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Bird diversity in an urban ecosystem: the role of local habitats in understanding the effects of urbanization

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ABSTRACT. Urbanization causes environment changes that directly affect biotic diversity, and understanding the relationship between fauna and urban features is a key aspect of urban planning. Birds are particularly affected by urbanization. Noise levels, for instance, negatively affect birds' behavior and social communication, while the presence of green areas promotes bird diversity. The effects of urbanization could differ according with the level of urbanization, and our goal was to understand how bird species assemblages are related to urban features in an intermediate stage of urbanization (a city in Brazil with 2,470 inhabitants/km²). We used canonical correspondence analysis (CCA) and generalized linear models (GLM) analyses to assess how bird species assemblages are affected by urban features (*e.g.*, noise level, abundance of buildings) as well as habitat features (*e.g.*, vegetation cover). Despite we did not find a clear pattern of urbanization both the urban and habitat features had, even if weak, an effect on bird species distribution. Bird species distribution was spatially correlated, and we identified three groups: 1) grassland and wetland species; 2) forest species; 3) species tolerant to habitat degradation. Species richness was positively related to the proportion of trees, abundance of people and presence of buildings, and negatively affected by higher levels of noise. The abundance of species decreased as noise levels increased, but the proportion of green areas (open or forest vegetation) had a positive effect. Agreeing with previous research, our study shows that noise levels and vegetation cover seem to be the best predictors of diversity in urban areas. Nevertheless, the presence of particular habitats (wetlands, grasslands, woodlots), patchily distributed in the urban matrix, could buffer the effects of urbanization on birds. These habitats should thus be taken into account in urban planning.

KEYWORDS. Neotropic, urban noise, green spaces, species richness, bird assemblage.

RESUMO. Diversidade de aves em um ecossistema urbano: o papel dos habitat locais na compreensão dos efeitos da urbanização. A urbanização resulta em alterações no ambiente que afetam diretamente a diversidade biótica, sendo fundamental a compreensão das relações entre a fauna e as características do ambiente urbano para o planejamento de uma cidade. O ruído, por exemplo, é uma característica do ambiente urbano que afeta negativamente o comportamento e comunicação social das aves, enquanto a presença de áreas verdes promove a diversidade. Os efeitos da urbanização sobre a fauna podem variar conforme o estágio de desenvolvimento urbano, assim, nosso objetivo foi analisar a distribuição da avifauna em uma área com estágio intermediário de urbanização (uma cidade brasileira com 2.470 habitantes/km²) e sua relação com a paisagem urbana. Nós realizamos uma análise de Correspondência Canônica (CCA) e Modelos Lineares Generalizados (GLM) para avaliar como a avifauna é afetada pelos componentes da paisagem urbana (*e.g.*, nível de ruído, número de construções, cobertura vegetal). Apesar de não termos encontrado um padrão claro de urbanização, tanto as características urbanas quanto as de habitat tiveram, mesmo que de forma branda, um efeito sobre a distribuição de espécies de aves. A distribuição das espécies foi espacialmente correlacionada, formando três grandes grupos: 1) espécies associadas aos ambientes campestres e úmidos; 2) espécies florestais; 3) espécies tolerantes aos ambientes degradados. A riqueza de espécies foi positivamente relacionada à proporção de árvores, à abundância de pessoas e à presença de prédios, porém teve efeito negativo com o aumento do nível de ruído. Áreas com maior nível de ruído apresentaram menor abundância de aves, enquanto as maiores abundâncias estiveram positivamente associadas à proporção de áreas verdes (vegetação campestre ou florestal). Nossos resultados concordam com estudos prévios que sugerem que o nível de ruído e a cobertura vegetal são as variáveis mais relevantes relacionadas à diversidade de aves em áreas urbanas. Contudo, a presença de habitat específicos (banhados, campos, matas), imersos na matriz urbana, poderiam amortizar os efeitos da urbanização sobre as aves, e estes deveriam ser considerados quando avaliado o planejamento urbano das cidades.

PALAVRAS-CHAVE. Neotrópico, ruído urbano, áreas verdes, riqueza de espécies, assembleia de aves.

Urban ecosystems are complex, heterogenic and dynamic, characterized mainly by dense agglomerations of people living in the same place. The urbanization process involves changes in the landscape, soil modifications, climate changes, and biodiversity loss, resulting in a new, distinct ecosystem (Pickett *et al.*, 2011). City growth changes the landscape – destroying natural habitats and creating new ones – and native species are replaced by a pool of a few species adapted to the urban environment (urban exploiters), promoting biotic homogenization (Blair, 1996, 2004; Rolando *et al.*, 1997; Clergeau *et al.*, 1998; Tait *et al.*, 2005; Chace & Walsh, 2006; McKinney, 2006; Evans *et al.*, 2009; Pickett *et al.*, 2011; Aronson *et al.*, 2014; Puga-Caballero *et al.*, 2014; Beninde *et al.*, 2015; Dallimer *et al.*, 2015). However, cities are not homogeneous environments, but rather have zoning according to the type of activity in or usage given to certain areas (parks, industrial zone, residential zone). Thus, in urban areas, bird species distribution is both related to the local habitat features (tree and shrub cover, density of houses and other buildings) and the degree of urbanization of the city (Rolando *et al.*, 1997; Evans *et al.*, 2009; Pickett *et al.*, 2011; Fontana *et al.*, 2011; Ortega-Álvarez & MacGregor-Fors, 2011; Aronson *et al.*, 2014).

The availability of green areas and the level of noise are two of the most important features affecting urban avian species assemblages (Chace & Walsh, 2006; Evans *et al.*, 2009; Fontana *et al.*, 2011; Toledo *et al.*, 2012; Njoroge *et al.*, 2013, Beninde *et al.*, 2015; Sacco *et al.*, 2015). High bird diversity in urban landscapes has been associated with high densities of trees and the presence of large green spaces connected or near to each other (*i.e.*, not fragmented, but connected by corridors or acting as stepping stones) (Evans *et al.*, 2009; Aronson *et al.*, 2014, Beninde *et al.*, 2015). High densities of human dwellings – and people – and high levels of noise are associated with lower levels of bird diversity (Evans *et al.*, 2009; Fontana *et al.*, 2011), but higher bird abundances (Evans *et al.*, 2009). This pattern of continuous decline of diversity and increase in abundance is exhibited along the rural-urban gradient (Blair, 1996; Chace & Walsh, 2006; McKinney, 2006; Puga-Caballero *et al.*, 2014; Bino *et al.*, 2008; Ortega-Álvarez & MacGregor-Fors, 2011), although diversity could peak at intermediate levels of disturbance, as in peri-urban areas (Blair, 1996, 2004; Tratalos *et al.*, 2007).

