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VEGETATION, URBANIZATION, AND BIRD RICHNESS IN A BRAZILIAN PERI-URBAN AREA

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ABSTRACT · Birds have received special attention in urban areas. Due to their conspicuousness and quick response to habitat changes, they perfectly fit the requirements as a bioindicator group. In this study, we assessed the relationships between urbanization intensity and vegetation characteristics and bird richness in greenspaces of the Federal University of São Carlos, São Paulo, Brazil. We found a significant positive relationship between exotic tree abundance and maximum tree height, and bird species richness; but no interaction effect between exotic tree abundance and maximum tree height. The results of this study suggest that the size and resources provided by trees are affecting bird richness in our study site. Although many of the resources (e.g., flowers, fruits, nesting sites) are provided by exotic plants in our study site, native ones were clearly underrepresented. Given the negative effects that exotic plant species can have on ecosystems, it is crucial to consider planting alternative native species that can offer resources similar to those currently available through exotic ones.

RESUMO · Vegetação, urbanização e riqueza de aves em uma área peri-urbana Brasileira
As aves tem recebido uma atenção especial em áreas urbanas por serem facilmente detectáveis e responderem facilmente às mudanças de habitat, enquadrando-se perfeitamente como grupo bioindicador nesses ambientes. Neste estudo foram avaliadas as relações entre a intensidade da urbanização e as características da vegetação das áreas verdes e a avifauna da Universidade Federal de São Carlos, São Paulo, Brasil. Foi encontrado uma relação positiva entre a riqueza de espécies de aves e a abundância de árvores exóticas e altura máxima das árvores, mas nenhuma interação entre a abundância de árvores exóticas e altura máxima das árvores foi registrada. Os resultados deste estudo apontam que a quantidade de recursos oferecido pelas árvores e o tamanho delas afetam diretamente a riqueza de aves na área estudada. Muitos dos recursos (ej. flores, frutos, locais de nidificação) são fornecidos por plantas exóticas, pois as nativas estão sub-representadas na área. Levando-se em conta os efeitos negativos que as espécies exóticas podem exercer sobre os ecossistemas, é fundamental considerar espécies nativas alternativas que possam oferecer recursos semelhantes aos atualmente disponíveis através das espécies exóticas.

KEY WORDS: Avian richness · Biodiversity · Exotic species · Trees · University campus · Urban ecology

INTRODUCTION

The human population has grown considerably in the last decades, with current projections estimating it will reach 9.7 billion by 2050 (UN 2015a). Such population growth has been related to the urban migration process recorded worldwide (Montgomery 2008). Currently, more than half of the total human population lives in urban systems, with its proportion still rising (Grimm et al. 2008). Human population, as well as the growth and establishment of urban areas are predicted to increase in developing countries, with Latin America not being an exception (UN 2015b). This is of major concern, as urban systems are linked to some of the most important components of global change (e.g., land-use change, biological invasions, biogeochemical cycle changes, climate change; Grimm et al. 2008), and thus represent an important threat for biodiversity (Czech & Krausman 2001, McKinney 2008).

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As part of such environmental concern, ecologists have focused on urban systems to quantify the response of wildlife species to this anthropogenic disturbance (Chace & Walsh 2006, Evans et al. 2009, van Heezik et al. 2010, Ortega-Álvarez & MacGregor-Fors 2011, Harrison & Winfree 2015). Birds have received particular attention because they form complex communities within urban areas, are conspicuous, and quickly respond to habitat changes, fitting as a bioindicator group (Savard et al. 2000, Savard & Falls 1981, Moreno et al. 2007). Although some general urban bird ecology patterns have been established in the past with research primarily from upland temperate areas (Marzluff et al. 2001, Chace & Walsh 2006), important ecological differences have been found for tropical and subtropical areas (Ortega-Álvarez & MacGregor-Fors 2011), which have been clearly understudied (McDonnell 2015).

