Urban Ecosyst (2011) 14:341–360
DOI 10.1007/s11252-011-0156-9

Bird diversity in a subtropical South-American City: effects of noise levels, arborisation and human population density

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Published online: 12 February 2011

Abstract Cities are highly modified environments in which the only areas that resemble natural landscapes are urban parks with low human population density. Attempts are frequently made to maintain high bird diversity in cities for aesthetic or educational reasons. However, it remains unclear whether local site characteristics are important in determining bird assemblage composition or whether simplification of the assemblage is an inevitable consequence of the changes associated with human population density. From May 1998 to December 1999, we undertook bird counts at 521 points in Porto Alegre, Rio Grande do Sul, southern Brazil. Our main goal was to understand the pattern of distribution of the bird species richness and density within the city and determine which variables most affect species assemblages. We recorded 132 species belonging to 43 families that are common in Rio Grande do Sul and obtained quantitative data on 121 species in survey sites. The two most abundant species (House Sparrow, *Passer domesticus* and Rock dove, *Columba livia*) were exotics. Analysis based on a reduced subset of 134 points surveyed in spring/early summer suggested that there was a North–south gradient in assemblage structure. Variation in assemblage structure was also affected by the number of trees, urban noise and human population density. However, human population density had a much smaller effect on richness and assemblage structure than variables subject to management, such as tree density and noise levels. These

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results suggest that complex communities may be maintained in densely populated urban areas of sub-tropical South-America given adequate urban planning.

Keywords Bird assemblage · Brazil · Urban · Diversity · Porto Alegre

Introduction

The global human population is predicted to grow from about 6.5 billion to 9 billion in 2050 (United 2006) with about 80% of people concentrated in cities and towns, mainly in developing countries (UNFPA 2007). This prediction indicates that cities will determine many of the patterns of global ecology (Lyle 1996).

Urbanization is fast, and urban sprawl results from immediate human necessities, usually without consideration of current or future environmental issues. In general, cities are considered places where vegetation cover is lower, or absent, forest areas are fragmented, biotic diversity is lower, between-site variation is reduced, and densities of introduced species are generally high in comparison with non-urban areas (Marzluff et al. 2001a; Chace and Walsh 2006). Urban areas usually have regional biotas that are similar in space and time (biological homogenization - (Chace and Walsh 2006; Olden and Rooney 2006)). Cities are also affected by many factors associated with human activities, such as noise and direct interference, such as activities near nests (Marzluff et al. 2001b). Latin America cities in particular are characterized by unplanned growth, overexploitation of natural resources and rapid change (MacGregor-Fors 2008).

Birds have frequently been used in ecological research, and are excellent indicators of urban-ecosystem stresses and changes (Savard et al. 2000; Sekercioglu 2006). Conserving native birds in cities also helps to preserve regional biodiversity, can promote well being in some inhabitants, and can promote conservation of biological resources in general (Platt and Lill 2006). Despite their potential use as indicators of urban quality, few studies on the ecology of urban avifauna have been undertaken in Brazil (Fontana 2004), or even in the Southern Hemisphere, in comparison with the Northern Hemisphere (Marzluff et al. 2001b; Chace and Walsh 2006).

In Brazil, most conservation-related studies on birds focused on the impact of forest fragmentation or the value of refuges (Willis 1979; Aleixo 1999a; Martensen et al. 2008), but studies of birds in areas of high human density are relatively recent (see Franchin 2009 for review). Bird studies of Brazilian or other Latin America cities have concentrated on surveys of urban parks and university *campi* (Feninger 1983; Matarazzo-Neuberger 1992; Mendonça-Lima and Fontana 2000; Valadão et al. 2006), comparisons between urban and rural areas (Ruszczyk et al. 1987; Reynaud and Thioulouse 2000; Leveau and Leveau 2004; Leveau and Leveau 2005), or surveys of only a small part of a city (Voss 1979a,b; Torga et al. 2007). The focus on species richness has shown that some parts of the cities are very poor bird habitat, and that other parts can sustain quite large numbers of species. However, this generalization could be made about almost any biome, including mega diverse habitats, such as tropical forests and coral reefs. To contribute to the understanding of cities to biodiversity conservation in sub-tropical areas, we evaluated the distribution of bird assemblages throughout the city of Porto Alegre, which is the largest and most urbanized city in Rio Grande do Sul State, Brazil. Because a single local feature, such as a city park, will not be able to sustain viable populations if it is not connected to other suitable areas, we studied the whole city as a mosaic of habitats resulting from constructions of different areas and heights, natural and highly modified parks, street arborisation, cemeteries, gardens etc. Our principal objective was to determine if the composition and diversity of bird assemblage is affected by urban noise, tree density and human-population density within the city.

Methods

Study area

Porto Alegre, the capital of Rio Grande do Sul State, Brazil, covers about 497 km^2 and was founded in 1732. It is the most populous city of the State with about 1.5 million inhabitants (IBGE 2005), and continues to grow outward over habitats that were originally mainly grasslands, marshes, gallery forests and Atlantic rainforests.

The climate is sub-tropical humid (Cfa) with temperatures in the warmest month above 22°C and rainfall (approximately 1,300 mm/year) relatively evenly distributed throughout the year. Although the climate is considered sub-tropical, Porto Alegre is in a transition zone where tropical maritime air masses are more frequent in summer and polar air masses are more frequent in winter. Altitude varies from 4 m to 300 ma.s.l. (mean range 80–100 ma.s.l.). The city covers two topographic sub-regions: highlands (granite hills) and lowlands of predominantly alluvial origin (Ruszczyk 1984). Guaiba Lake and Crista de Porto Alegre hills are the western and eastern boundaries of the city, respectively. The stream Arroio Dilúvio divides the city in northern and southern parts (Fig. 1). The northern part of the city is mainly industrial. The southern is mainly residential (see Menegat et al. 1998), with urban development expanding south during the last two decades.

The original vegetation was mainly sub-tropical rain forest, with trees up to about 15 m high. Only a few remnants of this flora are found today in the city, which includes 171 species of native trees and 77 species of native shrubs (Brack et al. 1998). Some of the original forest elements occur in less developed areas, such as hills and city parks, including species of *Ficus* (Moraceae), *Nectandra* (Lauraceae), *Sebastiana* (Euphorbiaceae), *Schinus* (Anacardiaceae), and *Baccharis* (Asteraceae). Vegetation in public streets, gardens, urban parks and squares is dominated by exotic species, such as *Ligustrum japonicum* (Oleaceae), *Melia azedarach* (Meliaceae), *Platanus acerifolia* (Platanaceae), and *Lagerstroemia indica* (Lythraceae) (Sanchotene 2000).

Within the study area, there are 395 public squares (305 ha), 11 implemented or predicted recreational parks, totaling 541 ha, and three private green areas covering 78 ha. There are three conservation units within the limits of the city. The Parque Estadual Delta do Jacuí, which covers 4423 ha, covers an archipelago in the middle of the Guaiba River. The other two protected conservation units, Reserva Biológica do Lami and Reserva do Morro Santana have a combined area of only 70 ha. The three conservation units were not included in this study since our questions addressed urban bird community structure.

Fontana (2005) considered 169 species of birds to occur regularly in Porto Alegre; 32 species were considered occasional; 13 species are in the process of colonization and 27 had previously been recorded but were considered locally extinct or nearly extinct in the city. Twenty six species were data deficient. Three resident species were considered non native: *P. domesticus*, *Columba livia* and *Estrilda astrild*.