Birds' responses to living in urban centers and the effects of disturbance in these areas have been studied for decades in the northern hemisphere (*e.g.*, Marzluff *et al.*, 2001; Chace & Walsh, 2006; Evans *et al.*, 2009; Pickett *et al.*, 2011; Davis *et al.*, 2012; Taylor *et al.*, 2013; Aronson *et al.*, 2014; Sol *et al.*, 2014; Beninde *et al.*, 2015), but are a relatively new research focus in South America (*e.g.*, Fontana *et al.*, 2011; Ortega-Álvarez & MacGregor-Fors, 2011; Toledo *et al.*, 2012; Njoroge *et al.*, 2013; Puga-Caballero *et al.*, 2014; Leveau *et al.*, 2015; Sacco *et al.*, 2015). Although urban species assemblages in South and North America show similar patterns, still there are several gaps to be filled (*e.g.*, demographic patterns, physiological responses, behavioral ecology, biotic homogenization; Ortega-Álvarez & MacGregor-Fors, 2011). Our goal was to evaluate how urbanization affects the bird species assemblage (species richness and abundance) of a medium-sized city in southern Brazil. We use features of the urban landscape to test the predictions that (1) the degree of urbanization affects bird species distribution, and intensely urbanized areas have lower species richness and higher species abundance than less urbanized areas; (2) both species richness and abundance diminished in proportion to noise level; (3) vegetation is an important component of the urban landscape for birds, and bird diversity will increase in proportion to the area of green space in the city (parks, gardens, orchards).

METHODS

Study area. Canoas (29°55'12"S, 51°10'48"W) is part of the metropolitan area of Porto Alegre (the capital and largest city of the state of Rio Grande do Sul, Brazil) known as Greater Porto Alegre. Built in the Depressão Central region (Central valley) on the Guaiba river basin, Canoas is bordered by the dos Sinos and Gravataí rivers, and is in the transition zone between Planície Costeira (Coastal Plain) and the Planalto Meridional (Meridional Plateau) (www.canoas.rs.gov.br). Climate is temperate (*Cfa*; Köppen, 1918), with a hot and humid summer. In the Bioma Pampa, which spreads over 63% of Rio Grande do Sul political territory, the municipality territory is classified as region of ecological tension, where grass, shrub and wetlands are predominant in surrounding areas of the urban zone. Currently Canoas has no rural areas and the population of 323,827 inhabitants is settled in an area of 131.1 km² (demography of 2,470.13 inhabitants/km²; IBGE, 2010). The city grew in a disordered way, scattered in patches of neighborhoods and villages that were settled in marshy and flooded areas. Industry had large impact on the city demography, as well as the local economy (Mayer, 2009). Despite the level of urbanization, Canoas has 16.2 m² of green areas per capita, making a total of 5.49 km² in the city (Estado da Cidade, 2014).

Sampling design. We randomly selected, 120 sites based on 60 maps of the municipality of Canoas (www.geo.canoas.rs.gov.br). Each map covers a 1.1 km² area, divided in 20 quadrants of 0.4 km². We randomly selected two quadrants on each map and established one sample unit in the center of each quadrant. Sample units were required to be a public area (*i.e.*, street, sidewalk, square) and were moved to the public location nearest the chosen center if necessary. Sample units were at least 200 m apart to guarantee independence between sampling units (Ralph *et al.*, 1993). We used this sampling design to facilitate a more homogeneous evaluation of the study area and to avoid a concentration of points in few regions of the municipality. We could not access two sites located on private properties, and so removed them because we did not find any accessible location nearby. Thus, we sampled a total of 118 sites (Fig. 1).