Most ornithological studies performed within urban areas have shown negative effects of urbanization on avian communities (Beissinger & Osborne 1982, Blair 1996, Cleargeau et al. 1998, McKinney 2002, Chace & Walsh 2006, Croci et al. 2008). In general, previous studies have identified several factors that shape urban bird communities: (1) vegetation presence and characteristics (Gavareski 1976, Munyenyembe et al. 1989, Blair 1996, Chace & Walsh 2006, Evans et al. 2009, MacGregor-Fors & Schondube 2011), (2) species competition (Kalisnoski 1975, Kath et al. 2009, MacGregor-Fors et al. 2010), (3) changes in predator communities (Woods et al. 2003, López-Flores et al. 2009), and (4) human activities (Blair 1996, Shochat et al. 2006, MacGregor-Fors & Schondube 2011). An important amount of urban ecology studies have focused on urban greenspaces, probably due to the biodiversity they shelter (Malagamba-Rubio et al. 2013). As important components of urban systems throughout Latin America, university campuses have been widely used as study sites for urban bird ecology research (Pablo-López & Díaz-Porras 2011). In this context, university campuses comprise important component of the greenspace network of many urban areas (Stiles 1990, Marín Gómez 2005).

As both urbanization intensity (given by the proportion of built "hard relatively impervious surfaces;" Eldgredge & Herenstein 2014) and vegetation characteristics are factors that have been shown to influence avian diversity in urban areas, we here assessed their potential relationships with bird species richness in greenspaces of the Federal University of São Carlos (referred to as UFSCar hereafter), São Paulo, Brazil. Based on previous knowledge, we predicted urbanization intensity to be negatively related to bird species richness. Although we expected native plants to be related to higher bird richness values, we expected some exotic species with high amounts of resources for birds to be positively related with bird species richness (Chace & Walsh 2006, MacGregor-Fors 2008, Evans et al. 2009, MacGregor-Fors et al. 2009, Maruyama et al. 2016).

METHODS

Study area. The university campus of the UFSCar (632.42 ha) is located in the northern peri-urban area of São Carlos (21°59'0.55"S, 47°52'49.37"W, ca. 850 m a.s.l.; Figure 1), in southeastern Brazil. The region is tropical with humid summers and dry winters, with an average annual temperature of 19.6°C (Melão et al. 2011). Within the campus, ca. 22% of the area is urbanized and includes several greenspaces, most of which were planted and are managed. Prior to urbanization, the typical vegetation was *cerrado*, particularly forest savanna and riparian forests.

Urbanization intensity and vegetation characteristics. To characterize our survey areas, we used maps of the Physical Development Office of UFSCar that include the polygon of the university campus as well as its impervious infrastructure and vegetation. We then established a 1 ha grid on the resulting polygon, generating a total of 280 quadrants. We measured vegetation characteristics and built cover, including buildings and asphalt for each quadrant. We visited all individual trees in the campus, collecting samples for identification and measuring their height. We identified trees to the species level whenever possible using literature (Lorenzi 2003, 2008, 2009a, 2009b). We categorized tree species as regionally native (occurrence in the state of São Paulo), as well as native (occurrence in other states of Brazil) and exotic (occurrence outside of Brazil) based on Lorenzi (2003, 2008, 2009a, 2009b).

We selected 14 quadrants in the study area that represent a gradient of urbanization intensity, ranging from low to high intensity values. In the selection of quadrants, we did not include those including water streams, unmanaged vegetation, or that were located near the campus boundaries that represented independent survey sites for bird surveys. In the 14 quadrants, we measured 16 variables: (1) built cover (%), (2) herbaceous plant cover (%), (3) tree cover (%), (4) tree abundance (individuals), (5) average tree height (m), (6) maximum tree height (m), (7) average tree diameter at breast height (DBH; cm), (8) maximum tree DBH (cm), (9) regionally native trees species (number of species), (10) regionally native tree abundance (individuals), (11) native tree species (number of species), (12) native tree abundance (individuals), (13) exotic tree richness (number of species), (14) exotic tree abundance (individuals), (15) number of fruit tree individuals with fruits (individuals), and (16) number of fruit tree species with fruits (individuals). We considered both tree richness and abundance as we intended to test the relative relationship of tree variability (given by richness) and resource availability on bird species richness.

