NEOTROPICAL BATS ASSEMBLAGES IN URBAN PARKS: EFFECT OF URBANIZATION AND MICROHABITAT

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Titulo: ENSAMBLE DE MURCIÉLAGOS NEOTROPICALES EN PAQUES URBANOS: EFECTO DE LA URBANIZACIÓN Y EL MICROHÁBITAT [1]

Autor: Raúl Andrés Rodríguez-Moreno [2]

Palabras Claves: Murciélagos, Riqueza, Parques Urbanos, Tamaño del Parque, Urbanización, Microhábitat.

Descripción: El entendimiento del efecto de la urbanización y el microhábitat sobre el ensamble de murciélagos es pobremente conocido en la Región Neotropical. La relación del ensamble de murciélagos al área, distancia de aislamiento, urbanización (desarrollo urbanístico alrededor del parque) y microhábitat (estructura del hábitat dentro del parque) de 12 parques urbanos en la ciudad Bucaramanga fueron estudiados a lo largo de dos estaciones secas (Julio - Octubre 2007 y Noviembre 2007 – Marzo 2008). Doce especies fueron registradas: ocho de ellas de la familia Phyllostomidae, y cinco frugívoras, el gremio más abundante. Parques urbanos de gran tamaño, con bajos niveles de perturbación y ricos en especies vegetales pueden incrementar la riqueza de especies de murciélagos. El uso de suelo destinado a actividades comerciales parece ser que favorece a los murciélagos frugívoros, sin embargo, este y usos de suelos residenciales y de protección tienden a reducir la abundancia de insectívoros y nectarívoros urbanos. De igual forma, la riqueza de especies vegetales dentro del parque puede incrementar la abundancia en general y la de murciélagos frugívoros. Solo esas especies de murciélagos aparentemente tolerantes a altos niveles de urbanización fueron abundantes en este ambiente. El área, urbanización, y microhábitat podrían actuar sinérgicamente influenciando el ensamble de murciélagos urbanos. La distancia de aislamiento no parece ejercer alguna influencia significativa sobre los murciélagos urbanos.

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ABSTRACT

Title: NEOTROPICAL BATS ASSEMBLAGES IN URBAN PARKS: EFFECT OF URBANIZATION AND MICROHABITAT [1]

Author: Raúl Andrés Rodríguez-Moreno [2]

Key words: Bats, Species Richness, Urban Park, Park Size, Urbanization, Microhabitat.

Description: The understanding of the effects of the urbanization and microhabitat on bat assemblages is poorly known in the Neotropical Region. The urban bat assemblage related to the area, isolation distance, urbanization (urban development around the patch) and microhabitat (habitat structure within the urban park) of 12 urban parks in Bucaramanga city was studied during two dry seasons (July – October 2007 and November 2007 – March 2008). Twelve species were recorded: eight of them of the family Phyllostomidae, and five frugivorous bats, the most abundant guild trophic. Large-sized lowly disturbed urban parks and rich plant species might increase bat species richness. Commercial land uses seemingly favored the guild of bat frugivorous but this and residential land uses and protective land use tend to reduce insectivores and nectarivores. In turn, plant richness inside urban park would increase overall and frugivores abundance. Only those bat species apparently tolerant to high urbanization levels were abundant in the urban environment. The area, urbanization, and microhabitat could act synergistically to influence the urban bats assemblage in Bucaramanga city. Isolation distance does not appear to exert any significant influence on urban bats; perhaps, the most of urban bats used wooded streets in Bucaramanga city as corridors connecting fragments (urban park).

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1. INTRODUCTION

The continuous urban development increase produces some positive and negative changes in animal assemblages (Kalko 1998; McKinney 2006; Savard et al. 2000); so the urban planners are defied to search for new alternatives to maintain or improve urban biodiversity. Urbanization is a dynamic and drastic process that fragmented natural areas, and spread them within a human-dominated matrix (Avila-Flores and Fenton 2005, Clergeau et al. 1998), while promote the extinction of native species (e.g., habitat specialists) (McKinney 2006). The urban wildlife refuges and urban parks could play an important role as stable and transient habitats conserving local biological diversity in such environments (see Everette et al. 2001).