Sampling design

Surveys were undertaken in the zone classified as intensely occupied in the Master Plan of Porto Alegre (PPDUA 1999). Field work was conducted from May 1998 to December 1999 in the 170 km^2 of the continental portion of the city, which is the most urbanized area (Fig. 1). This survey provides a general description of bird assemblage diversity and composition. However, there was considerable temporal fluctuation in the presence of migratory species and some species were more difficult to detect outside the breeding season. Bird detectability also varied throughout the day. Therefore, we used a subset of the points sampled between 05:50 and 10:00, and in spring/summer (September to early December 1998 and 1999) to quantify patterns in assemblage spatial variation. Preliminary analyses indicated little temporal variation within these periods.

Birds were counted at points selected randomly using the following procedure: (1) 42 road-directory maps representing the urbanized area of the city (GUIA 1998) were numbered from 0 to 41; (2) each map was divided in 827 squares of 0.5 cm side (7,854 m^2 in terrain) and the potential sample unit was placed in the middle of each square; (3) the 20 points to be surveyed on each day were drawn using the Excel random-number generator. Points over Guaiba Lake (approximately 33%) were discarded. The process was repeated successively, until the species accumulation curve stabilized and the points covered the whole study area (Fig. 1).

Bird sampling

Field work started approximately 30 min after sunrise and extended throughout the day. All sites located over land (residential gardens, portions of streets, malls, city parks, clubs, parking lots, cemeteries, etc.) were surveyed, whether they would be subjectively considered suitable habitat for birds or not. Points where we could not obtain permission to enter, such as military land and the airport, were substituted by the next available point drawn.

Point counts (based on Bibby et al. 1992) were conducted by the same two trained ornithologists from two to four days a month, totalizing 50 field expeditions and 521 point counts. Birds were detected visually and/or by vocalizations in an area of 50 m radius around the observers, since previous studies had shown that most birds in Porto Alegre could be detected within this distance. We did not include species suspected of being captive or clearly pets. Surveys were undertaken all months of the year on sunny and non-windy days. The duration of count (8 min) was established from a preliminary study.

Habitat guilds

Bird species were classified in habitat guilds based on general literature (Belton 1994, Sick 1997) and personal observations. Three groups were recognized: open field species (OF) (e.g. native fields, marshes, and cultivated pastures habitats); forest species (F) (e.g. native or exotic forest fragments, forest edge or wooded park vegetation habitats); urban (U) (human constructions of any type, such as roads, bridges, buildings or paved areas habitats).

Independent variables

Variables used as indirect measures of urbanization were urban noise (N), number of trees (TD), and human population density (HD). Spatial variables recorded were longitude (LO) and latitude (LA) (UTM coordinate system) and time of day (H). Temperature (T) was measured but not included in analyses as there was little variation in this variable during spring surveys.

The urban noise was the maximum noise recorded during the 8 min of the duration of the point count. It was measured in the middle of the point by one of the observers with a

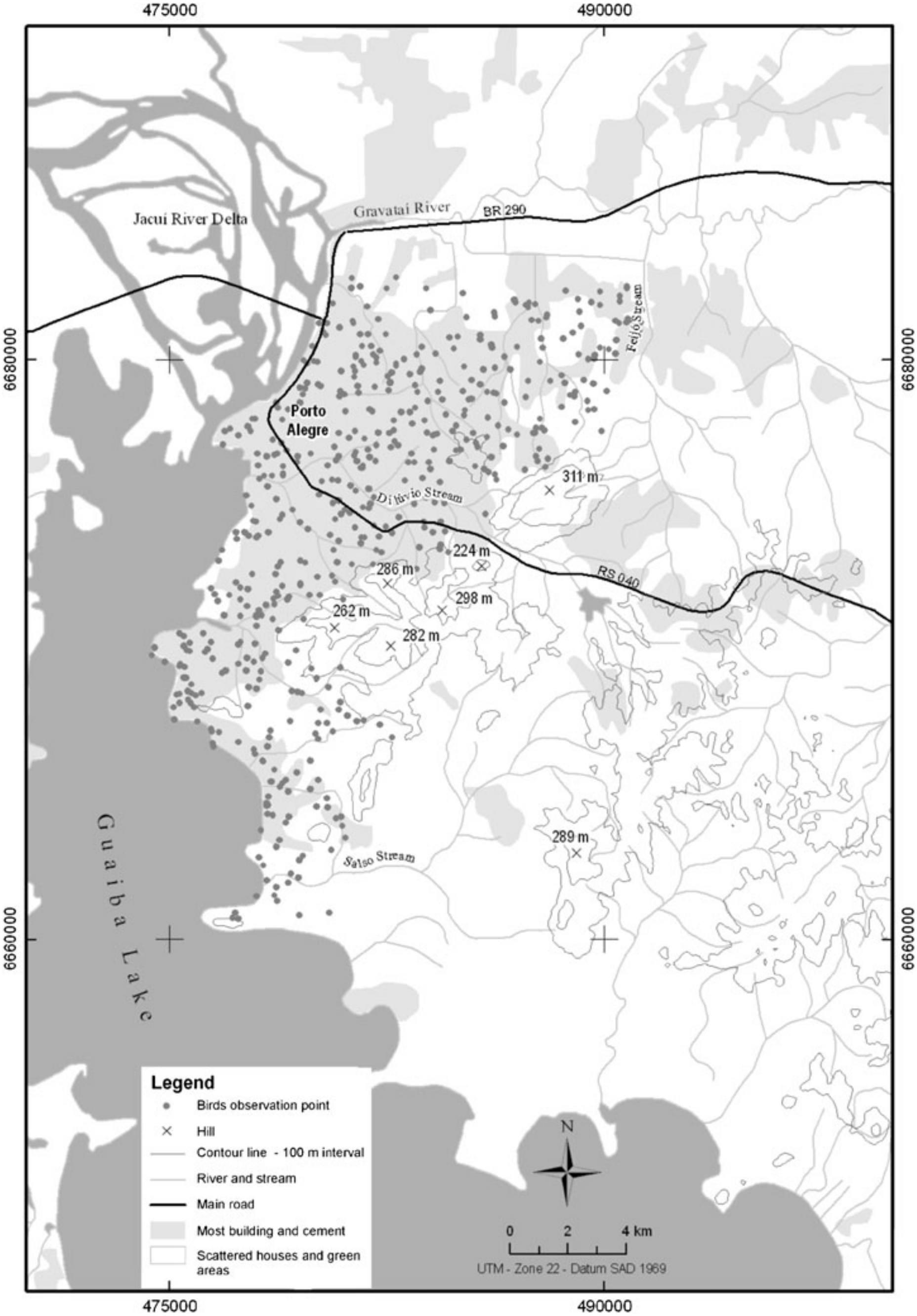


Fig. 1 Study site, showing the distribution of 521 points sampled in Porto Alegre, Rio Grande do Sul State, Brazil, in the years 1998 and 1999

sound meter (in decibels), which was held at waist height and pointed towards the street. The maximum urban noise varied from 73.4 to 113.4 (mean=91.06, S.D=± 8.77).

Tree density was estimated on a categorical scale within 50 m of each point count: 0 (zero to 3 individuals), 1 (4-8 individuals), 2 (9–15 individuals), 3 (15–20 individuals) and 4 (>20 individuals). Trees were defined as any woody vegetation taller than 2 m. The percentages of tree densities were 3.7%, 14.1%, 31.1%, 28.4% and 22.0% for categories 0, 1, 2, 3, and 4, respectively.