Bird surveys. We surveyed birds in the 14 selected quadrants using a modified version of the area search (Ralph et al. 1996), in which we surveyed birds for a longer period to maximize species detection (330 min

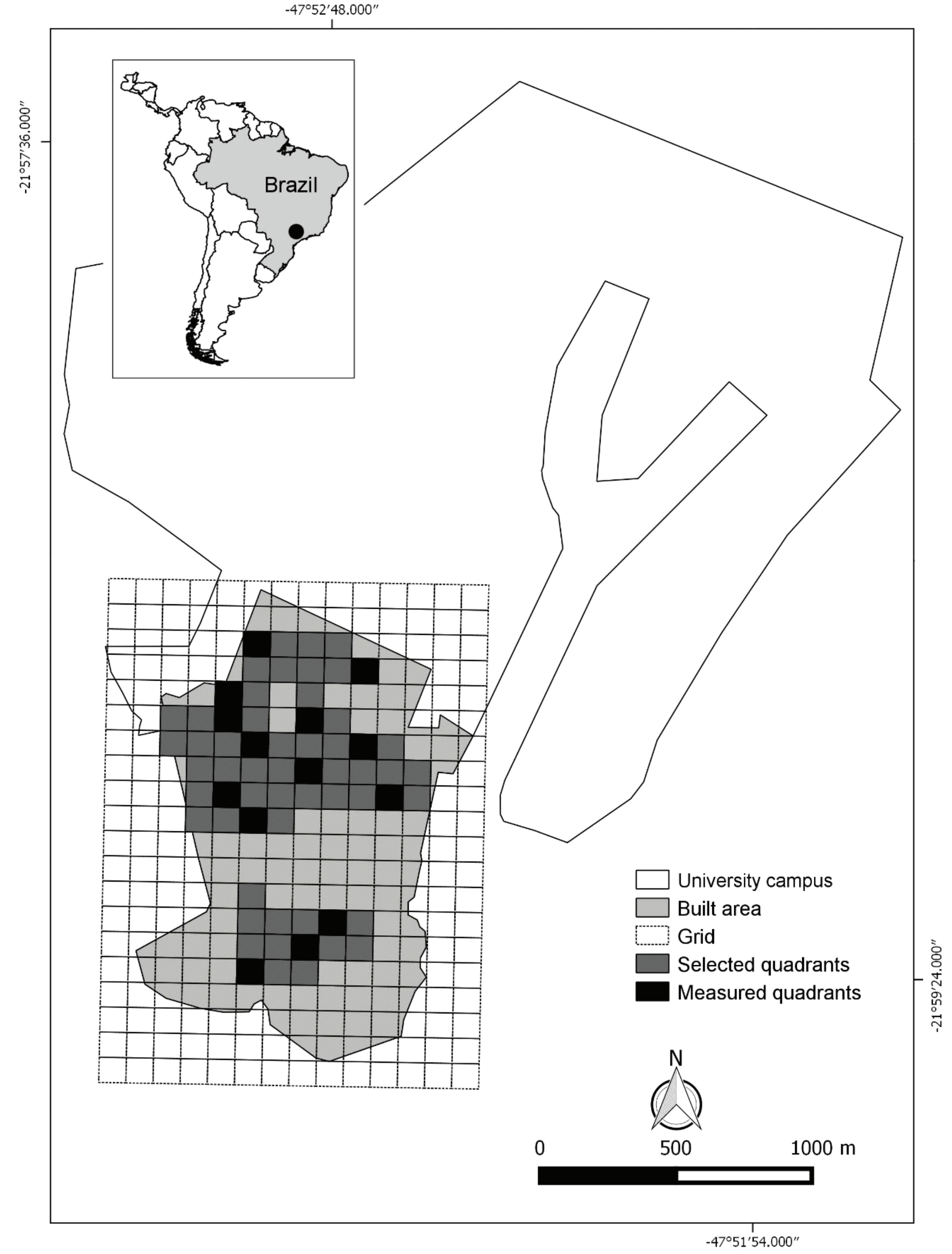

Figure 1. Map of study area depicting the distribution of the surveyed plots within the university campus of the Federal University of São Carlos, São Paulo, Brazil.

