did the total average percentage of the area.
Percentage of exotic grasses	Gra.co	
Percentage of herbaceous vegetation	Her.co	
Litter height	Lit.he	We measured the litter height in each square of PVC during the measurements of the previous percentages by inserting a ruler and making the reading when the ruler was between the litter and the soil
Canopy cover percentage	C.co	We measured the percentage of the spherodensiometer squares occupied by the light that passed through the canopy, assuming that the lower the luminosity, the greater the canopy cover. We settled the spherodensiometer at the breast height (1.50 m), and we performed five measurements, one at the center and another four, one at each end of the 10x10m area, thus obtaining the mean of this percentage

Highest tree	Hig.Tr	We estimate the height of the base to the canopy of the highest tree using a digital tape
Canopy height,	Can.he	By visually estimating the height of the tallest trees
Diameter at the chest height of the trees	M.DAP	We measured the stems of arboreal individuals with stems with a diameter at breast height (DBH) greater than 10 cm using a tape-measure. For multicaulin plants with at least one stem with DBH greater than 10 cm, all stems were recorded
Area of the private forest	Are.for	We measured area of the private forest using the area measurement function of the Google Pro 2017
Percentage of private forests over the area of gated communities	Per.for	We measured the percentage of private forest area dividing the value of the forest area of the gated communities by the total value of gated communitie, turning that value into percentage

Table 2 - Structural values of variables of private forests in gated communities in Sorocaba, Brazil. Tree richness (Tr.ric), Tree density (Tr.den), Shrub richness (Sh.ric), Density of shrubs (Sh.den), Number of epiphytes (Ep), Number of standing dead trees (dea.tr), Litter cover (Lit.co), Herb cover (Her.co), Grass cover (Gra.co), Litter height (Lit.he), Canopy cover percentage (C.co), Highest Tree (hig.tr), Canopy height (Can.he), DAP mean (m.DAP), Forest cover in hec (Are.for), Percentage of the forest cover (Per.for).

	Mean	**Standard Error**	**Min**	**Max**
Tr.ric	7.23	0.45	3	18
Tr.den	17.3	1.80	4	65
Sh.ric	11.26	1.03	0	30
Sh.den	62.06	9.16	0	244
Dea.tr	2.80	0.57	0	19
Lit.co	65.6	4.34	0	100
Her.co	6.25	1.03	0	27
Gra.co	15.04	3.53	0	98
Lit.he	1.85	0.12	0.1	3.65
C.co	60.3	2.98	4.2	90
Hig.tr	8.6	0.45	1.41	16.21
Can.he	5.50	0.18	3	8.14
M.DAP	39.27	2.35	14.36	75.85
Are.for	5.16	0.32	0.17	9.1
Per.for	16.51	1.48	2.7	43.4