The urbanization effects on overall biodiversity depend on three factors: spatial scale, urbanization intensity, and species-specific responses (Avila-Flores and Fenton 2005; Gehrt and Chelsvig 2003; Gehrt and Chelsvig 2004; Savard et al. 2000). However, as a general rule, urbanization has a negative impact on animals (e.g., *Birds*: Clergeau et al. 1998; *Insect:* Blair and Launer 1997; *Lizards:* Germaine and Wakeling 2001), including bats (Kurta and Teramino 1992). Some processes related to urbanization may promote this negative impact, as well as species loss and/or abundance decrease: habitat loss, changes in the configuration of suitable habitats (e.g., area and isolation effect), lower connectivity, and secondary fragmentation *sensu* Soulé et al. (1992) (see Avila-Flores and Fenton 2005; Fernández-Juricic and Jokimäki 2001; McKinney 2002). Several studies in temperate and tropical regions agree on richness, abundance, and possibly the reproductive success reductions of most bat species in urban areas, while increasing the abundance of a few opportunistic species (Avila-

Flores and Fenton 2005; Bredt and Uieda 1996; Hourigan et al. 2006; Kurta and Teramino 1992). However, this response is not consistent in all the studies; some aspects of the urbanization can promote increases in biodiversity (McKinney 2002). Gehrt and Chelsvig (2003) documented positive relationships between urban habitats and bat activity in Chicago metropolitan area, as a result of the characteristics of the regional landscape dominated by farms and non-associated natural areas; these latter areas do not offer the necessary habitat to maintain the assemblage of bats, in contrast to urban environment.

The urbanization and microhabitat effects on the bat assemblages are poorly understood in the Neotropical Province. Bredt and Uieda (1996), De Knegt et al. (2005), in Brazil, Alberico et al. (2005) and Sampedro-Marín et al. (2007), in Colombia described the local fauna associated with urban areas, without considering the influence of multiple urban variables on bats. This study is intended to describe and to determine the abundance and richness of the bats assemblage that use the parks in the Bucaramanga city; and to examine how these attributes are related to the area, isolation, habitat structure within the urban park (hereafter microhabitat), and urban development around the patch (hereafter urbanization).

2. METHODS

2.1. Study area

This study was conducted in twelve urban parks in Bucaramanga city, Santander, Colombia, 7°08' N, 73°08' W: Antonia Santos, San Pío, Centenario, Universidad Cooperativa de Colombia (UCC), Santander, Bolívar, Escuela Ecológica La Flora, Uribe-Uribe, Turbay, Leones, Álvarez, and Solón Wilches (Fig. 1). The Bucaramanga urban center covers an area of 3,715 km^2 and is populated by 509,918 inhabitants; the altitude of the Bucaramanga is 960 m, but it decreases slightly from city eastern to western areas. This area has a tropical dry climate (mean annual rainfall is 1,400 mm and mean annual temperature is 24°C), with a bimodal rainfall regime, with one peak from March to May and a second from October and November.

Bucaramanga has an extensive network of wooded urban parks and streets. The vegetation consists of trees (e.g., *Anacardium excelsum*, *Ficus* sp., *Licania tomentosa*, *Mangifera indica*, *Pithecellobium dulce*, *Tabebuia* sp., *Terminalia cattapa*, *Bauhinia* sp., *Ceiba pentandra*), shrubs, lawns, and flowering species, mostly exotic species. All studied parks are bounded by roads, cleared open areas, or buildings. Parks of different sizes were selected from the center of the city to the suburban area (La Flora park), so that the effects of park size, isolation, habitat structure and urbanization could be separated. The average size and isolation of the study parks was 13,447.7 m^2 (range = 1,200 – 105,000 m^2, S.D. = 1.29) and 1,799.1 m (range = 1,140 - 2,450 m, S.D. = 0.34), respectively.

2.2 Bats survey

Urban parks were surveyed during the dry seasons from July to October 2007 and between November 2007 and March 2008, regardless of the moon phase. Bats were captured for 7 consecutive hours with six mist nets, each of 12 m long and 2.6 m high, put at sunset during four nights per park. One net was used for low height captures, whereas two nets stacked on top of each other for an effective capture height of 7.5 m.