divided in two surveys: 180 min during the morning and 150 min during in the afternoon). We performed bird surveys in February and March of 2014, during the breeding season, searching birds throughout the quadrants, recording all birds seen or heard actively using the surveyed habitat. We also recorded birds that were clearly foraging in the air above the vegetation in the studied quadrant (e.g., swallows). We identified bird species using field guides (Sick 2001, Grantsau 2010) and took pictures and recorded songs of those species that were not identified in the field for further identification. We visited each quadrant twice to survey birds at regular intervals in different days without rain or strong wind, once after dawn (07:00–10:00 h) and once before dusk (16:00–18:30 h), when bird activity peaks (Bibby et al. 2000).

Data analysis. We performed correlations between the measured urbanization intensity and vegetation characteristics with bird species richness. We considered all independent variables that showed signifi-

Table 1. Bird species list and frequency of occurrence per quadrant in the Federal University of São Carlos, São Paulo, Brazil. Species nomenclature follow that of Remsen et al. (2016).

Species	Frequency	Species	Frequency
Coragyps atratus	4/14	*Tyrannus albogularis*	2/14
Elanus leucurus	2/14	*Tyrannus melancholicus*	10/14
Geranospiza caerulescens	2/14	*Tyrannus savana*	1/14
Vanellus chilensis	7/14	*Empidonomus varius*	3/14
Columba livia	11/14	*Fluvicola nengeta*	7/14
Columbina talpacoti	6/14	*Xolmis velatus*	2/14
Patagioenas picazuro	14/14	*Cyanocorax cristatellus*	6/14
Zenaida auriculata	14/14	*Cyanocorax chrysops*	3/14
Crotophaga ani	1/14	*Pygochelidon cyanoleuca*	12/14
Guira guira	2/14	*Progne tapera*	1/14
Athene cunicularia	1/14	*Riparia riparia*	1/14
Phaethornis pretrei	1/14	*Troglodytes aedon*	6/14
Eupetomena macroura	9/14	*Turdus leucomelas*	10/14
Anthracothorax nigricollis	1/14	*Turdus amaurochalinus*	6/14
Chlorostilbon lucidus	6/14	*Mimus saturninus*	11/14
Amazilia lactea	3/14	*Zonotrichia capensis*	12/14
Ramphastos toco	2/14	*Ammodramus humeralis*	1/14
Picumnus albosquamatus	4/14	*Setophaga pitiayumi*	2/14
Colaptes campestris	5/14	*Icterus pyrrhopterus*	2/14
Dryocopus lineatus	2/14	*Molothrus bonariensis*	10/14
Caracara plancus	6/14	*Coereba flaveola*	9/14
Milvago chimachima	5/14	*Nemosia pileata*	4/14
Falco sparverius	1/14	*Ramphocelus carbo*	1/14
Falco femoralis	2/14	*Coryphospingus cucullatus*	1/14
Psittacara leucophthalmus	8/14	*Thraupis sayaca*	12/14
Forpus xanthopterygius	5/14	*Thraupis palmarum*	2/14
Brotogeris chiriri	7/14	*Tangara cayana*	7/14
Thamnophilus doliatus	1/14	*Tersina viridis*	5/14
Lepidocolaptes angustirostris	9/14	*Dacnis cayana*	4/14
Furnarius rufus	12/14	*Sicalis flaveola*	7/14
Camptostoma obsoletum	2/14	*Sicalis luteola*	2/14
Elaenia flavogaster	4/14	*Volatinia jacarina*	3/14
Serpophaga subcristata	8/14	*Sporophila lineola*	3/14
Myiarchus ferox	3/14	*Sporophila ardesiaca*	1/14
Pitangus sulphuratus	11/14	*Sporophila caerulescens*	13/14
Machetornis rixosa	6/14	*Piranga flava*	1/14
Myiodynastes maculatus	1/14	*Euphonia chlorotica*	5/14
Megarynchus pitangua	3/14	*Euphonia violacea*	1/14
Myiozetetes similis	5/14	*Passer domesticus*	10/14