Figures

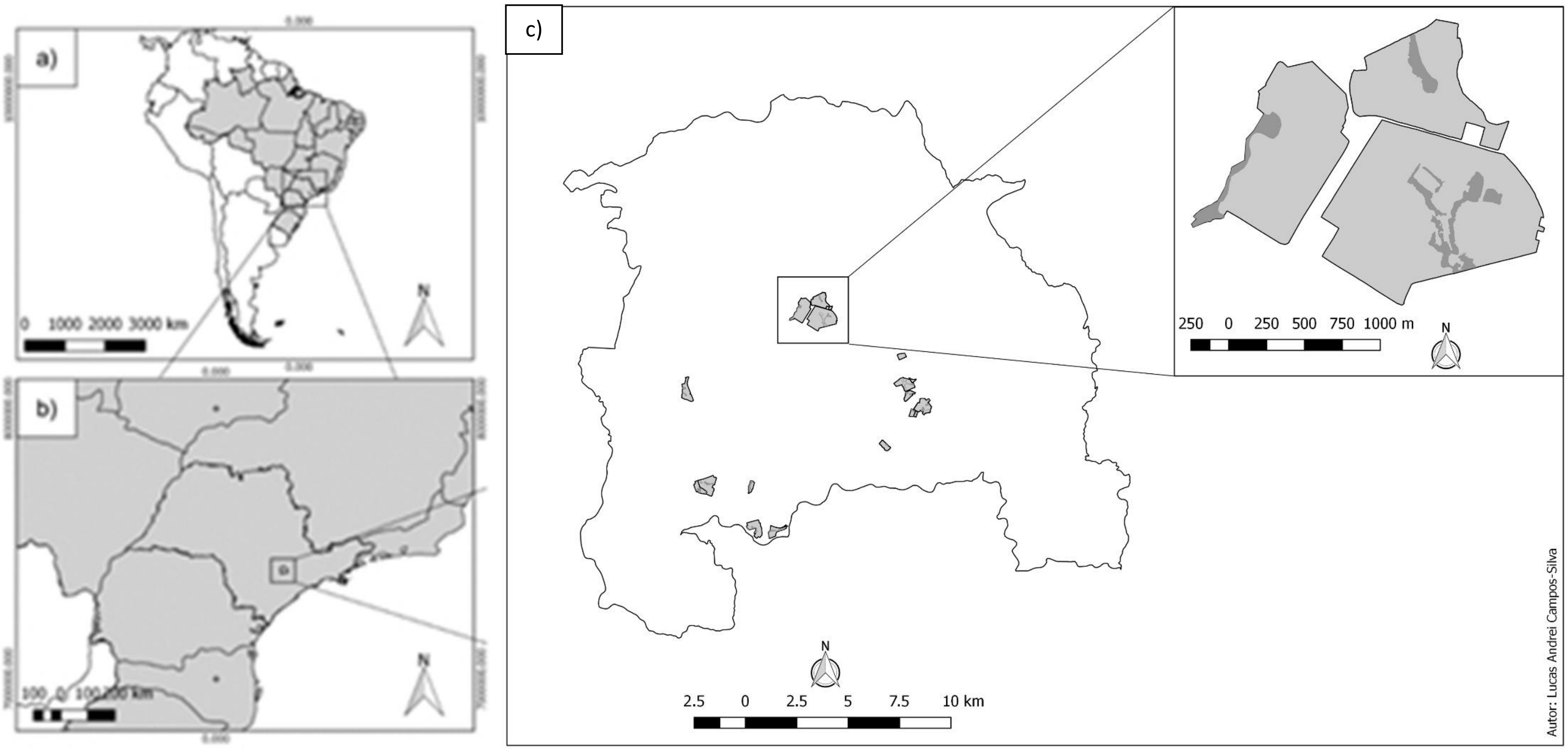


Fig. 1 - Location of the study area on three distinct scales. a) Location of Brazil in South America b) Location of Sorocaba in the state of São Paulo; c) Territorial boundary of the city of Sorocaba and the private forest fragments studied, located within the gated communities, with examples of private forest (in dark gray) of three gated communities (in light gray) (Source: IBGE 2017).

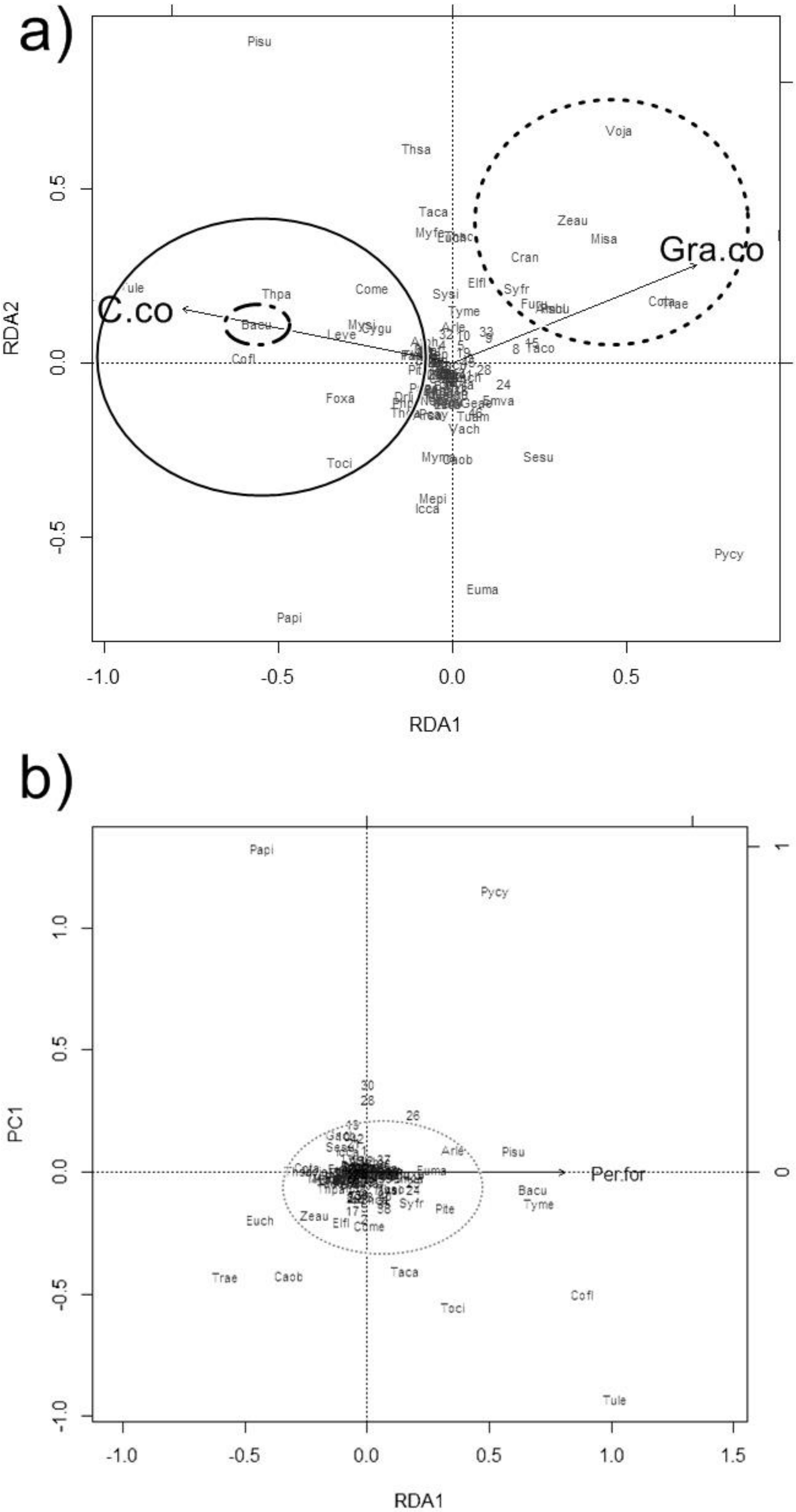


Fig. 2 – a) Redundancy analysis (RDA) relating the influence of environmental variables on birds from private forests of gated communities in Sorocaba, Brazil. The acronyms of the species are described in the Online Resource 4. The circle filled, the dotted and the little dotted refer to semidependent species, independent and dependent on forests respectively. The numbers are the fixed points. **b)** Redundancy analysis (RDA) relating the influence of spatial variables on the species of birds of private forests of gated communities in Sorocaba, Brazil. The acronyms of the species are described in the Online Resource 4. The dotted circle highlights the large number of species associated with the intermediate values of the exploratory variable.