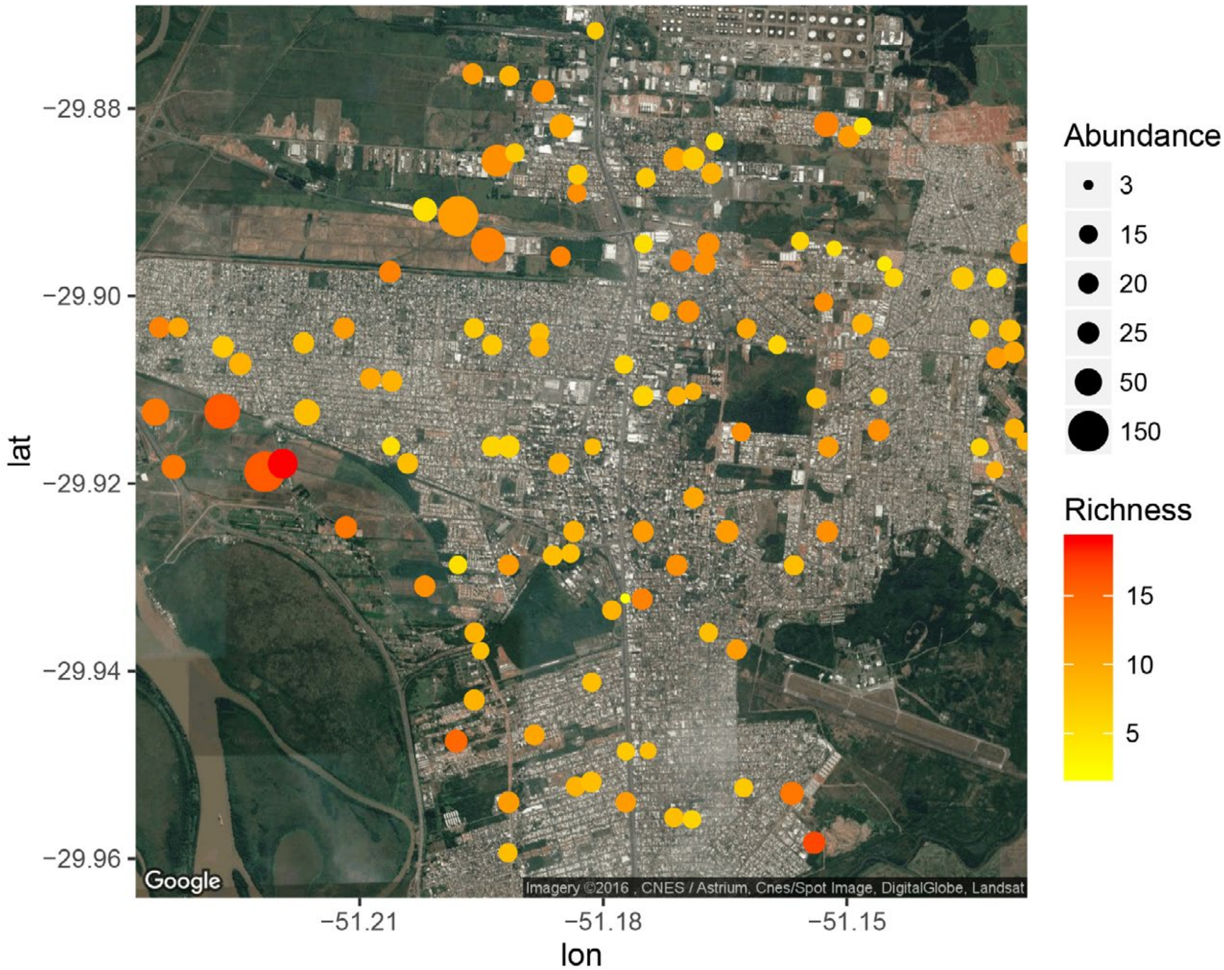

Fig. 1. Bird species richness and overall abundance recorded in point counts (surveyed on September 2013) in the municipality of Canoas, Rio Grande do Sul, Brazil.

Tab. I. Explanatory variables (Ca, categorical; Co, continuous) measured on each sample unit in the urban area of Canoas, Rio Grande do Sul, Brazil.

Variables	Class	Description
Houses	Co	Number of houses
Buildings	Ca, binary	Number of buildings with more than two floors
Pavilions	Ca, binary	Number of large horizontal buildings typically for industrial purposes
Other structures	Ca, binary	Number of buildings with low flow of people (supermarkets, sports facilities, parking lots)
People	Co	Number of persons passing by or standing at the point-count area
Pets	Co	Number of pets observed on the point-count area
Vegetation cover	Co	Percent of the sample unit covered by trees (aerial image)
Trees	Co	Number of trees higher than 3 m
Grass	Co	Percent of the sample unit covered by open areas (grassland, gardens)
Noise	Co	The mean of the three measures of sound frequency (measured at 0 min, 5 min and 10 min during bird counts)

In each sample unit (50 m radius from a central point), we measured the following variables related to the degree of urbanization (descriptions of each variable are in Tab. I): 1) Noise; 2) density of 'Trees'; 3) density of 'People'; 4) density of 'Pets'. We measured the percentage of 'Vegetation cover' and 'Grass' (open areas: grassland, gardens; Tab. I) – using satellite images provided by Google Pro (for Canoas, the images with the best available resolution were dated from January/2009 to December/2013). We also measured the abundance of buildings in each sample (number of 'Houses', 'Buildings', 'Pavilions', and 'Other structures'; all but houses later transformed into categorical variables; Tab. I).

We carried out bird surveys in September 2013, at the beginning of the breeding season. We conducted 10-min point-count surveys using a 50m fixed radius (RALPH *et al.*, 1993), starting at dawn and lasting for 4 h (until 10:00 AM). We recorded all birds seen or heard, except birds flying above 20 m over the area, which we ignored in order to avoid double-counting during the census (annotated as an occasional record to compose the list of birds of Canoas).

Data analysis. We first constructed three matrices: 1) species abundance (number of individuals per point-count); 2) variables indicating the urban gradient (eight non-collinear variables); and 3) a spatial matrix with the geographical coordinates of each point-count (latitude and longitude). To avoid multi-collinearity, we selected only variables with Spearman correlation index below |0.6|: we excluded 'Traffic' and 'Pets' from the analyses and instead used the correlated variables 'Houses' (rho = 0.63) and 'Noise' (rho = 0.75). After the first investigation of data we eliminated two samples. These samples were outliers because they were located in an open, not urbanized area, where the major source of disturbance was traffic noise from the highway BR-386.

We tested the spatial correlation between species distribution and urban variables using a Mantel test (LEGENDRE & LEGENDRE, 1998), performed with R (R DEVELOPMENT CORE TEAM, 2015) using *vegan* package (OKSANEN *et al.*, 2015). The Spearman rho was used as the correlation coefficient. We used 9999 iterations with permutations of the matrix elements to calculate the P value for the test statistic, assuming no correlation between matrices as null hypothesis. The species distribution was spatially correlated (P = 0.01), so we performed a partial Mantel test to evaluate the correlation between species abundance and urban variables, weighting the spatial correlation.

To analyze the relationships between bird species assemblage and the urban variables, we performed a canonical correspondence analysis (CCA) (LEGENDRE & LEGENDRE, 1998) using on CANOCO v4.5 (TER BRAAK & ŠMILAUER, 2002). Variables were centralized and standardized and the rare species were down-weighted to minimize their individual effects. To test the correlation between species abundance and urban variables, we used a Monte Carlo test with 9999 unrestricted permutations, assuming no correlation as the null hypothesis (TER BRAAK & ŠMILAUER, 2002).

Finally, we used generalized linear models (GLM) to evaluate how urbanization affected bird species richness and abundance. To model species richness, we used the residuals of the linear regression of these variables as the response variable and also used Gaussian error and identity function. Because species richness is correlated with abundance (because more birds are detected as richness increased), we used the residuals as surrogate of species richness. To model the abundance (logarithmically transformed) we used the number of individuals in each point-count as the response variable, and used Gaussian error and identity function. We started by including eight variables as predictors in each model, and searched for the best subset using a backward stepwise procedure. We used second-order Akaike's Information Criterion (AICc) to select competing models, assuming that models with $\Delta AICc \leq 2$ explain the data equally well. We performed the GLMs with R (R DEVELOPMENT CORE TEAM, 2015), using the *MuMIn* package (BARTON, 2014) to build and select models.