cant moderate-to-strong correlations with bird species richness ($r > 0.5$, $P < 0.05$; Peck et al. 2008), and selected those with highest variation (SD) when redundant (i.e., tree cover–tree abundance; exotic tree richness–exotic tree abundance; maximum tree height–average tree height–maximum tree DBH–average tree DBH; fruit tree richness–fruit tree abundance). We then ran a linear model with the independent variables identified as related with bird richness (dependent variable). As suggested by Crawley (2007, 2012), we selected the two independent variables that were significantly related to bird species richness in the initial model and performed two reduced models: one additively relating both significantly related independent variables from the initial model with the recorded bird species richness and another one mul-

Table 2. Pearson correlation coefficients (and associated p-values) between urbanization intensity and vegetation characteristics, and bird species richness in the university campus of the Federal University of São Carlos, São Paulo, Brazil. SD refers to the standard deviations of habitat variables.

Variable	r	*P*	SD
Built cover	0.36	0.19	1492.82
Herbaceous plant cover	-0.43	0.11	1512.83
Tree cover	0.53	0.04	1531.16
Tree abundance	0.62	0.01	34.3
Native Brazilian tree abundance	0.25	0.37	17.07
Regionally native tree abundance	0.36	0.2	15.33
Exotic tree abundance	0.75	0.001	21.25
Native Brazilian tree richness	0.47	0.08	3.92
Regionally native tree richness	0.42	0.12	3.72
Exotic tree richness	0.7	0.004	6.44
Average tree height	0.6	0.02	2.73
Maximum tree height	0.74	0.002	6.3
Average tree DBH	0.59	0.02	0.35
Maximum tree DBH	0.68	0.007	1.24
Fruit tree abundance	0.66	0.009	9.85
Fruit tree richness	0.6	0.02	3.44

tiplicatively relating both the significantly related independent variables from the initial model with the recorded bird species richness, seeking for potential interactions between the independent variables. We performed all statistical procedures in R (R Core Team 2015).

RESULTS

We recorded a total of 78 bird species of 27 families and 11 orders. Average bird richness per quadrant was 28.21 ± 10.40 (± SD) species (range: 12–42). We recorded two species that were present in all quadrants (Picazuro Pigeon, *Patagioenas picazuro* and Eared Dove, *Zenaida auriculata*), while 14 species (17.72%) occurred in just one quadrant (Table 1). Correlation results identified ten variables significantly correlated with bird richness (Table 2). After eliminating redundant variables, we used a set of four variables (i.e., tree cover, exotic tree abundance, maximum tree height, fruit tree abundance) for the initial linear model. This model showed a strong and significant positive relationship between bird species richness and: (1) exotic tree abundance and (2) maximum tree height (R^2 = 0.76, F = 11.37, *P* = 0.001; Table 3). A subsequent reduced additive model, only considering exotic tree abundance and maximum tree height showed similar results (R^2 = 0.74, F = 20.46, *P* < 0.001), while the reduced interaction model showed no significant interaction between these two variables ($F_{1,13}$ = 0.17, *P* = 0.68; Table 3).

Table 3. Linear additive and interaction models relating tree cover, exotic tree abundance, maximum tree height, and fruit tree abundance with bird species richness in the university campus of the Federal University of São Carlos, São Paulo, Brazil. (a): Initial additive model, (b): Reduced additive model, (c): Reduced interaction model.