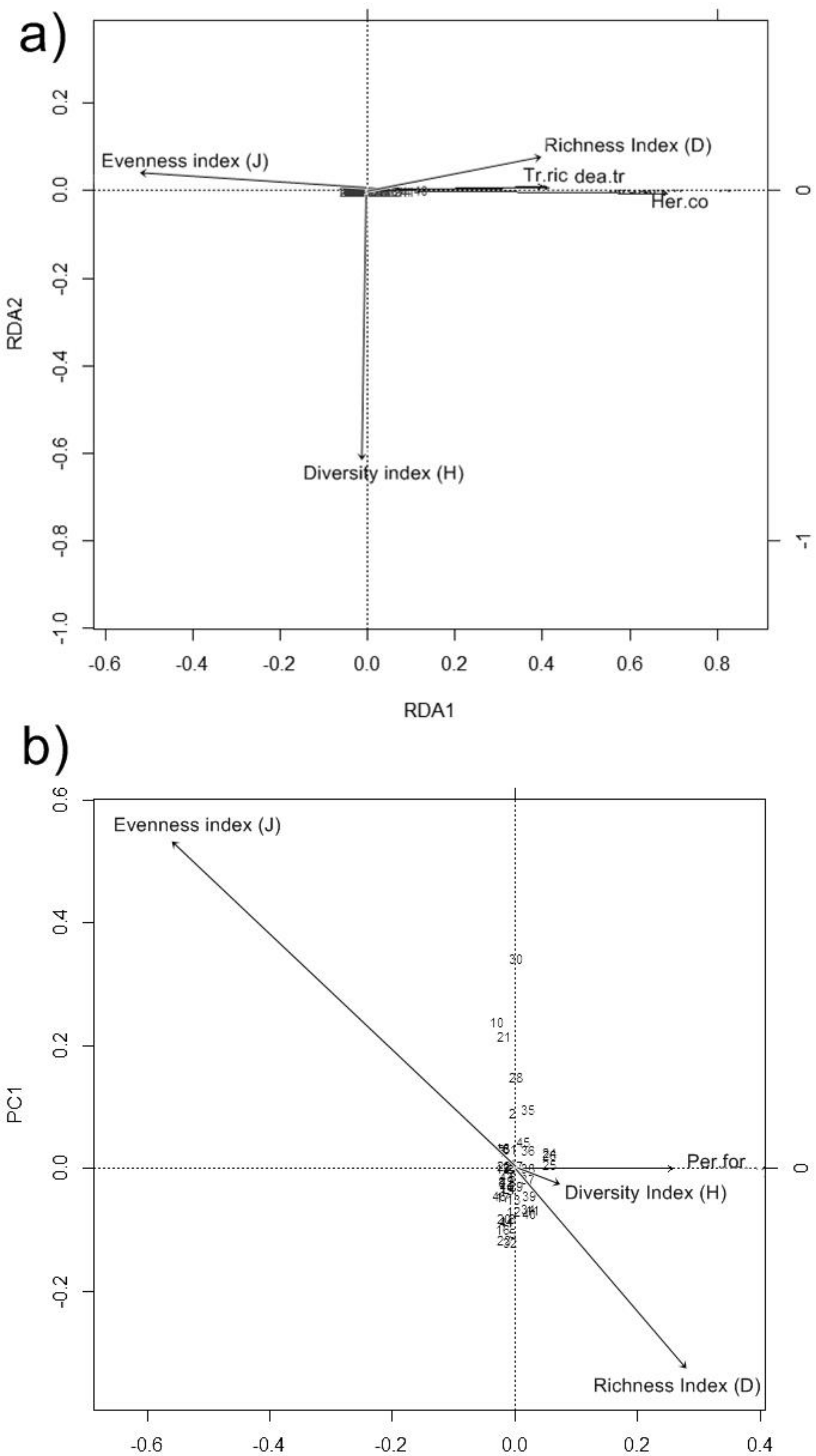


Fig. 3 – a) Redundancy analysis (RDA) relating the influence of local environmental variables as a function of the ecological indexes of the bird species of private forests of gated communities in Sorocaba, Brazil. Number of standing dead trees (dea.tr), Tree richness (Tr.ric), Herb cover (Her.co), Pielou's evenness index (J'), Margalef's richness index (D') and Shannon-Wiener's diversity index (H). b) Redundancy analysis (RDA) relating the influence of spatial variables as a function of the ecological indexes of the bird species of private forests of gated communities

in Sorocaba, Brazil. Pielou's evenness index (J’), Margalef’s richness index (D') and Shannon-Wiener’s diversity index (H), Percentage of the forest cover (Per.for). The numbers are the fixed points.