RESULTS

We recorded 2,897 individuals from 100 bird species (13 only recorded occasionally, outside the point-count area) and 38 families (Appendix 1). Most of these species inhabit open habitats (grassland, shrublands and open areas; 46%), and are omnivorous (36%) (Appendix 1). Sites outside the urban core had more species richness and abundance (Fig. 1). These are dominated by grass and wetlands, where large flocks of Shiny cowbird [*Molothrus bonariensis* (Gmelin, 1789); 85 individuals] and Bare-faced ibis [*Phimosus infuscatus* (Lichtenstein, 1823); 90 individuals], for instance, were recorded.

Bird species distribution were spatially correlated (Mantel test, $p < 0.01$), while urban variables were not (Mantel test, $p = 0.98$). Species assemblages, in turn, were not correlated with urban variables (partial Mantel test, $p = 0.25$). The canonical axes of CCA, despite significance ($p < 0.01$) and the average correlation between species and environmental variables (Pearson correlation, axis I = 0.75, axis II = 0.66), explained only 13% of variability in the data (axis I = 7.1%, axis II= 1.9%). Notwithstanding, CCA separated more-urbanized areas from those that were less urbanized, the latter having a larger proportion of open vegetation cover (grass and wetlands) (left to right on axis I) and wooded areas, with greater vegetation cover (distinguished from other variables on axis II) (Fig. 2). Synanthropic and/or exotic species [*e.g.* House sparrow *Passer domesticus* (Linnaeus, 1758), Rock dove (*Columba livia* Gmelin, 1789), Blue-and-white swallow *Pygochelidon cyanoleuca* (Vieillot, 1817)] were recorded more frequently in more urbanized sites, characterized by higher densities of people and houses; the presence of buildings, pavilions and other structures; and higher levels of noise. Sites with greater proportions of open vegetation, lower levels of noise, and an absence or lower frequency of urban structures (house, buildings) were dominated by wetland species [*e.g.*, White-browed meadowlark *Sturnella superciliaris* (Bonaparte, 1850), White-faced ibis *Plegadis chihi* (Vieillot, 1817) and Chestnut-capped blackbird *Chrysomus ruficapillus* (Vieillot, 1819)], and grass/shrubland species [*e.g.*, White monjita *Xolmis irupero* (Vieillot, 1823), Shiny cowbird]. Forested species, such as Variable antshrike (*Thamnophilus caerulescens* Vieillot, 1816) and Golden-crowned warble [*Basileuterus culicivorus* (Deppe, 1830)] were present and more abundant in sites with a greater abundance of vegetation cover (percentage cover and number of trees).

We selected four competing models for analysis of species richness (Tab. II). The most important variables, retained in all models, were abundance of houses, noise and percentage of vegetation cover. Abundance of people, presence of buildings and other structures were the other variables selected in our GLMs (each only in one model). Species richness was positively related to the proportion of arboreal vegetation ('Trees'), abundance of people and presence of buildings (Tab. II), while areas with higher noise

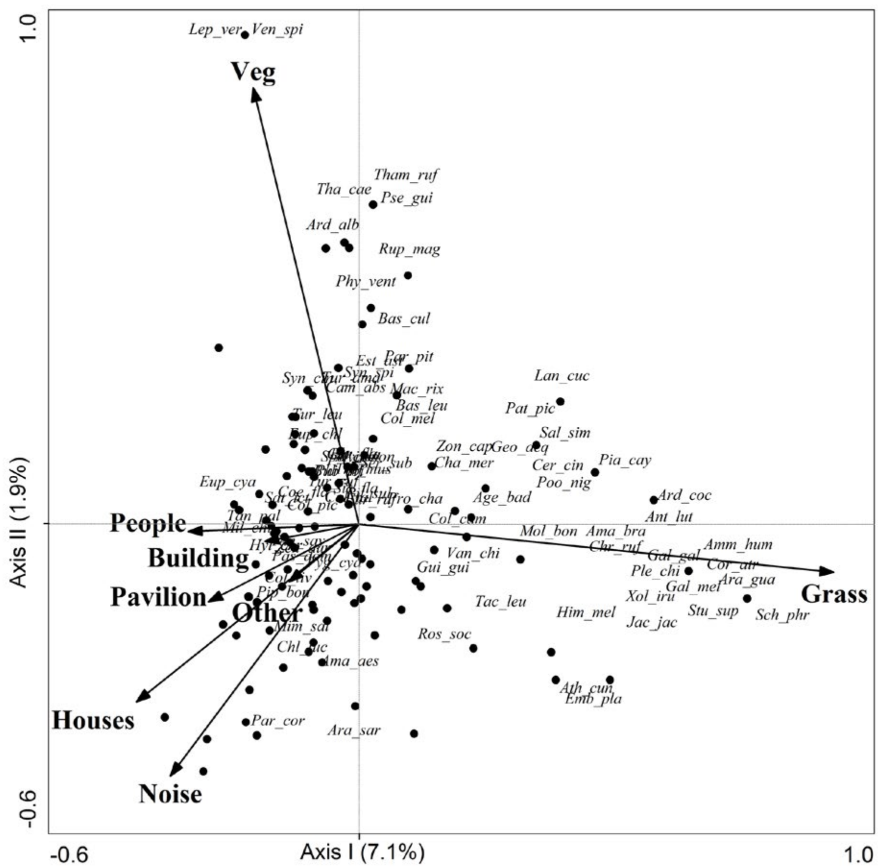

Fig. 2. Ordination diagram presenting the first two axes of the Canonical Correspondence Analysis (CCA) (percent of explained variability: axis I = 7.1%, axis II = 1.9%) based on the distribution of species abundance in 118 sample units (dots) in the urban area of Canoas, Rio Grande do Sul, Brazil, and its correlation with seven explanatory variables (arrows). The first axis shows the urbanization gradient (negatives values on left = more urbanized regions; positive values on right = less urbanized regions). All axes were significant (Monte Carlo test with 9,999 permutations: P < 0.001). Species names are given in full in Appendix 1. Variables are described in Tab. I.