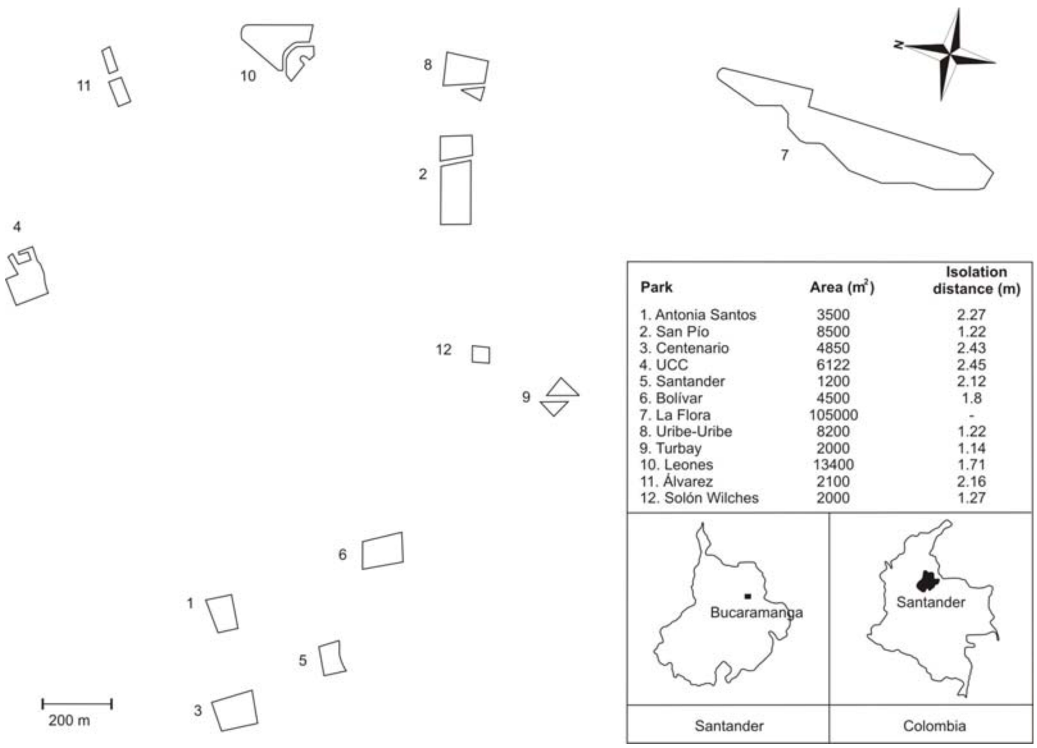

Fig. 1 Location and distribution of the urban parks within Bucaramanga, Santander

Each captured bat was identified and individually marked, drilling the wing with a numerical combination to avoid recapture; additionally sex, age, and reproductive condition were recorded. Bat nomenclature followed Simmons (2005), and Albuja and Gardner (2005). Bats were assigned to one of the following broad feeding guilds depending on their main diet: frugivorous, insectivorous, nectarivorous, and omnivorous

(Muñoz 2001). Vouchers were deposited in the Mammals Collection of Museo de Historia Natural of Universidad Industrial de Santander.

2.3. Measured variables

Four independent variables: park size, isolation, microhabitat, and urbanization, were measured at each park. Park size (m^2) was obtained from official records of the Municipality of Bucaramanga. The Escuela Ecológica La Flora park is a 105,000 m^2 forest patch located by southeastern Bucaramanga, was regarded as the most stand of the regional species pool (large island). La Flora Park is 8 fold bigger than the largest urban park and contains almost all the urban bat species recorded in Bucaramanga; the isolation was measured by means of straight-line distances (km) from each urban park to La Flora park in satellite imagery with Google Earth® version 4.2.

The following microhabitat variables were measured in 20 m radius circular plots centered in mist-netting system: number of stems with height of plants less than 11, 11-21, 21-31, 31-41, 41-51 m and more than 51 m; number of stems with diameter at breast height (d.b.h) less than 0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8, 0.8-1 m and more than 1 m; amount of light, number of streetlights, canopy openness in percentage, vegetal richness, and the soil park pavement proportion. The tree height (m) was measured by using a clinometer. The amount of light was measured according to the record of shutter aperture (f / n), keeping constant the shutter speed and ISO number with an SLR camera. Canopy openness percentage was estimated from a photograph taken one meter above the ground, this was modified to concave lens with Adobe Photoshop® and then analyzed with Winphot Version 5.0 (Steege

1996). The values for each microhabitat trait measured at each circular plot were averaged for the whole park.