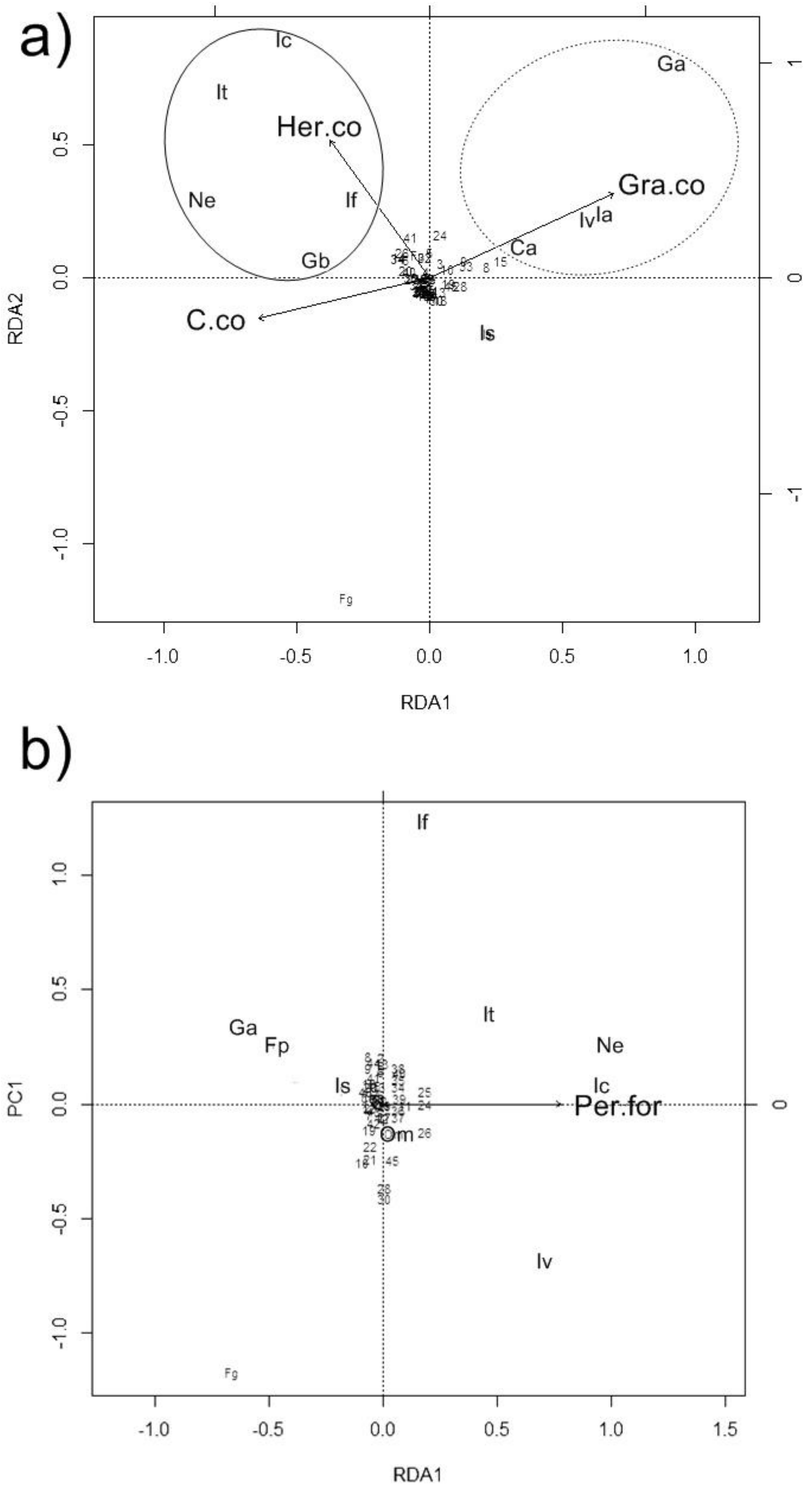


Fig. 4 – a) Redundancy analysis (RDA) relating the influence of environmental variables as a function of the trophic guilds of birds of private forests of gated communities in Sorocaba, Brazil. The acronyms of the guilds are described in the Online Resource 4. Canopy cover percentage (C.co), Herb cover (Her.co), Grass cover (Gra.co). The filled

circle and the dotted one refer to the trophic guilds related to florestal environments and open areas respectively. The numbers are the fixed points. **b)** Redundancy analysis (RDA) relating the influence of environmental variables as a function of the trophic guilds of birds of private forests of gated communities in Sorocaba, Brazil. The acronyms of the guilds are described in the Online Resource 4. Per.for - Percentage of the forest cover.