Tab. II. Competing models (ΔAICc < 2) for the influence of environmental variables in bird species richness (considering the residual of the linear regression of bird species richness and abundance). Variables with negative coefficients are indicated by a minus sign within the brackets. Variables retained in the best candidate model are in bold (df, degrees of freedom; AICc, corrected Akaike's Information Criterion; ΔAICc, difference in AICc between the current model and the best model; w, Akaike weights).

Modelo	df	AICc	ΔAICc	Weight
(-Houses)+(-Noise)+Vegetation	5	531.21	0.00	0.46
(-Houses)+(-Noise)+Vegetation+People	6	532.84	1.63	0.20
(-Houses)+(-Noise)+Vegetation+(-Other)	6	533.17	1.96	0.17
(-Houses)+(-Noise)+Vegetation+Buildings	6	533.19	1.97	0.17

Tab. III. Competing models (ΔAICc < 2) for the influence of environmental variables in bird species abundances. Variables with negative coefficients are indicated by a minus sign within the brackets. Variables retained in the best candidate model are in bold (df, degrees of freedom; AICc, corrected Akaike's Information Criterion; ΔAICc, difference on AICc between the current model and the best model; w, Akaike weights).

Modelo	df	AICc	ΔAICc	Weight
Grass+(-Noise)	4	155.83	0.00	0.29
Grass	3	156.95	1.12	0.17
Grass+(-Noise)+(-Houses)	5	157.22	1.39	0.15
Grass+(-Noise)+Pavilions	5	157.35	1.52	0.14
Grass+(-Noise)+(-Buildings)	5	157.43	1.60	0.13
Grass+(-Noise)+Vegetation	5	157.62	1.79	0.12

levels, abundance of houses and presence of other structures have low species richness. We selected six models for analysis of species abundance (Tab. III). Species abundance decreased as noise levels increased (noise level was selected in all models), and also decreased with the abundance of houses and presence of buildings. The proportion of vegetation cover (both open and arboreal) in a site had a positive effect on bird abundance (as we can see in Fig. 1), as did the presence of pavilions.

DISCUSSION

Our results suggest that the city of Canoas has a rural-urban gradient similar to those of other urban centers (Blair, 1996; Chace & Walsh, 2006; McKinney, 2006; Bino *et al*., 2008; Ortega-Álvarez & MacGregor-Fors, 2011; Puga-Caballero *et al*., 2014). The urbanized areas are in the core of the city, surrounded by areas of grass, shrub and wetlands (Fig. 1). Hence, the bird species assemblage varies along the gradient from grass and wetland species (*e.g.*, Shiny cowbird, Chestnut-capped blackbird, White-faced ibis) to urban-adapted species, such the Gilded hummingbird [*Hylocharis chrysura* (Shaw, 1812)], Bananaquit [*Coereba flaveola* (Linnaeus, 1758)] and Sayaca tanager [*Tangara sayaca* (Linnaeus, 1766)], which are common in parks and gardens (Sick, 1997; Fontana *et al*., 2011). Introduced species like the House sparrow, Rock dove and Common waxbill [*Estrilda astrild* (Linnaeus, 1758)], also dominate the urban landscapes (Blair, 2004; Bino *et al*., 2008; Fontana *et al*., 2011; Ortega-Álvarez & MacGregor-Fors, 2011; Aronson *et al*., 2014).

Although some effects of urbanization on the bird species assemblage were not so clear, the regression models nonetheless showed well known effects of urbanization. The proportion of arboreal vegetation cover was the most important variable predicting an increase in species richness in Canoas, corroborating the known role of green areas as biodiversity enhancers in urban centers (Chace & Walsh, 2006; Evans *et al*., 2009; Fontana *et al*., 2011; Ortega-Álvarez & MacGregor-Fors, 2011; Toledo *et al*., 2012; Njoroge *et al*., 2013; Aronson *et al*., 2014; Beninde *et al*., 2015; Sacco *et al*., 2015). Open landscapes prevail in the Canoas region, and the arboreal component is characterized by gardens, squares and parks in the urban area; this contrasts with cities with large forested areas on the borders, for instance around Porto Alegre (Fontana *et al*., 2011). As observed in other studies, plots of open vegetation (squares, gardens, golf courses) usually have higher biodiversity (Evans *et al*., 2009; Aronson *et al*., 2014; Beninde *et al*., 2015). Therefore, these areas are home to particular bird species assemblages that are distinct from rural and peri-urban avifauna.

On the other hand, the negative effects of urbanization upon bird diversity are clearly showed in the relationships between species richness and the level of noise and the density of houses. Noise is a striking feature of urban centers, usually related to low species richness and abundance (Fontana *et al*., 2011; Pickett *et al*., 2011; Sacco *et al*., 2015). Together with other human activities, noise may constrain species' ability settle in urban centers, which leads to loss of diversity and differentiation in bird species assemblages (Francis *et al*., 2009; Fontana *et al.*, 2011; Rolando *et al.,* 1997; Slabbekoorn & Peet, 2003; Bisson *et al.*, 2011; Pickett *et al*., 2011; Chávez-Zichinelli *et al*., 2013).

In addition to noise, the density of houses and presence of buildings affected both species richness and abundance in our study. Although both variables are related to urbanization, they are not good indicators of urbanization, as their effects are dependent on the scale analyzed and the particular process of urbanization for each city (Evans *et al*., 2009). In Canoas, the density of houses appears to indicate densely urbanized areas, and adds to other urban features (noise, buildings) in negatively affecting the avifauna. Although negatively related to bird abundance, presence of buildings was positively related to species richness, probably due to the occurrence of aerial foragers (*e.g.*, Hirundinidae) and species that nest or live in rocky habitats (*e.g.*, Apodidade) (Blair, 1996, 2004; Aronson *et al*., 2014).

Bird abundance tends to increase with urbanization, which is an artifact of the higher density of a few urban exploiters, often exotic species (Croci *et al*., 2008; Chace & Walsh, 2006; Bino *et al*., 2008; Ortega-Álvarez & MacGregor-Fors, 2011; Aronson *et al*., 2014; Francis, 2015). Omnivores and synanthropic species [*e.g.*, Rock dove, Rufous-bellied thrush (*Turdus rufiventris* Vieillot, 1818), Great kiskadee *Pitangus sulphuratus* (Linnaeus, 1766)] were very abundant in Canoas. These species are generalists in diet and habitat use, and have great ecological plasticity: they are more efficient at exploiting resources in urban areas that are new to native species (Blair, 1996).