The human population density was obtained from the 1996 demographic census (IBGE 2005). To find the human density of each point surveyed, we plotted all points over a digital map containing the information on human population of that Census Sector of Porto Alegre. Densities of human population varied from no inhabitants to 42.53 people by km^2 (mean=6.71, SD=± 7.42) in the Census Sectors where points were placed.

Geographical coordinates (latitude and longitude - UTM) were taken with a GPS. Time of day was measured in minutes at each point count. Initial time to survey in point counts used in analyses varied from 5:53 a.m. to 9:40 (the average starting count time was 8:12 a.m.).

Statistical analysis

Descriptive statistical analyses were based on the 521 points surveyed in four seasons. Bird relative densities were estimated based on a presumed area of 7,854 m^2 sampled for each point. No attempt was made to convert these to absolute densities because of the potentially enormous number of confounding variables for each species. Therefore, relative densities can probably only be compared cautiously within species, and relative-density data were only used to describe general patterns in species composition with multivariate ordination. Original data will be available at http://ppbio.inpa.gov.br.

A subset of 134 points with little seasonal variation was used in multivariate analyses to quantify patterns in the assemblage. To reduce dimensionality of the bird assemblage data, dissimilarities in composition were summarized with Hybrid Multidimensional Scaling (HMDS), using the Pattern Analysis Package PATN (Belbin 1992). The Bray-Curtis association index was used for quantitative data, and Sørensen distance measure was used for presence/absence data. Ordinations were based on the relative densities of species within sites, and species abundances were standardized (*i.e.* divided by sum of squares) to give the same weight to all species. Differences between sites in species richness and predictor variables were calculated using Euclidean Distance.

The coefficient of regression (r^2 statistic) was used to describe the proportion of the variance in the original distances captured by the ordinations. This procedure might, however, slightly underestimate the effectiveness of the HMDS, which does not require a linear relationship between the input and output distances.

The decision to use ordinations in only two dimensions was made a priori because it is difficult to observe patterns in more than two axes, and because two dimensions usually capture the major gradients. However, we also used ordinations in other dimensions to verify that our choice of dimensionality did not affect the conclusions of the inferential analyses.

To test significance of effects of independent variables on multivariate ordination axes, we used Multivariate Analysis of Covariance (MANCOVA) in the Systat 10.0 (SPSS 2000) package for statistical data analysis.

Results

Taxonomic composition and relative abundance

During the overall bird survey (n=521 points) we recorded qualitatively 132 species of birds from 43 families in Porto Alegre. It was not possible to count all species, and we obtained counted 8,698 individuals from 121 species that were contacted 4,016 times. The number of species recorded per point varied from zero to 28 (mean=7.7, S.D.± 4.1 species/point). The number of individuals recorded per point varied from zero to 167 (mean=16.7±13.8 individuals/point).

Two introduced species, House Sparrow (*Passer domesticus*) and Rock Dove (*Columba livia*) had the highest number of individuals registered and introduced species represented about 40% of the total number of individuals recorded. House sparrows occurred in more points than any other species, but 8 native species occurred in more points than the Rock Dove (Appendix 1). Most species were represented by few individuals (Fig. 2). Variation in abundance was lower when only native species were included (Appendix 1). The richest bird families of Rio Grande do Sul were poorly represented in the city (Fig. 3). Forest-associated species (most woodpeckers, flycatchers, thrushes, and seedeaters) constituted 40% of the assemblage. The rest of the birds were open-field or marsh birds, such as herons or ducks. Thirteen open-field and eight forest birds had only one record in the city (Appendix 1).

Variables affecting number of species (NSP) recorded

Multiple regression (NSP=0.00*LO-0.00*LA+1.44*TD-0.22*N-12.73*H-2.19*HD, R^2=0.55, $F_{6,127}$=25.5, P<0.001) indicated that the number of species registered per point (NSP) was related only to noise (N - P<0.001), tree density (TD - P<0.001), log human population density (HD – P<0.001) and latitude (LA – P=0.021), but not to longitude (LO – P=0.108) or time of survey (H – P=0.081). Tree density was positively related to the number of species recorded (Fig. 4a) and negatively related to noise

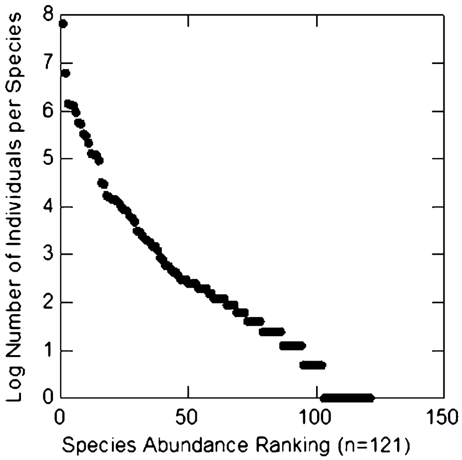


Fig. 2 Relative-abundance logarithmic curve of avifauna at Porto Alegre, illustrating the high relative abundance of a few common species (n=121)