(a) R^2 = 0.76, F = 11.37, *P* = 0.001, Residual SE: 5.07 on 9 df		
Variable	F	*P*
Tree cover	2.38	0.15
Exotic tree abundance	13.49	0.005
Maximum tree height	9.96	0.01
Fruit tree abundance	0.55	0.47
(b) R^2 = 0.74, F = 20.46, *P* < 0.001, Residual SE: 5.12 on 11 df		
Variable	F	*P*
Exotic tree abundance	12.22	0.004
Maximum tree height	11.11	0.006
(c) R^2 = 0.73, F = 12.67, P < 0.001, Residual SE: 5.40 on 10 df		
Variable	F	*P*
Exotic tree abundance	11.3	0.01
Maximum tree height	10.27	0.01
Exotic tree abundance × Maximum tree height	0.17	0.68

DISCUSSION

Due to their complexity and vegetation characteristics, university campuses have been considered as potential refuges for biodiversity in urban matrices (Carbó-Ramirez et al. 2011, Pablo-López & Díaz-Porras 2011, Motta-Junior & Vasconcellos 1996, Motta-Junior et al. 1996, Lopes & Anjos 2006). In this study, we recorded a total of 78 bird species that comprise ca. 36% of the total recorded species in the campus (214 species; Motta-Junior & Vasconcellos 1996). We are aware that our sampling size and methods underestimate true bird richness in the study area; yet, our study focuses on the ecological relationship between urbanization intensity and several vegetation characteristics with bird richness (measured as an 'ecological snapshot'), rather than an inventory. With this in mind, our results show that maximum tree height and exotic tree abundance in the studied plots were positively and independently correlated with bird species richness. As noted previously in the literature, tree height has been identified as an important driver of bird species richness in less-urbanized areas, such as university campuses and suburbs. For instance, Munyenyembe et al. (1989) and MacGregor-Fors (2008) discuss that bird diversity can increase in sites with taller trees, often represented by aged trees in established neighborhoods or suburban university campuses that provide an important amount of intrinsic and associated resources for birds (e.g., flowers, fruits, nesting sites).

The positive significant relationship we found between exotic tree abundance and bird species richness is in agreement with several previously published studies (MacGregor-Fors 2008, Aslan & Rejmanek 2010, Gleditsch & Carlo 2011, Gray & van Heezik 2015, Maruyama et al. 2016). It is noticeable that urban areas often have more exotic than native plants species (McKinney 2006, Falfán & MacGregor-Fors 2016). Some of the reasons explaining the abundance of exotic trees and shrubs in urban areas include their rapid-growth, aesthetics (generally involving flowers or fruits), and the resources they provide (e.g., shade, fruits) (Dwyer et al. 1992). As stated before, we were not able to assess the role of tree variability (species richness) and resource availability (abundance) at the same time due to multicolinearity issues (r = 0.88, $P < 0.001$). However, two of the initial correlations show a slightly higher coefficient of correlation between exotic tree abundance and bird species richness (r = 0.75, $P = 0.001$), when compared to that of exotic tree richness and bird species richness (r = 0.70, $P = 0.004$). The latter suggests that although the variability in exotic trees could be driving bird species richness, the abundance of these trees (which could be related to the abundance of the resources they provide for birds) is also important, explaining slightly more variance (Green et al. 1989, Sogge et al. 2008, MacGregor-Fors 2008, Gray & van Heezik 2015). Although our final reduced models do not consider fruiting tree rich.ness or abundance, the latter was also correlated to bird species richness (Table 2), partially supporting the notion that these resources are important bird-attractors (MacGregor-Fors 2008, Gray & van Heezik 2015).

In summary, our study suggests that the size and abundance of trees are affecting bird richness in a Brazilian university campus. It is noteworthy that although many of the vegetation-related resources for birds are provided by exotic plants in our study area, native trees are clearly underrepresented. Due to the detrimental effects that exotic plant species can have (Vitousek et al. 1997), with focal concerns in urban areas (Grimm et al. 2008), we disagree that increasing exotic tree abundance is a sustainable way to tackle bird conservation in urban areas. Hence, we conclude that it is imperative to consider native species that can offer the resources that exotics are currently providing for native wildlife in the study site. If we are to include biological conservation approaches in urban areas (Cornelis & Hermy 2004, Alvey 2006, Sanderson & Huron 2011), urban planners and managers, as well as landscape architects and other urban stakeholders, are in the urgent need of detailed lists of native plants that could fulfill both ecological and social needs.

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