We found a high abundance of urban exploiters, like House sparrows, Rock doves and Eared doves [*Zenaida auriculata* (Des Murs, 1847)], in more urbanized areas, in agreement with the pattern found in other studies (Blair, 2004; Chace &Walsh, 2006; Bino *et al*., 2008; Fontana *et al*., 2011; Ortega-Álvarez & MacGregor-Fors, 2011; Aronson *et al*., 2014; Puga-Cabalero *et al*., 2014). However, his pattern of abundant urban exploiters does not reflect a positive overall effect of urbanization on bird abundance. In fact, pavilions were the only urban feature positively related to abundance, probably because they offer local resources for a few common species. On the other hand, peri-urban areas of the city, which were used for agriculture in past decades, showed high abundance of a few species (*e.g.*, Bare- and White-faced ibises, Shiny cowbird). This concentration of birds in peri-urban areas (Fig. 1) masks the expected pattern seen along a rural-urban gradient: increase in abundance from rural areas to urban centers (Blair, 1996; Chace & Walsh, 2006; McKinney, 2006; Bino *et al*., 2008; Ortega-Álvarez & MacGregor-Fors, 2011; Puga-Caballero *et al*., 2014).

The city of Canoas does not have a clear pattern of urbanization, reflecting the disorganized growth of the city (Mayer, 2009). Despite the existence of a core area, with buildings and commercial areas, there are still plots of habitats patchily distributed inside the city, buffering bird species distribution from urban effects. The presence of wetlands, grasslands (vacant lots, lawns and squares) and woodlots (urban parks, gardens) offers habitats to species less adapted to the urban environment (urban avoiders), reducing the biotic homogenization and maintaining part of the pre-urbanization pool of species. We agree with Fontana *et al*. (2011), that the level of noise seems to be the best variable indicating the degree of urbanization. Along with vegetation cover or related parameters (density of trees, presence of green areas) (Chace & Walsh, 2006; Evans *et al.*, 2009; Aronson *et al*., 2014; Beninde *et al*., 2015), the level of noise would be the best variable to use in order to recognize levels of urbanization.

Finally, given the increasing concern with sustainable urban development, seeking environment-friendly urban growth that preserves cities' biodiversity (Pickett *et al*., 2011; Aronson *et al*., 2014; Beninde *et al*., 2015), urban planners need to take into account how the city works ecologically (Pickett *et al*., 2011), for example, how the biota responds to an urban environment. This is essential for conservation and management purposes. The effects of the level of noise and presence of green areas on urban-dwelling birds, for instance, are well known (*e.g.*, Chace & Walsh, 2006; Evans *et al*., 2009; Aronson *et al*., 2014; Beninde *et al*., 2015), and should be considered in urban planning policies. Supporting citizens in maintaining residential vegetation (*e.g.*, private yards), and, hence, keeping areas of native vegetation inside the urban area, is a simple example of how to increase a city's green areas and promote biological conservation (Smith *et al*., 2014).

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Appendix 1. Species abundance (SA, number of individuals) and frequency of occurrence (Fr, number of points with where target species was recorded divided by the total of point-counts) recorded in 118 point-counts in the urban area of Canoas, Rio Grande do Sul, Brazil. Taxonomy and common names are listed according to the Brazilian Ornithological Records Committee (Piacentini *et al.*, 2015). Diets and foraging habitats are given according to Sick (1997). Species marked with a 'X' in SA column were those recoded only occasionally (*i.e.*, outside the point-count limits). Diet: Omn, omnivore; Car, carnivore; Pis, piscivore; Ins, insectivore; Sca, scavenger; Gra, granivore; Fru, frugivore; Nec, nectarivore; Snail, snail. Habitat: Wet, wetland; Grass, grassland; For, forest; Wood, woodlots; Palm, palm forest; Shrub, shrublands; Marsh, marshes; Mang, mangroves; Water, river, lakes and/or coastal areas; Rice, rice fields; Urb, urban; Gen, generalists; Open, open areas.

Taxon	Common name	SA	Fr	Diet	Habitat	Species code
Anseriformes						
Anatidae						
Callonetta leucophrys (Vieillot, 1816)	Ringed Teal	X		Omn	Wet	Cal_leu
Amazonetta brasiliensis (Gmelin, 1789)	Brazilian Teal	5	0.025	Omn	Wet	Ama_bra
Ciconiiformes						
Ciconiidae						
Ciconia maguari (Gmelin, 1789)	Maguari Stork	X		Car	Wet	Cic_mag
Suliformes						
Phalacrocoracidae						
Nannopterum brasilianus (Gmelin, 1789)	Neotropic Cormorant	X		Pis	Water	Nan_bra
Pelecaniformes						
Ardeidae						
Nycticorax nycticorax (Linnaeus, 1758)	Black-crowned Night-Heron	X	X	Car	Water	Nyc_nyc
Bubulcus ibis (Linnaeus, 1758)	Cattle Egret	25	0.008	Ins	Grass	Bub_ibi
Ardea cocoi Linnaeus, 1766	Cocoi Heron	2	0.008	Car	Water	Ard_coc
Ardea alba Linnaeus, 1758	Great Egret	3	0.017	Car	Water; Marsh	Ard_alb
Syrigma sibilatrix (Temminck, 1824)	Whistling Heron	X	X	Car	Grass; Rice	Syr_sib
Threskiornithidae						
Plegadis chihi (Vieillot, 1817)	White-faced Ibis	98	0.051	Ins	Wet; Rice	Ple_chi
Phimosus infuscatus (Lichtenstein, 1823)	Bare-faced Ibis	120	0.025	Omn	Wet	Phi_inf
Platalea ajaja Linnaeus, 1758	Roseate Spoonbill	X		Ins	Wet; Mang	Pla_aja
Cathartiformes						
Cathartidae						
Coragyps atratus (Bechstein, 1793)	Black Vulture	3	0.008	Sca	Gen; Urb	Cor_atr
Accipitriformes						
Accipitridae						
Circus buffoni (Gmelin, 1788)	Long-winged Harrier	X		Car	Wet; Grass	Cir_buf
Rostrhamus sociabilis (Vieillot, 1817)	Snail Kite	4	0.025	snail	Wet	Ros_soc
Heterospizias meridionalis (Latham, 1790)	Savanna Hawk	2	0.008	Car	Grass	Het_mer
Rupornis magnirostris (Gmelin, 1788)	Roadside Hawk	1	0.008	Car	Grass; For	Rup_mag
Gruiformes						
Aramidae						
Aramus guarauna (Linnaeus, 1766)	Limpkin	1	0.008	Snail	Wet	Ara_gua
Rallidae						
Aramides saracura (Spix, 1825)	Slaty-breasted Wood-Rail	1	0.008	Omn	For; Wet	Ara_sar
Gallinula galeata (Lichtenstein, 1818)	Common Gallinule	2	0.008	Omn	Water	Gal_gal
Porphyriops melanops (Vieillot, 1819)	Spot-flanked Gallinule	1	0.008	Omn	Water	Por_mel
Charadriiformes						
Charadriidae						
Vanellus chilensis (Molina, 1782)	Southern Lapwing	83	0.263	Ins	Wet, Grass	Van_chi
Recurvirostridae						
Himantopus melanurus Vieillot, 1817	White-backed Stilt	6	0.017	Ins	Wet, Water	Him_mel
Scolopacidae						
Gallinago paraguaiae (Vieillot, 1816)	South American Snipe	X		Omn	Wet	Gal_par
Jacanidae						
Jacana jacana (Linnaeus, 1766)	Wattled Jacana	17	0.051	Omn	Wet	Jac_jac
Columbiformes						
Columbidae						
Columbina talpacoti (Temminck, 1810)	Ruddy Ground-Dove	76	0.347	Gra	Open; Wet	Col_tap
Columbina picui (Temminck, 1813)	Picui Ground-Dove	65	0.314	Gra	Grass	Col_pic
Columba livia Gmelin, 1789	Rock Pigeon	118	0.280	Gra	Urb	Col_liv
Patagioenas picazuro (Temminck, 1813)	Picazuro Pigeon	4	0.025	Gra, Fru	For; Wood	Pat_pic
Zenaida auriculata (Des Murs, 1847)	Eared Dove	118	0.390	Gra	Grass	Zen_aur