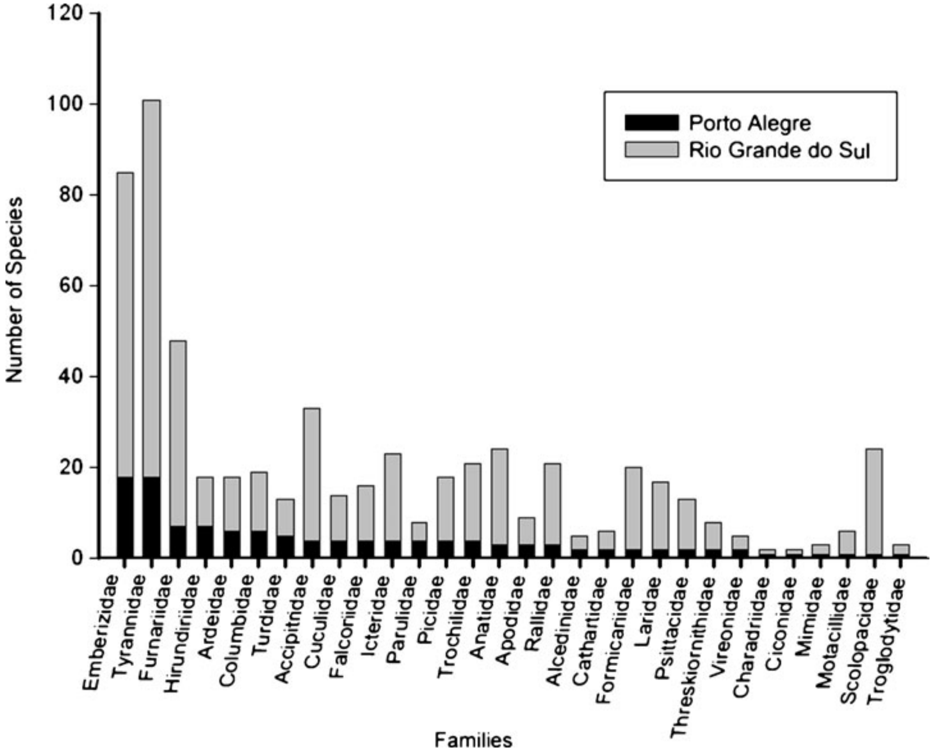
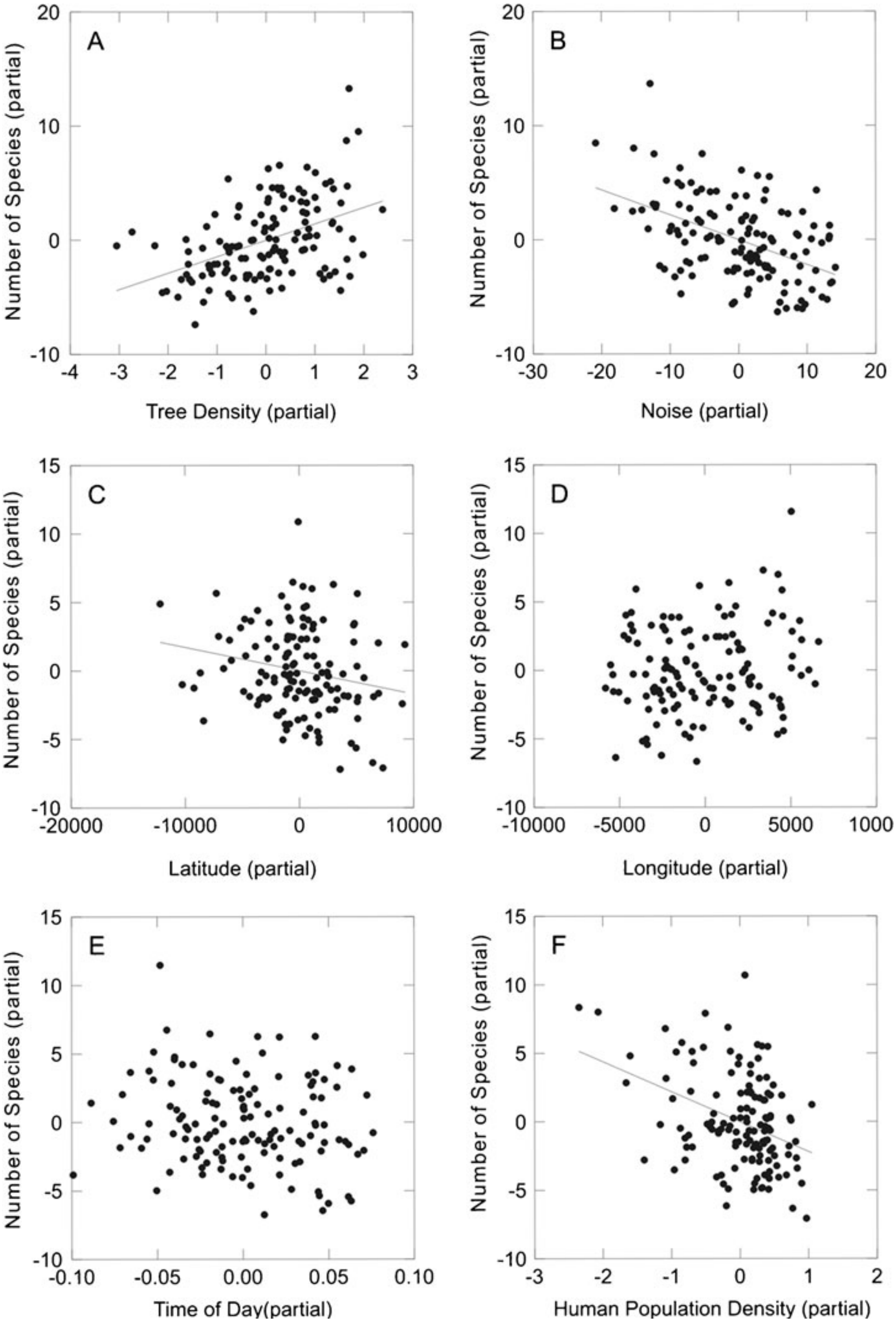


Fig. 3 Number of species of each family encountered in Porto Alegre compared to the species richness of these families recorded for the State of Rio Grande do Sul. Emberizidae includes Emberizidae, Thraupidae, Fringilidae, Cardinalidae and *Coereba flaveola*; Turdidae includes Turdidae and Polioptidae

(Fig. 4b), latitude (Fig. 4c) and human population density (Fig 4f). There was little evidence of colinearity among the predictor variables (tolerance>0.5 in all cases). The partial regressions for longitude (Fig. 4d) and time of day (Fig. 4e) gave no indication of nonlinear effects that could compromise the statistical tests.

The standardised regression coefficients (bs) for the model indicated stronger effects of tree density (bs=0.36) and noise (bs=0.39) than the indirect effect of human population density (bs=0.29). Addition of the direct effect of human population density increased the R^2 by only 0.08, whereas exclusion of tree density and noise, the

Fig. 4 Partial regressions derived from de multiple regressions (see Results) relating number of species recorded per point with (**a**) index of tree density (varying from 0 to 4), (**b**) Eight minutes maximum urban noise in decibels, (**c**) Latitude in UTM, (**d**) Longitude in UTM, (**e**) Survey time (hours and minutes) and (**f**) human population density (in km^2). Variables in partial regressions can take negative values because they represent how much that variable causes deviation from the expected value if all other variables were constrained to be constant. That is, they represent the independent effect of that variable. In nature, the observed value will always be different because other variables will not be constrained to be constant


A
B
C
D
E
F
Number of Species (partial)
Tree Density (partial)
Noise (partial)
Latitude (partial)
Longitude (partial)
Time of Day(partial)
Human Population Density (partial)
20
10
0
-10
15
5
-5
-4
-3
-2
-1
1
2
3
-30
-20
-10
-20000
-10000
10000
-5000
5000
1000
-0.10
-0.05
0.00
0.05
0.10

two indirect effects expected to be influenced by human population density, reduced the R^2 by 0.32. There was little colinearity between human population density, tree density and noise, and the latter variables were only associated with 5% of the variance in human population density.

Multivariate patterns in species distributions

The two ordination axes captured more of the variance in the original distances for site normalized quantitative data (r^2=0.63) than for presence-absence data (r^2=0.54). For quantitative data on species composition, MANCOVA indicated that the ordination axes were significantly related to latitude (Pillai Trace=0.074, $F_{2,126}$=5.06, P=0.008), number of trees (Pillai Trace=0.160, F $_{2,126}$=11.97, P<0.001) and log human population density (Pillai Trace=0.100, F $_{2,126}$=6.99, P=0.001). There were no significant effects of longitude (Pillai Trace=0.029, F $_{2,126}$=1.90, P=0,153), noise (Pillai Trace=0.043, F $_{2,126}$=2.82, P=0,064) or time of day (Pillai Trace=0.007, F $_{2,126}$=4.13, P=0.663).

Ordinations based on presence-absence data were affected by latitude (Pillai Trace= 0.130, $F_{2,126}$=9.42, P<0.001), longitude (Pillai Trace=0.068, F $_{2,126}$=4.59, P=0,012), number of trees (Pillai Trace=0.267, F $_{2,126}$=22.96, P<0.001), noise (Pillai Trace= 0.065, F $_{2,126}$=4.36, P=0,015) and log human population density (Pillai Trace=0.086, F $_{2,126}$=5.92, P=0.003), but not by time of day (Pillai Trace=0.027, F $_{2,126}$=1.76, P=0.177).

The factors that affected species composition were generally the same as those that affected the number of species registered per point, and the species composition was not independent of the number of species recorded per point. The two ordination axes based on quantitative data predicted almost 60% of the variance in the number of species recorded (R^2=0.59, $F_{2,131}$=93.2, P<0.001) and the two ordination axes based on presence-absence data predicted over 50% of the variance in the number of species (R^2=0.52, $F_{2,131}$=71.8, P<0.001).