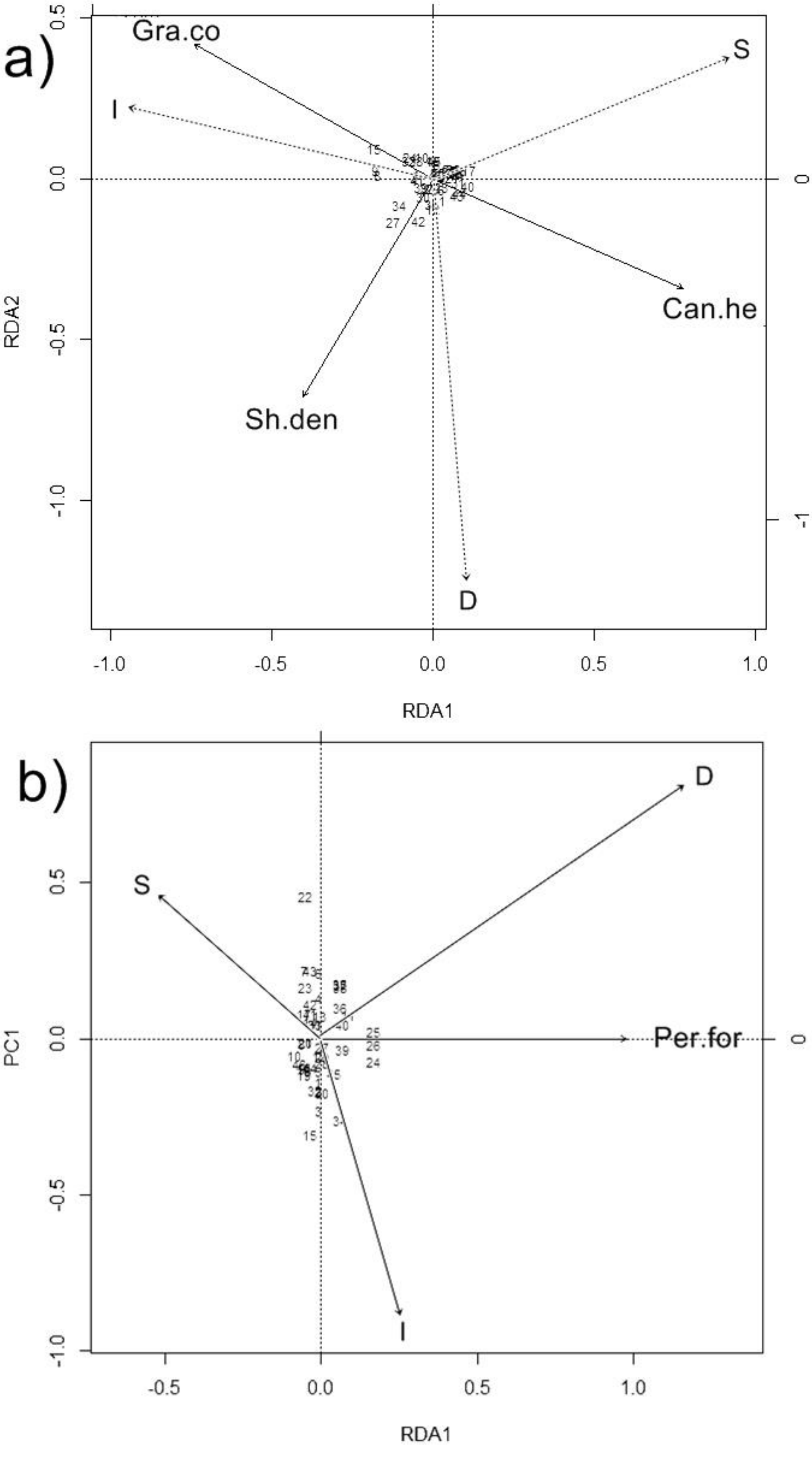
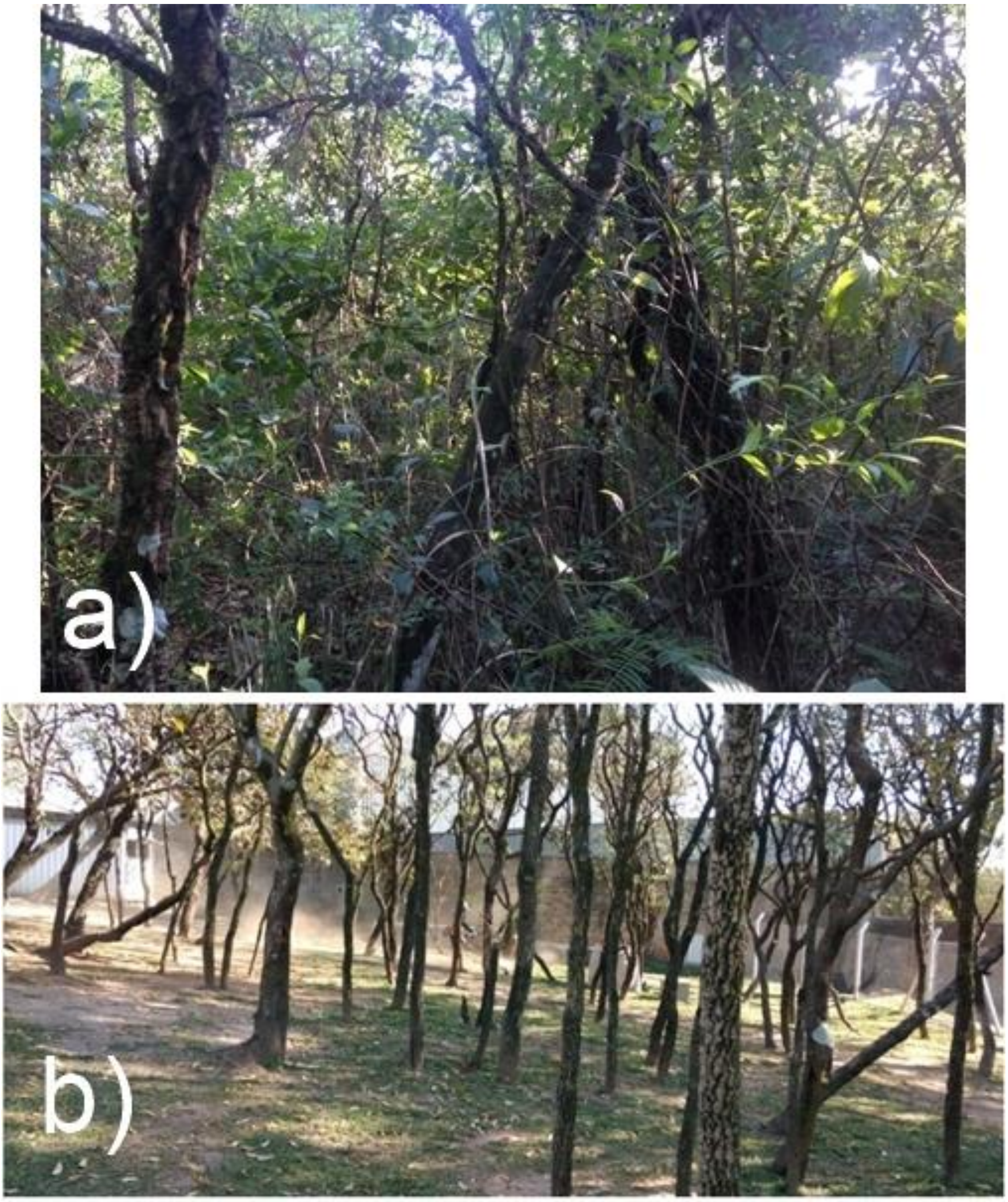


Fig. 5 – a) Redundancy analysis (RDA) relating the influence of environmental variables as a function of the forest dependence of birds of private forests of gated communities in Sorocaba, Brazil. Independent of forests (I); semi-dependent on forests (S), and dependent on forests (D). Grass cover (Gra.co), Density of shrubs (Sh.den), Canopy height (Can.he). The numbers are the fixed points. **b)** Redundancy analysis (RDA) relating the influence of spatial variables as a function of the forest dependence of birds of private forests of gated communities in Sorocaba, Brazil. Independent of forests (I); semi-dependent on forests (S), and dependent on forests (D). Per.for - Percentage of the forest cover.