Appendix 1. Cont.

Taxon	Common name	SA	Fr	Diet	Habitat	Species code
Leptotila verreauxi Bonaparte, 1855	White-tipped Dove	1	0.008	Fru, Gra	Grass; Shrub; For	Lep_ver
Cuculiformes						
Cuculidae						
Piaya cayana (Linnaeus, 1766)	Squirrel Cuckoo	1	0.008	Car	For	Pia_cay
Crotophaga ani Linnaeus, 1758	Smooth-billed Ani	X		Car	Open	Cro_ani
Guira guira (Gmelin, 1788)	Guira Cuckoo	8	0.025	Car	Grass	Gui_gui
Strigiformes						
Strigidae						
Athene cunicularia (Molina, 1782)	Burrowing Owl	1	0.008	Car	Grass	Ath_cun
Apodiformes						
Apodidae						
Chaetura meridionalis Hellmayr, 1907	Sick's Swift	4	0.025	Ins	Grass; Urb	Cha_mer
Trochilidae						
Chlorostilbon lucidus (Shaw, 1812)	Glittering-bellied Emerald	2	0.017	Nec	Shrub; Urb	Chl_luc
Hylocharis chrysura (Shaw, 1812)	Gilded Hummingbird	17	0.127	Nec	For; Shrub	Hyl_chr
Piciformes						
Picidae						
Melanerpes candidus (Otto, 1796)	White Woodpecker	X		Omn	Grass	Mel_can
Veniliornis spilogaster (Wagler, 1827)	White-spotted Woodpecker	1	0.008	Ins	For	Vem_spi
Colaptes melanochloros (Gmelin, 1788)	Green-barred Woodpecker	3	0.025	Ins	For; Shrub; Open	Col_mel
Colaptes campestris (Vieillot, 1818)	Campo Flicker	22	0.110	Ins	Grass	Col_cam
Falconiformes						
Falconidae						
Caracara plancus (Miller, 1777)	Southern Caracara	1	0.008	Omn	Grass; Open	Car_pla
Milvago chimachima (Vieillot, 1816)	Yellow-headed Caracara	1	0.008	Omn	Open	Mil_chm
Milvago chimango (Vieillot, 1816)	Chimango Caracara	2	0.017	Car	Grass; Open	Mil_chg
Falco sparverius Linnaeus, 1758	American Kestrel	X		Car	Grass	Fal_spa
Psittaciformes						
Psittacidae						
Myiopsitta monachus (Boddaert, 1783)	Monk Parakeet	33	0.136	Fru	Grass, Wood	Myi_mon
Amazona aestiva (Linnaeus, 1758)	Turquoise-fronted Parrot	2	0.008	Fru	For, Palm	Ama_aes
Passeriformes						
Thamnophilidae						
Thamnophilus ruficapillus Vieillot, 1816	Rufous-capped Antshrike	2	0.008	Ins	Grass; For	Tha_ruf
Thamnophilus caerulescens Vieillot, 1816	Variable Antshrike	2	0.008	Ins	For; Shrub	Tha_cae
Furnariidae						
Furnarius rufus (Gmelin, 1788)	Rufous Hornero	154	0.712	Ins	Open	Fur_ruf
Schoeniophylax phryganophilus (Vieillot, 1817)	Chotoy Spinetail	2	0.008	Ins	Grass; Shrub	Sch_phr
Certhiaxis cinnamomeus (Gmelin, 1788)	Yellow-chinned Spinetail	9	0.051	Ins	Open	Cer_cin
Synallaxis cinerascens Temminck, 1823	Gray-bellied Spinetail	1	0.008	Ins	For	Syn_cin
Synallaxis spixi Sclater, 1856	Spix's Spinetail	4	0.034	Ins	For	Syn_spi
Rhynchocyclidae						
Phylloscartes ventralis (Temminck, 1824)	Mottle-cheeked Tyrannulet	4	0.034	Ins	For	Phy_ven
Tyrannidae						
Camptostoma obsoletum (Temminck, 1824)	Southern Beardless-Tyrannulet	10	0.059	Omn	For; Shrub	Cam_obs
Elaenia flavogaster (Thunberg, 1822)	Yellow-bellied Elaenia	27	0.152	Omn	Grass; Shrub	Ela_fla
Serpophaga subcristata (Vieillot, 1817)	White-crested Tyrannulet	5	0.034	Ins	Grass; Shrub	Ser_sub
Pitangus sulphuratus (Linnaeus, 1766)	Great Kiskadee	165	0.771	Omn	Gen; Urb	Pit_sul
Machetornis rixosa (Vieillot, 1819)	Cattle Tyrant	5	0.025	Ins	Grass	Mac_rix
Satrapa icterophrys (Vieillot, 1818)	Yellow-browed Tyrant	5	0.042	Ins	For; Shrub	Sat_ict
Xolmis irupero (Vieillot, 1823)	White Monjita	5	0.042	Ins	Grass; Shrubs	Xol_iru
Vireonidae						
Cyclarhis gujanensis (Gmelin, 1789)	Rufous-browed Peppershrike	X		Omn	For; Shrub	Cyc_guj
Hirundinidae						
Pygochelidon cyanoleuca (Vieillot, 1817)	Blue-and-white Swallow	78	0.339	Ins	Gen; Urb	Pyg_cya
Progne chalybea (Gmelin, 1789)	Gray-breasted Martin	38	0.161	Ins	Gen; Urb	Pro_cha
Tachycineta leucorrhoa (Vieillot, 1817)	White-rumped Swallow	8	0.034	Ins	Gen; Urb	Tac_leu