Although there was a north–south gradient in species density after taking into account other predictor variables, areas with high and low species densities were found throughout the city (Fig. 5a), and ordinations axes based on presence-absence data (Fig. 5b) and quantitative data (Fig. 5c) also showed no consistent trends when other predictor variables were not taken into account. Therefore, geographic coordinates alone have little capacity to predict bird assemblage patterns.

Discussion

The 132 species found in this study correspond to approximately 78% of the birds that have been recorded regularly from Porto Alegre and 21% of the birds known to occur in Rio Grande do Sul State (Bencke 2001; Fontana 2005). Most of the birds are common species of the State (Belton 1994). All species of the Families Conopophagidae, Estrildidae, Passeridae, Phalacrocoracidae, and Recurvirostridae were recorded, but these families have only one species in Rio Grande do Sul. All four species of warblers (Parulidae) from the State were recorded in the city. Families with mostly forest species, such as Formicariidae and Thamnophilidae, were not well represented in Porto Alegre.

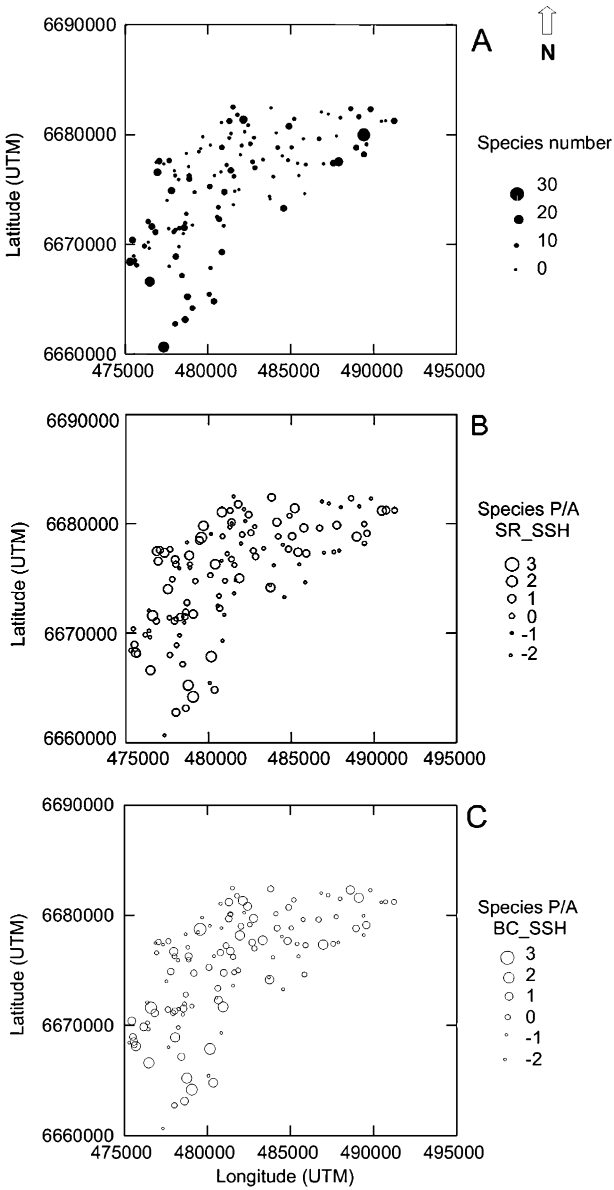


Fig. 5 Spatial distribution of species richness and relative composition of the Porto Alegre avifauna. **a.** Number of Species/point; **b.** composition presence/absence data ordinated with Sørensen Association Index and Semi-Strong HMDS (SRS_SSH); **c.** composition quantitative data ordinated with Bray-Curtis Association Index and Semi-Strong HMDS (BC_SSH). The size of symbols is proportional to the number of sepecies (part **a**) or the value o a single ordination axis, which is centred on zero (part **b** and **c**)

The Porto Alegre bird community has a few very common species, and many relatively rare species, as do most diverse, well-studied communities (Magurran 2005). The bird fauna of Porto Alegre is dominated by seven native species and two introduced species. Although the Rock Dove had the second highest number of registers of individuals, it occurred in a lower number of sites than seven native species. Therefore, the bird community of Porto Alegre is not only dominated by introduced species.

The number of species recorded was higher than reports for most cities in Brazil (Matarazzo-Neuberger 1992; Souza 1995), or even natural subtropical habitats. For instance, species richness is comparable to that of tropical semi-deciduous forests of similar area in São Paulo State, such as Santa Genebra forest (134 species), or the Atlantic forest, such as Jacupiranga (142 species) and Boracéia forests (132 species) (Willis and Oniki 1981; Aleixo and Vielliard 1995). Direct comparison is not possible because the sampling was not uniform across the whole area of interest in the other studies. It is generally considered that cities have low bird diversities, dominated by introduced species even though biomass and density may be high (Lancaster and Rees 1979; Beissinger and Osborne 1982; Bezzel 1985; Cam et al. 2000). An increase in urban species diversity is frequently observed at regional and local scales (Olden and Rooney 2006) as a result of a variety of influences, such as. presence of remnant vegetation, human supplementation, non-native predators, and preponderance of "edge" species (Emlen 1974; Chace and Walsh 2006; McKinney 2006). Although the cities cannot substitute more natural areas in terms of bird conservation, they can have an important role in complementing other areas, and may conserve more species than some areas of intensive agriculture, such as rice monocultures (Dias and Burger 2005) or fragments in sugar cane plantations (Piratelli et al. 2005). Most of the more common birds recorded are solitary or pair−forming passerines, with the exception of Blue-and-white Swallows (*Pygochelidon cyanoleuca*), White-rumped Swallows (*Tachycineta leucorrhoa*), and Chesnut-capped Blackbirds (*Chrysomus ruficapillus*). Some non−passerine birds were recorded a few times at high abundances, indicating gregarious behavior (e.g. Neotropic cormorant [*Phalacrocorax brasilianus*], Bare-faced Ibis [*Phimosus infuscatus*], Wattled jacana [*Jacana jacana*], Southern Lapwing [*Vanellus chilensis*], and most of the doves). Aggregations of similar species are common in cities (Feninger 1983; Belton 1994; Mendonça-Lima and Fontana 2000).

Many families that have many species in the State were rarely observed in Porto Alegre. Families Strigidae and Caprimulgidae were not considered, as most of their species are nocturnal, and hence poorly sampled by the methods we used. Generally, species and families common in natural open habitats do better in the city. Species usually found in forests, such as wood creepers (Formicariidae) and many flycatchers (Tyrannidae) are poorly represented in the city. Thrushes, pigeons and swallows are common colonizers of cities, and were found in abundance in Porto Alegre. Erz (1983) considered falcons, swifts, swallows (rock or cliff-dwellers) to be typical elements of European cities, with some park-land or open wood-land species (e.g. doves) and even forest species, but ground-breeding birds were generally lacking. Southern Lapwing and Rufous-collared Sparrow (*Zonotrichia capensis*) are ground-breeding birds and were frequently recorded in Porto Alegre.

Birds are affected by factors such as vegetation cover and diversity, and also by habitat heterogeneity (Lancaster and Rees 1979; Clergeau et al. 1998; Morneau et al. 1999; Clergeau et al. 2006a; Clergeau et al. 2006b). The results of this study indicate that, in Porto Alegre, as well as the number of trees, anthropogenic factors, such as urban noise, affect species assemblages.