Electronic supplemental material



Online Resource 1: Examples of native forest areas of gated communities and their variations in local structure due to anthropogenic action. a) Native forest area with lower degree of anthropization (vegetation formation of "Cerradao"). b) native vegetation with a higher degree of anthropization, where it is possible to observe the total absence of sub-forest. It is possible to perceive the typical trees of “Cerradao”.

Online Resource 2: Extension in hectares of native vegetation patches studied of gated communities in the city of Sorocaba, São Paulo, Brazil.

	Area of native vegetation patches studied (Hectares)			
Gated communitie	1	2	3	4
1	3.28	0.61	1.72	
2	0.99			
3	2			
4	0.18			
5	2.37			
6	1.22	1.1		
7	1.9	1.8		
8	1.43	6.72		
9	5.45			
10	4.71			
11	2.92	0.86	2.1	0.24
12	5.1			
13	3.1	3.52		
14	3.42			
15	1	3.56	0.91	
16	0.78			
17	0.1			

Online Resource 3: Status of forest dependence of birds and their descriptions.

Forest Dependency Status	**Description**
Dependent	Species of birds found preferentially in forest habitat environments.
Semi-dependent	Species of birds found preferentially on forest edges, but are also found in open environments.
Independent	Species of birds that are found in open areas (*e.g.* swamps, fields).

Online Resource 4: Species of birds observed in private forests during fixed points between September 2016 and September 2017 in Sorocaba-SP. Legend: Acr = Acronyms of the species. GT = trophic guild, carnivorous (Ca); scavenger (Ne); large frugivores (Fg); small frugivores (Fp); granivores of open area (Ga); forest edge granivores (Gb); insectivorous of open areas (Ia); insectivorous of canopy (Ic); insectivores of foliage (If); insectivorous of understory (Is); trunk-twig insectivores (It); aerial insectivores (Iv); nectarivores-insectivores (Ne); omnivores (On) and piscivores (Pi). DF = degree of forest dependence: independent (I), semi-dependent (S) and dependent (D). FO = Occurrence Frequency (%). TC = Total of Individuals.

Order	Family	Scientific	English	Acr	GT	DF	FO	TC
Galliformes	Cracidae	*Penelope obscura*	Dusky-legged Guan	Peob	Fg	D	5.88	1
Piciformes	Picidae	*Picumnus temminckii*	Ochre-collared Piculet	Pite	It	D	17.65	4
		Veniliornis spilogaster	White-spotted Woodpecker	Vesp	It	S	5.88	1
		Colaptes melanochloros	Green-barred Woodpecker	Come	It	S	29.41	5
		Celeus flavescens	Blond-crested Woodpecker	Cefl	It	D	11.76	3
		Dryocopus lineatus	Lineated Woodpecker	Drli	It	S	17.65	3
Cuculiformes	Cuculidae	*Piaya cayana*	Squirrel Cuckoo	Pcay	Om	S	11.76	3
		Crotophaga ani	Smooth-billed Ani	Cran	Ia	S	5.88	1
		Aratinga leucophthalma	White-eyed Parakeet	Arle	Fg	I	23.53	11
		Forpus xanthopterygius	Blue-winged Parrotlet	Foxa	Fg	S	17.65	15
Apodiformes	Trochilidae	*Phaethornis pretrei*	Planalto Hermit	Phpr	Ne	S	23.53	6
		Eupetomena macroura	Swallow-tailed Hummingbird	Euma	Ne	I	29.41	9
		Pseudoscops clamator	Striped Owl	Pscl	Ca	S	5.88	1
		Patagioenas picazuro	Picazuro Pigeon	Papi	Fg	S	76.47	42
		Patagioenas cayennensis	Pale-vented Pigeon	Paca	Fg	S	11.76	2
		Zenaida auriculata	Eared Dove	Zeau	Ga	I	17.65	5

to be continued...

Continuation...

Order	Family	Scientific	English	Acr	GT	DF	FO	TC
		Columbina talpacoti	Ruddy Ground-dove	Cota	Ga	I	23.53	8
		Leptotila verreauxi	White-tipped Dove	Leve	Gb	S	29.41	5
		Leptotila rufaxilla	Grey-fronted Dove	Leru	Gb	D	5.88	1
Gruiformes	Aramidae	*Aramus guarauna*	Limpkin	Argu	Om	I	5.88	1
		Aramides saracura	Slaty-breasted Wood-rail	Arsa	Om	S	11.76	3
		Pardirallus nigricans	Blackish Rail	Pani	Om	S	5.88	1
		Gallinula chloropus	Common Moorhen	Gach	Om	I	11.76	4
Charadriiformes	Charadriidae	*Vanellus chilensis*	Southern Lapwing	Vach	Ia	I	5.88	1
Pelecaniformes	Ardeidae	*Nycticorax nycticorax*	Black-crowned Night-heron	Nyny	Om	I	5.88	1
		Syrigma sibilatrix	Whistling Heron	Sysi	Ia	I	5.88	1
	Cathartidae	*Coragyps atratus*	Black Vulture	Coat	De	I	5.88	1
Passeriformes	Tyrannidae	*Leptopogon amaurocephalus*	Sepia-capped Flycatcher	Leam	Is	D	5.88	1
		Todirostrum cinereum	Common Tody-flycatcher	Toci	If	S	58.82	26
		Camptostoma obsoletum	Southern Beardless-tyrannulet	Caob	If	I	52.94	16
		Elaenia flavogaster	Yellow-bellied Elaenia	Elfl	If	S	23.53	5
		Serpophaga subcristata	White-crested Tyrannulet	Sesu	If	S	35.29	7
		Myiophobus fasciatus	Bran-coloured Flycatcher	Myfa	Is	I	5.88	1
		Myiarchus swainsoni	Swainson's Flycatcher	Mysw	Ic	S	5.88	2
		Myiarchus ferox	Short-crested Flycatcher	Myfe	Ic	S	17.65	3
		Myiarchus tyrannulus	Brown-crested Flycatcher	Myty	Ic	I	5.88	1

to be continued...