Appendix 1. Cont.

Taxon	Common name	SA	Fr	Diet	Habitat	Species code
Troglodytidae						
Troglodytes musculus Naumann, 1823	Southern House Wren	82	0.534	Omn	Gen; Urb	Tro_mus
Turdidae						
Turdus leucomelas Vieillot, 1818	Pale-breasted Thrush	4	0.034	Omn	Gen; Urb	Tur_leu
Turdus rufiventris Vieillot, 1818	Rufous-bellied Thrush	119	0.636	Omn	Gen; Urb	Tur_ruf
Turdus amaurochalinus Cabanis, 1850	Creamy-bellied Thrush	5	0.042	Omn	Gen; Urb	Tur_ama
Mimidae						
Mimus saturninus (Lichtenstein, 1823)	Chalk-browed Mockingbird	16	0.076	Omn	Open; Shrub	Mim_sat
Motacillidae						
Anthus lutescens Pucheran, 1855	Yellowish Pipit	4	0.017	Omn	Grass; Wet	Ant_lut
Passerelidae						
Zonotrichia capensis (Statius Muller, 1776)	Rufous-collared Sparrow	13	0.093	Omn	Grass; Open	Zon_cap
Ammodramus humeralis (Bosc, 1792)	Grassland Sparrow	2	0.017	Gra	Grass	Amm_hum
Parulidae						
Setophaga pitiayumi (Vieillot, 1817)	Tropical Parula	1	0.008	Ins	For	Set_pit
Geothlypis aequinoctialis (Gmelin, 1789)	Masked Yellowthroat	8	0.059	Ins	Wet; Shrub	Geo_aeq
Basileuterus culicivorus (Deppe, 1830)	Golden-crowned Warbler	7	0.042	Ins	For	Bas_cul
Myiothlypis leucoblephara (Vieillot, 1817)	White-browed Warbler	2	0.017	Ins	For	Bas_leu
Icteridae						
Amblyramphus holosericeus (Scopoli, 1786)	Scarlet-headed Blackbird	X		Omn	Wet	Amb_hol
Chrysomus ruficapillus (Vieillot, 1819)	Chestnut-capped Blackbird	19	0.034	Omn	Wet	Chr_ruf
Pseudoleistes guirahuro (Vieillot, 1819)	Yellow-rumped Marshbird	2	0.008	Omn	Wet	Pse_gui
Agelaioides badius (Vieillot, 1819)	Grayish Baywing	17	0.042	Omn	Open	Age_bad
Molothrus bonariensis (Gmelin, 1789)	Shiny Cowbird	315	0.254	Omn	Grass; Open	Mol_bon
Sturnella superciliaris (Bonaparte, 1850)	White-browed Meadowlark	2	0.008	Omn	Grass	Stu_sup
Thraupidae						
Pipraeidea bonariensis (Gmelin, 1789)	Blue-and-yellow Tanager	6	0.042	Fru	For	Pip_bon
Paroaria coronata (Miller, 1776)	Red-crested Cardinal	3	0.008	Omn	Grass; Shrub	Par_cor
Tangara sayaca (Linnaeus, 1766)	Sayaca Tanager	112	0.492	Fru	Gen; Urb	Tan_sy
Tangara palmarum (Wied, 1821)	Palm Tanager	13	0.059	Omn	For; Palm	Tan_pal
Sicalis flaveola (Linnaeus, 1766)	Saffron Finch	61	0.161	Gra	Grass	Sic_fla
Coryphospingus cucullatus (Statius Muller, 1776)	Red-crested Finch	4	0.025	Omn	For	Lan_cuc
Coereba flaveola (Linnaeus, 1758)	Bananaquit	99	0.627	Nec	For	Coe_fla
Sporophila caerulescens (Vieillot, 1823)	Double-collared Seedeater	3	0.025	Gra	Grass	Spo_car
Embernagra platensis (Gmelin, 1789)	Great Pampa-Finch	2	0.008	Omn	Grass; Wet	Bem_pla
Saltator similis d'Orbigny & Lafresnaye, 1837	Green-winged Saltator	1	0.008	Omn	For	Sat_sim
Poospiza nigrorufa (d'Orbigny & Lafresnaye, 1837)	Black-and-rufous Warbling-Finch	2	0.017	Omn	For	Poo_nig
Fringillidae						
Euphonia chlorotica (Linnaeus, 1766)	Purple-throated Euphonia	7	0.059	Fru	For	Eup_chl
Euphonia cyanocephala (Vieillot, 1818)	Golden-rumped Euphonia	2	0.008	Fru	For	Eup_cya
Estrildidae						
Estrilda astrild (Linnaeus, 1758)	Common Waxbill	18	0.025	Gra	Gen; Urb	Est_est
Passeridae						
Passer domesticus (Linnaeus, 1758)	House Sparrow	568	0.881	Omn	Gen; Urb	Pas_dom