Level of urbanization can be described by the relative development of different man-made structures, such as residential and business areas, and there is generally a peak in species richness at intermediate levels of urban development that may reflect habitat diversity (Blair 1996). However, there was no tendency for unimodal peaks in bird density in relation to any of the indices of urban development (human population density, tree density, noise levels) that we investigated. The latitudinal gradient found in composition and the number of species may be explained by the fact that there are more commercial and industrial areas in the north, and more residential in the south (see Menegat et al. 1998), but the latitudinal gradient was weak in relation to the effects of the local environmental factors.

Changes in species composition along spatial or environmental gradients have important implications for regional biodiversity planning (Olden and Rooney 2006). This study indicates that increases in bird abundance and diversity can be obtained by increasing the number of trees and reducing noise levels, or the environmental conditions associated with them, even in areas with high population density.

Ruszczyk (1984, 1986) concluded that diurnal Lepidoptera were associated with a environmental gradient, oriented northwest−southeast in Porto Alegre. That distribution could result from an effect of time since settlement, because urbanization in Porto Alegre started from west to east, accompanying the human colonization along avenues radiating outward from the commercial centre. A similar pattern could be expected for birds, since the number of species and individuals of butterflies were negatively correlated with the presence of human constructions. A similar pattern was found for seven bird species in Porto Alegre (Ruszczyk *et al.* 1987). Nevertheless, our results for the whole bird assemblage revealed a north–south gradient in Porto Alegre that did not coincide with the gradient in butterflies. Although gradients in number of species and assemblage composition can be detected for birds, after taking into account environmental conditions, there are no strong patterns associated with geographical coordinates that would allow their use for macro zoning. High numbers of species and all types of assemblages can be found in most regions within the city.

Cities worldwide hold an avifauna that can be rich, with more or less non-native species, depending on habitat features within and around the cities (Jokimäki and Kaisanlahti-Jokimäki 2003). Urbanization causes biotic homogenization and consequently increases similarities of regional biotas, reducing world biodiversity. That constitutes one of the big challenges in conservation biology. We suggest that conservation of birds in cities should be part of strategies to conserve native local species. In the case of Porto Alegre, and probably other Neotropical cities, the effects of high population densities can be largely mitigated by maintaining as much green spaces between the buildings as possible and reducing direct interference by negative factors, such as noise levels.

Acknowledgments We thank André de Mendonça−Lima and Cristian Joenck for help in the field. Roberto Reis and Juliana Bosi de Almeida gave a valuable help with the first English version. Clarissa Fontana and Luciane Salvi helped format the figures. We thank Andreas Kindel, Luis dos Anjos, Helena Romanowisky and Márcio Martins for their valuable suggestions on CSF dissertation and Walter Voss and Márcio Repenning for bibliography and improvement of the manuscript. Lucio Lucateli and Henrich Hasenack, from Idrisi Resource Study Center (UFRGS), did the map of Fig. 1. Museu de Ciências e Tecnologia—Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS), Fundação Zoobotânica do Rio Grande do Sul (FZBRS), and Instituto Nacional de Pesquisas da Amazonia (INPA) provided logistical support. Secretariate of Urban Planning provided data on Porto Alegre Census Sectors. This work was partially supported by a CNPq fellowship to Carla Suertegaray Fontana (1998).

Appendix

Table 1 Recorded birds from Porto Alegre city in the years of 1998 and 1999

Family Name[a]	Species Name[a]	English Name[a]	Hab	NR	A	F(%)	FR (%)	DER	D(Km2)	DPR
Passeridae	*Passer domesticus*	House Sparrow	U	449	2503	86.180	11.180	0.288	611.696	176.026
Columbidae	*Columba lívia*	Rock Dove	U	165	889	31.670	4.109	0.102	217.258	22.205
Furnariidae	*Furnarius rufus*	Rufous Hornero	OF	307	470	58.925	7.644	0.054	114.861	6.207
Tyrannidae	*Pitangus sulphuratus*	Great Kiskadee	OF	325	462	62.380	8.093	0.053	112.906	5.997
Hirundinidae	*Pygochelidon cyanoleuca*	Blue-and-white Swallow	U?	207	451	39.731	5.154	0.052	110.218	5.715
Turdidae	*Turdus rufiventris*	Rufous-bellied Thrush	F	252	393	48.369	6.275	0.045	96.043	4.340
Thraupidae	*Thraupis sayaca*	Sayaca Tanager	F	234	318	44.914	5.827	0.037	77.715	2.841
Coerebidae	*Coereba flaveola*	Bananaquit	F	260	310	49.904	6.474	0.036	75.759	2.700
Apodidae	*Chaetura meridionalis*	Sick's Swift	OF	133	252	25.528	3.312	0..029	61.585	1.784
Troglodytidae	*Troglodytes musculus*	Southern House-Wren	OF	225	240	43.186	5.603	0.028	58.652	1.618
Charadriidae	*Vanellus chilensis*	Southern Lapwing	OF	50	207	9.597	1.245	0.024	50.588	1.204
Columbidae	*Columbina picui*	Picui Ground-Dove	OF	105	167	20.154	2.615	0.019	40.812	0.784
Phalacrocoracidae	*Phalacrocorax brasilianus*	Neotropic Cormorant	OF	8	163	1.536	0.199	0.019	39.835	0.747
Icteridae	*Molothrus bonariensis*	Shiny Cowbird	OF	88	161	16.891	2.191	0.019	39.346	0.728
Trochilidae	*Hylocharis chrysura*	Gilded Hummingbird	OF	129	143	24.760	3.212	0.016	34.947	0.575
Hirundinidae	*Progne chalybea*	Grey-breasted Martin	OF	52	90	9.981	1.295	0.010	21.995	0.228
Tyrannidae	*Tyrannus melancholicus*	Tropical Kingbird	OF	64	87	12.284	1.594	0.010	21.262	0.213
Columbidae	*Columbina talpacoti*	Ruddy Ground-Dove	OF	47	69	9.021	1.170	0.008	16.863	0.134
Thraupidae	*Thraupis bonariensis*	Blue-and-yellow Tanager	F	41	67	7.869	1.021	0.008	16.374	0.126
Emberizidae	*Zonotrichia capensis*	Rufous-collared Sparrow	OF	59	64	11.324	1.469	0.007	15.641	0.115
Cuculidae	*Guira guira*	Guira Cuckoo	OF	25	62	4.798	0.623	0.007	15.152	0.108
Turdidae	*Turdus amaurochalinus*	Creamy-bellied Thrush	F	48	59	9.213	1.195	0.007	14.419	0.098
Tyrannidae	*Camptostoma obsoletum*	Southern Beardless-Tyrannulet	F	49	54	9.405	1.220	0.006	13.197	0.082
Tyrannidae	*Serpophaga subcristata*	White-crested Tyrannulet	F	47	51	9.021	1.170	0.006	12.464	0.073