Continuation...

Order	Family	Scientific	English	Acr	GT	DF	FO	TC
		Tyrannus melancholicus	Tropical Kingbird	Tyme	Ic	I	29.41	10
		Empidonomus varius	Variegated Flycatcher	Emva	Ic	S	5.88	1
		Megarynchus pitangua	Boat-billed Flycatcher	Mepi	Om	S	23.53	4
		Myiodynastes maculatus	Streaked Flycatcher	Myma	Om	S	29.41	12
		Myiozetetes similis	Social Flycatcher	Mysi	Om	S	23.53	4
		Pitangus sulphuratus	Great Kiskadee	Pisu	Om	I	82.35	39
	Thamnophilidae	*Thamnophilus doliatus*	Barred Antshrike	Thdo	If	D	5.88	1
		Thamnophilus caerulescens	Variable Antshrike	Thca	If	D	17.65	7
	Furnariidae	*Furnarius rufus*	Rufous Hornero	Furu	Ia	I	11.76	2
		Synallaxis frontalis	Sooty-fronted Spinetail	Syfr	If	S	23.53	6
	Vireonidae	*Cyclarhis gujanensis*	Rufous-browed Peppershrike	Cygu	Om	S	29.41	7
		Vireo olivaceus	Red-eyed Vireo	Viol	If	D	5.88	1
		Turdus leucomelas	Pale-breasted Thrush	Tule	Om	S	76.47	65
		Turdus amaurochalinus	Creamy-bellied Thrush	Tuam	Om	S	11.76	6
	Mimidae	*Mimus saturninus*	Chalk-browed Mockingbird	Misa	Om	S	11.76	3
	Troglodytidae	*Troglodytes aedon*	House Wren	Trae	If	I	76.47	39
	Hirundinidae	*Pygochelidon cyanoleuca*	Blue-and-white Swallow	Pycy	Iv	I	52.94	24
	Passeridae	*Passer domesticus*	House Sparrow	Pado	Om	I	5.88	4
	Emberizidae	*Zonotrichia capensis*	Rufous-collared Sparrow	Zoca	Gb	I	5.88	1
		Ammodramus humeralis	Grassland Sparrow	Amhu	Ia	I	5.88	1

to be continued...

Continuation...

Order	Family	Scientific	English	Acr	GT	DF	FO	TC
	Parulidae	*Parula pitiayumi*	Tropical Parula	Parpi	If	S	5.88	1
		Geothlypis aequinoctialis	Masked Yellowthroat	Geae	If	I	5.88	2
		Basileuterus culicivorus	Golden-crowned Warbler	Bacu	If	D	35.29	16
		Basileuterus flaveolus	Flavescent Warbler	Bafl	Is	D	5.88	1
	Coerebidae	*Coereba flaveola*	Bananaquit	Cofl	Ne	S	82.35	51
	Thraupidae	*Thlypopsis sordida*	Orange-headed Tanager	Thso	Om	D	23.53	5
		Nemosia pileata	Hooded Tanager	Nepi	Ic	D	5.88	2
		Tachyphonus coronatus	Ruby-crowned Tanager	Taco	Is	D	11.76	2
		Thraupis sayaca	Sayaca Tanager	Thsa	Om	S	100.00	87
		Thraupis palmarum	Palm Tanager	Thpa	Om	S	47.06	14
		Euphonia chlorotica	Purple-throated Euphonia	Euch	Fp	S	29.41	11
		Tangara cayana	Burnished-buff Tanager	Taca	Om	I	52.94	19
		Dacnis cayana	Blue Dacnis	Daca	Fp	S	5.88	1
	Emberizidae	*Coryphospingus cucullatus*	Red-crested Finch	Cocu	Gb	I	5.88	1
		Volatinia jacarina	Blue-black Grassquit	Voja	Ga	I	11.76	3
	Icteridae	*Icterus pyrrhopterus*	Epaulet Oriole	Icca	Ic	S	17.647	8

Online Resource 5: Indices of abundance of the species recorded in the gated communities.

Species	Gated communities															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Ammodramus humeralis							1.87										
Aramus guarauna						1.87											
Aratinga leucophthalma	4.35									4.35		2.17				1.87	
Aramides saracura		2.17								1.87							
Basileuterus culicivorus					1.87		3.27			3.27			3.27	4.35	2.17		
Basileuterus flaveolus									1.99								
Camptostoma obsoletum	4.35		1.87					2.17	2.2		1.87	2.17	1.87	2.17			1.87
Celeus flavescens													2.17		1.87		
Coragyps atratus							1.87										
Coereba flaveola	6.52	2.17	1.87		1.87	3.27		1.87	4.4	7.69	4.35	4.35	14.13	1.87		3.27	1.87
Colaptes melanochloros	1.87								1.99				1.87	1.87	1.87		
Columbina talpacoti	2.17		1.87				4.35				1.87						
Crotophaga ani			1.87														
Cyclarhis gujanensis					2.17				2.2		1.87	1.87		1.87			
Dacnis cayana	1.87																
Dryocopus lineatus							1.87							1.87	1.87		
Elaenia flavogaster			1.87			1.87			2.2				1.87				
Empidonomus varius										1.87							
Euphonia chlorotica	1.87		1.87					4.35	1.99		1.87	1.87	2.17				
Eupetomena macroura	1.87									2.17			3.27				2.17
Fluvicola nengeta								4.35									
Forpus xanthopterygius								1.87	2.2				13.43				
Furnarius rufus							1.87	1.87									

to be continued...