Threskiornithidae	*Phimosus infuscatus*	Bare-faced Ibis	OF	5	50	0.960	0.125	0.006	12.219	0.070
Columbidae	*Zenaida auriculata*	Eared Dove	OF	30	64	5.758	0.747	0.007	15.641	0.115
Fringillidae	*Euphonia chlorotica*	Purple-throated Euphonia	F	40	45	7.678	0.996	0.005	10.997	0.057
Tyrannidae	*Tyrannus savana*	Fork-tailed Flycatcher	OF	33	43	6.334	0.822	0.005	10.509	0.052
Tyrannidae	*Machetornis rixosa*	Cattle Tyrant	OF	24	40	4.607	0.598	0.005	9.775	0.045
Hirundinidae	*Progne tapera*	Brown-chested Martin	OF	21	33	4.031	0.523	0.004	8.065	0.031
Estrildidae	*Estrilda astrild*	Common Waxbill	OF	6	32	1.152	0.149	0.004	7.820	0.029
Ardeidae	*Ardea alba*	Great Egret	OF	15	30	2.879	0.374	0.003	7.332	0.025
Parulidae	*Parula pitiayumi*	Tropical Parula	F	26	28	4.990	0.647	0.003	6.843	0.022
Vireonidae	*Cyclarhis gujanensis*	Rufous-browed Peppershrike	F	26	26	4.990	0.647	0.003	6.354	0.019
Picidae	*Colaptes campestris*	Campo Flicker	OF	15	27	2.879	0.374	0.003	6.598	0.020
Parulidae	*Basileuterus leucoblepharus*	White-browed Warbler	F	23	24	4.415	0.573	0.003	5.865	0.016
Hirundinidae	*Tachycineta leucorrhoa*	White-rumped Swallow	OF	13	24	2.495	0.324	0.003	5.865	0.016
Emberizidae	*Sicalis flaveola*	Saffron Finch	F	17	22	3.263	0.423	0.003	5.376	0.014
Tyrannidae	*Elaenia flavogaster*	Yellow-bellied Elaenia	F	18	19	3.455	0.448	0.002	4.643	0.010
Icteridae	*Chrysomus ruficapillus*	Chestnut-capped Blackbird	OF	4	18	0.768	0.100	0.002	4.399	0.009
Parulidae	*Basileuterus culicivorus*	Golden-crowned Warbler	F	15	16	2.879	0.374	0.002	3.910	0.007
Jacanidae	*Jacana jacana*	Wattled Jacana	OF	3	16	0.576	0.075	0.002	3.910	0.007
Furnariidae	*Cranioleuca obsoleta*	Olive Spinetail	F	15	15	2.879	0.374	0.002	3.666	0.006
Columbidae	*Leptotila verreauxi*	White-tipped Dove	F	14	14	2.687	0.349	0.002	3.421	0.006
Parulidae	*Geothlypis aequinoctialis*	Masked Yellowthroat	OF	13	14	2.495	0.324	0.002	3.421	0.006
Rallidae	*Aramides saracura*	Slaty-breasted Wood-Rail	F	11	13	2.111	0.274	0.001	3.177	0.005
Tyrannidae	*Elaenia parvirostris*	Small-billed Elaenia	F	12	12	2.303	0.299	0.001	2.933	0.004
Psittacidae	*Myiopsitta monachus*	Monk Parakeet	F	6	11	1.152	0.149	0.001	2.688	0.003
Threskiornithidae	*Plegadis chihi*	White-faced Ibis	OF	5	12	0.960	0.125	0.001	2.933	0.004
Ardeidae	*Egretta thula*	garça-branca-pequena	OF	7	12	1.344	0.174	0.001	2.933	0.004
Icteridae	*Agelaioides badius*	Bay-winged Cowbird	OF	2	11	0.384	0.050	0.001	2.688	0.003
Furnariidae	*Synallaxis spixi*	Spix's Spinetail	OF	10	11	1.919	0.249	0.001	2.688	0.003
Picidae	*Colaptes melanochloros*	Green-barred Woodpecker	F	10	11	1.919	0.249	0.001	2.688	0.003
Mimidae	*Mimus saturninus*	Chalk-browed Mockingbird	OF	6	10	1.152	0.149	0.001	2.444	0.003

Table 1 (continued)

Family Name[a]	Species Name[a]	English Name[a]	Hab	NR	A	F(%)	FR (%)	DER	D(Km2)	DPR
Thamnophilidae	*Thamnophilus caerulescens*	Variable Antshrike	F	8	10	1.536	0.199	0.001	2.444	0.003
Cuculidae	*Crotophaga ani*	Smooth-billed Ani	OF	7	9	1.344	0.174	0.001	2.199	0.002
Falconidae	*Falco sparverius*	American Kestrel	OF	9	10	1.727	0.224	0.001	2.444	0.003
Falconidae	*Milvago chimachima*	Yellow-headed Caracara	F	8	10	1.536	0.199	0.001	2.444	0.003
Accipitridae	*Rupornis magnirostris*	Roadside Hawk	F	9	9	1.727	0.224	0.001	2.199	0.002
Emberizidae	*Poospiza nigrorufa*	Black-and-rufous Warbling-Finch	OF	7	7	1.344	0.174	0.001	1.711	0.001
Trochilidae	*Chlorostilbon lucidus*	Glittering-bellied Emerald	OF	7	8	1.344	0.174	0.001	1.955	0.002
Anatidae	*Anas versicolor*	Silver Teal	OF	2	8	0.384	0.050	0.001	1.955	0.002
Anatidae	*Amazonetta brasiliensis*	Brazilian Teal	OF	2	8	0.384	0.050	0.001	1.955	0.002
Tyrannidae	*Poecilotriccus plumbeiceps*	Ochre-faced Tody-Flycatcher	F	6	7	1.152	0.149	0.001	1.711	0.001
Tyrannidae	*Elaenia obscura*	Highland Elaenia	OF	7	7	1.344	0.174	0.001	1.711	0.001
Furnariidae	*Anumbius annumbi*	Firewood-Gatherer	OF	4	6	0.768	0.100	0.001	1.466	0.001
Furnariidae	*Schoeniophylax phryganophila*	Chotoy Spinetail	OF	7	8	1.344	0.174	0.001	1.955	0.002
Scolopacidae	*Gallinago paraguaiae*	South American Snipe	OF	3	7	0.576	0.075	0.001	1.711	0.001
Ardeidae	*Bubulcus íbis*	Cattle Egret	OF	4	8	0.768	0.100	0.001	1.955	0.002
Cuculidae	*Piaya cayana*	Squirrel Cuckoo	F	7	7	1.344	0.174	0.001	1.711	0.001
Cathartidae	*Coragyps atratus*	Black Vulture	OF	2	4	0.384	0.050	0.000	0.978	0.000
Emberizidae	*Poospiza lateralis*	Red-rumped Warbling-Finch	F	4	5	0.768	0.100	0.001	1.222	0.001
Turdidae	*Turdus albicollis*	White-necked Thrush	F	6	6	1.152	0.149	0.001	1.466	0.001
Tyrannidae	*Satrapa icterophrys*	Yellow-browed Tyrant	OF	3	5	0.576	0.075	0.001	1.222	0.001
Tyrannidae	*Xolmis irupero*	White Monjita	OF	3	5	0.576	0.075	0.001	1.222	0.001
Thamnophilidae	*Thamnophilus ruficapillus*	Rufous-capped Antshrike	F	5	5	0.960	0.125	0.001	1.222	0.001
Apodidae	*Streptoprocne zonaris*	White-collared Swift	OF	3	5	0.576	0.075	0.001	1.222	0.001
Psittacidae	*Amazona aestiva*	Blue-fronted Parrot	U	1	5	0.192	0.025	0.001	1.222	0.001
Columbidae	*Patagioenas picazuro*	Picazuro Pigeon	F	4	5	0.768	0.100	0.001	1.222	0.001
Icteridae	*Sturnella superciliaris*	White-browed Blackbird	OF	3	4	0.576	0.075	0.000	0.978	0.000
Thraupidae	*Pipraeidea melanonota*	Fawn-breasted Tanager	F	4	4	0.768	0.100	0.000	0.978	0.000