Continuation...

Species	**Gated communities**																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Gallinula chloropus						2.17		2.17									
Geothlypis aequinoctialis															2.17		
Icterus cayanensis									5.49	1.87					2.17		
Leptopogon amaurocephalus													1.87				
Leptotila rufaxilla															1.87		
Leptotila verreauxi							1.87		1.99		1.87			1.87	1.87		
Megarynchus pitangua								1.87	1.99				1.87				1.87
Mimus saturninus	1.87						2.17										
Myiophobus fasciatus						1.87											
Myiarchus ferox	1.87						1.87					1.87					
Myiodynastes maculatus						3.27					1.87	1.87	1.87		6.52		
Myiozetetes similis					1.87			1.87	1.99				1.87				
Myiarchus swainsoni									2.2								
Myiarchus tyrannulus														1.87			
Nemosia pileata	2.17																
Nycticorax nycticorax						1.87											
Patagioenas cayennensis						1.87	1.87										
Passer domesticus								4.35									
Pardirallus nigricans						1.87											
Patagioenas picazuro	6.52			2.17	2.17	1.87	2.17	3.27	6.59	3.27	6.52	2.17	5.43		3.27		1.87
Parula pitiayumi	1.87																
Piaya cayana													1.87		2.17		
Penelope obscura		1.87															

to be continued...

Continuation...

Species	Gated communities																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Phaethornis pretrei	3.27				1.87								1.87				
Pitangus sulphuratus	5.43	2.17		1.87	1.87	2.17		2.17	3.3	5.43	2.17	3.27	5.43	5.43	1.87	2.17	
Picumnus temminckii	1.87									1.87			2.17				
Pseudoscops clamator							1.87										
Pygochelidon cyanoleuca	2.17						1.87	7.69		7.69	2.17	1.87		1.87	2.17	1.87	
Serpophaga subcristata							1.87	2.17		1.87				1.87	1.87		1.87
Synallaxis frontalis						1.87				2.17		2.17			1.87		
Syrigma sibilatrix												1.87					
Tangara cayana					1.87	1.87	1.87	1.87	3.3	2.17		4.35	3.27	2.17	1.87		
Tachyphonus coronatus			1.87						1.99								
Thamnophilus caerulescens						5.43						1.87	1.87				
Thamnophilus doliatus															1.87		
Thraupis palmarum	2.17				1.87			1.87	6.59				1.87	1.87	1.87	1.87	
Thraupis sayaca	1.87	3.27	3.27	4.35	3.27	3.27	2.17	4.35	13.19	6.52	5.43	7.69	6.52	8.7	6.52	4.35	1.87
Thlypopsis sordida	2.17								1.99	1.87		1.87					
Todirostrum cinereum	4.35	1.87				1.87		5.43	3.3	5.43		1.87	3.27	2.17	1.87		
Troglodytes aedon	6.52		3.27		1.87	2.17	4.35	1.87	2.2	1.87	1.87	6.52	6.52		5.43		1.87
Turdus amaurochalinus									5.49							1.87	
Turdus leucomelas	7.69	1.87			2.17		1.87	3.27	3.3	1.87	4.35	7.69	13.43	6.52	5.43	4.35	
Tyrannus melancholicus	3.27				2.17					3.27			1.87	1.87			
Vanellus chilensis	1.87																
Veniliornis spilogaster													1.87				
Vireo olivaceus														1.87			

to be continued...

Continuation...

Species	**Gated communities**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**		**15**	**16**	**17**
Volatinia jacarina			1.87				1.87					1.87					
Zenaida auriculata	2.17		2.17						1.99								
Zonotrichia capensis														1.87			

Online Resource 6: Richness and spatial variables recorded by fixed point and by gated communities. GC - gated communities; FP - fixed points of the respective gated communities; Richness - Richness of birds; Are.for - forest area of gated communities in hectares; Per.for - percentage of forest cover of gated communities; TA - total area of the gated communities in hectares.

GC	FP	Richness	Are.for	Per.for	TA
1	1	9	5.6	15	37.40
	2	4			
	3	13			
	4	9			
	5	13			
	6	8			
2	7	7	0.99	7.4	13.40
3	8	8	2.97	6.6	45.23
	9	5			
4	10	3	0.25	2.7	9.12
5	11	14	2.37	30.7	7.71
6	12	12	2.31	16	14.39
	13	10			
7	14	12	3.69	10.8	34.19
	15	9			
8	16	13	9.1	7.9	114.47
	17	8			
	18	5			
	19	7			
9	20	12	5.44	8.5	64.11
	21	4			
	22	9			
	23	14			
10	24	11	4.71	43.4	10.85
	25	11			
	26	11			
11	27	8	7.22	17.2	42.06
	28	3			
	29	9			
	30	2			
12	31	8	5.05	13.4	37.72
	32	14			
	33	8			
	34	13			
13	35	6	6.61	26.5	24.98
	36	8			
	37	11			
	38	10			

to be continued...

Continuation...

GC	FP	Richness	Are.for	Per.for	TA
14	39	12	5.03	27.3	18.41
	40	14			
15	41	11	5.49	10.6	51.70
	42	9			
	43	8			
	44	8			
16	45	8	0.77	22.9	3.38
17	46	8	0.17	5.1	3.26