Tyrannidae	*Myiarchus swainsoni*	Swainson's Flycatcher	F	4	6	0.768	0.100	0.001	1.466	0.001
Tyrannidae	*Myiophobus fasciatus*	Bran-colored Flycatcher	F	4	4	0.768	0.100	0.000	0.978	0.000
Tyrannidae	*Phylloscartes ventralis*	Mottle-cheeked Tyrannulet	F	3	4	0.576	0.075	0.000	0.978	0.000
Laridae	*Chroicocephalus maculipennis*	Brown-hooded Gull	OF	2	4	0.384	0.050	0.000	0.978	0.000
Cathartidae	*Cathartes aura*	Turkey Vulture	OF	2	4	0.384	0.050	0.000	0.978	0.000
Fringillidae	*Euphonia cyanocephala*	Golden-rumped Euphonia	F	3	3	0.576	0.075	0.000	0.733	0.000
Emberizidae	*Sporophila caerulescens*	Double-collared Seedeater	F	2	3	0.384	0.050	0.000	0.733	0.000
Motacillidae	*Anthus lutescens*	Yellowish Pipit	OF	2	3	0.384	0.050	0.000	0.733	0.000
Vireonidae	*Vireo olivaceus*	Red-eyed Vireo	F	3	3	0.576	0.075	0.000	0.733	0.000
Tyrannidae	*Lathrotriccus euleri*	Euler's Flycatcher	F	3	3	0.576	0.075	0.000	0.733	0.000
Picidae	*Veniliornis spilogaster*	White-spotted Woodpecker	F	3	3	0.576	0.075	0.000	0.733	0.000
Falconidae	*Milvago chimango*	Chimango Caracara	OF	2	3	0.384	0.050	0.000	0.733	0.000
Ardeidae	*Nycticorax nycticorax*	Black-crowned Night-Heron	OF	3	3	0.576	0.075	0.000	0.733	0.000
Cardinalidae	*Saltator similis*	Green-winged Saltator	F	2	2	0.384	0.050	0.000	0.489	0.000
Thraupidae	*Thraupis palmarum*	Palm Tanager	F	2	2	0.384	0.050	0.000	0.489	0.000
Turdidae	*Turdus leucomelas*	Pale-breasted Thrush	F	1	2	0.192	0.025	0.000	0.489	0.000
Hirundinidae	*Alopochelidon fucata*	Tawny-headed Swallow	OF	1	2	0.192	0.025	0.000	0.489	0.000
Conopophagidae	*Conopophaga lineata*	Rufous Gnateater	F	2	2	0.384	0.050	0.000	0.489	0.000
Rallidae	*Pardirallus nigricans*	Blackish Rail	OF	2	2	0.384	0.050	0.000	0.489	0.000
Accipitridae	*Rostrhamus sociabilis*	Snail Kite	OF	1	2	0.192	0.025	0.000	0.489	0.000
Ardeidae	*Syrigma sibilatrix*	Whistling Heron	OF	1	2	0.192	0.025	0.000	0.489	0.000
Icteridae	*Molothrus rufoaxillaris*	Screaming Cowbird	OF	1	1	0.192	0.025	0.000	0.244	0.000
Emberizidae	*Paroaria coronata*	Red-crested Cardinal	OF	1	1	0.192	0.025	0.000	0.244	0.000
Emberizidae	*Ammodramus humeralis*	Grassland Sparrow	OF	1	1	0.192	0.025	0.000	0.244	0.000
Thraupidae	*Trichothraupis melanops*	Black-goggled Tanager	F	1	1	0.192	0.025	0.000	0.244	0.000
Tyrannidae	*Pyrocephalus rubinus*	Vermilion Flycatcher	OF	1	1	0.192	0.025	0.000	0.244	0.000
Tyrannidae	*Tolmomyias sulphurescens*	Yellow-olive Flycatcher	F	1	1	0.192	0.025	0.000	0.244	0.000
Furnariidae	*Syndactyla rufosuperciliata*	Buff-browed Foliage-gleaner	F	1	1	0.192	0.025	0.000	0.244	0.000
Furnariidae	*Synallaxis cinerascens*	Gray-bellied Spinetail	F	1	1	0.192	0.025	0.000	0.244	0.000
Picidae	*Piculus aurulentus*	Yellow-browed Woodpecker	F	1	1	0.192	0.025	0.000	0.244	0.000

Table 1 (continued)

Family Name[a]	Species Name[a]	English Name[a]	Hab	NR	A	F(%)	FR (%)	DER	D(Km2)	DPR
Trochilidae	*Stephanoxis lalandi*	Plovercrest	F	1	1	0.192	0.025	0.000	0.244	0.000
Trochilidae	*Anthracothorax nigricollis*	Black-throated Mango	OF	1	1	0.192	0.025	0.000	0.244	0.000
Caprimulgidae	*Podager nacunda*	Nacunda Nighthawk	OF	1	1	0.192	0.025	0.000	0.244	0.000
Cuculidae	*Tapera naevia*	Striped Cuckoo	F	1	1	0.192	0.025	0.000	0.244	0.000
Laridae	*Larus dominicanus*	Kelp Gull	OF	1	1	0.192	0.025	0.000	0.244	0.000
Recurvirostridae	*Himantopus mexicanos*	Black-necked Stilt	OF	1	1	0.192	0.025	0.000	0.244	0.000
Rallidae	*Gallinula chloropus*	Common Moorhen	OF	1	1	0.192	0.025	0.000	0.244	0.000
Falconidae	*Caracara plancus*	Southern Caracara	OF	1	1	0.192	0.025	0.000	0.244	0.000
Ardeidae	*Ardea cocoi*	Cocoi Heron	OF	1	1	0.192	0.025	0.000	0.244	0.000
Anatidae	*Anas georgica*	Yellow-billed Pintail	OF	1	1	0.192	0.025	0.000	0.244	0.000
Emberizidae	*Coryphospingus cucullatus*	Red-crested Finch	F	•	•	•	•	•	•	•
Polioptilidae	*Polioptila dumicola*	Masked Gnatcatcher	F	•	•	•	•	•	•	•
Hirundinidae	*Stelgidopteryx ruficollis*	Southern Rough-winged Swallow	OF	•	•	•	•	•	•	•
Picidae	*Celeus flavescens*	Blond-crested Woodpecker	F	•	•	•	•	•	•	•
Alcedinidae	*Chloroceryle amazona*	Amazon Kingfisher	OF	•	•	•	•	•	•	•
Alcedinidae	*Ceryle torquatus*	Ringed Kingfisher	OF	•	•	•	•	•	•	•
Apodidae	*Cypseloides senex*	Great Dusky Swift	OF	•	•	•	•	•	•	•
Strigidae	*Athene cunicularia*	Burrowing Owl	OF	•	•	•	•	•	•	•
Accipitridae	*Accipiter striatus*	Sharp-shinned Hawk	F	•	•	•	•	•	•	•
Accipitridae	*Buteo brachyurus*	Short-tailed Hawk	F	•	•	•	•	•	•	•
Ciconiidae	*Ciconia maguari*	Maguari Stork	OF	•	•	•	•	•	•	•

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Habitat type (Hab (Aleixo 1999b) U urban, OF open field, F forest or forest border)); Number of records (NR); Abundance (A); Frequency (F); Relative frequency (FR); Relative species density (DER); Density (D); Relative population density (DPR). • variable not measured/521 qualitative points sample. Taxonomic names are according CBRO (2008). Original data in Fontana (2004)

[a] CRBO (2008)

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