Land use, amount of pedestrian, and traffic volume were used as measurements of urbanization around each patch (Municipality of Bucaramanga 2004): the proportion of land used for residential, commercial, and environmental protection (green zone) activities within each landscape scene, were determined by considering the variable land use from satellite imagery Google Earth® v. 4.2. The total area to measure these factors was a 0.3 km circular plot of ratio from park center.

The relative amount of pedestrian within the park was measured by counting the number of people (walking and sitting) visiting each park during the survey for a period of two minutes. Traffic volume, was the number of vehicles (parked or in movement) in three or four street around of the urban park during two minutes.

2.4. Statistical analyses

All the variables were transformed with Ln (x+1) or arcsine of square root (percents) to achieve normality before the statistics analyses. A principal component analysis was performed on the correlation matrix to reduce the number of variables associated to measures of microhabitat. Only those factors that explained a cumulative variance ≥ 70% were selected, and factor loadings were rotated with a varimax raw transformation. The scores of each park were used on the principal components selected for further analysis.

Since the area is strongly correlated (Pearson correlation matrices) with most independent variables and showed tolerance values less than 0.2, indicating multicollinearity and reducing the predictive power of the other independent variables, we decided to perform a simple linear regression contemplating only the relationship of the area on the dependent variables.

A multiple regression analysis with forward-stepwise selection procedures was used to determine relationships between bat richness and abundance, and the remaining independent variables: isolation, microhabitat, and urbanization. Most of values of tolerance were > 0.4 so that most variables had a small redundancy or large contribution to the regression. However, similar to area, some variables associated to measures of urbanization (e.g., protection use land and traffic volume) slightly exhibited multicollinearity. A resume measure of urbanization, urban index (UI) from Gerth and Chelsvig (2003) was modified and used in a subsequent regression analysis in order to reduce the multicollinearity effect on the models:

$$UI = \frac{1}{\left[\left(IC + RD + PU\right) * P * TV\right]} * 100$$

Where:

IC is the proportion of land use in commercial use, ***RD*** is that one of residential, and ***PU*** is the protective; ***P*** is the pedestrian and ***TV*** is traffic volume. High values in the UI reflect low levels of urbanization around urban park.

3. RESULTS

3.1. Species richness and abundance

The total effort was 125,798.4 m^2*h mist net from July 2007 to March 2008 (*sensu* Straube and Bianconi 2002). A total of 1,490 bats of 12 species belonging to families Phyllostomidae, Vespertilionidae, Molossidae, and Emballonuridae were captured (Table 1). The Phyllostomidae was the most diverse family, represented by eight species followed by the Vespertilionidae with two species and one species each from the families Molossidae and Emballonuridae.

Artibeus lituratus, *A. jamaicensis,* and *Glossophaga soricina* were typical and dominant on almost all sites because of their maximum relative abundance on all occupied parks: respectively, 72 %, 19 %, and 3 % of all bat numbers. The insectivore *Rhogeessa io*, *Myotis nigricans*, and *Molossus molossus* and the nectarivore *Lonchophylla concava* were recorded in less than half of the total number of parks. *Platyrrhinus helleri*, *Sturnira ludovici*, *Carollia perspicillata,* and *Saccopteryx leptura* were detected in an only park appearing to be the most restrictedly distributed.

The frugivorous bats were most abundant the guild (91.7%) present in all parks, followed by nectarivores (3.7%), insectivores (3.6%), and omnivores (1%).

Table 1 List and distribution of bat species recorded in urban parks of Bucaramanga city. F = Frugivore, N = Nectarivore, I = Insectivore and O = Omnivore

Family	Species	Guild	La Flora	UCC	Leones	San Pío	Uribe Uribe	Centenario	Bolívar	Antonia Santos	Álvarez	Turbay	Solón Wilches	Santander	Total
Phyllostomidae	*Phyllostomus discolor*	O	X	X											15
	Artibeus lituratus		X	X	X	X	X	X	X	X	X	X	X	X	1066
	A. jamaicensis		X	X	X	X	X	X	X	X	X	X	X	X	278
	Carollia perspicillata	F	X												3
	Platyrrhinus helleri		X												2
	Sturnira ludovici		X												17
	Lonchophylla concava	N	X						X						3
	Glossophaga soricina		X	X	X	X		X	X		X	X	X	X	52
Vespertilionidae	*Myotis nigricans*					X	X				X		X		6
	Rhogeessa io	I	X	X	X		X				X				15
Emballonuridae	*Saccopteryx leptura*				X										3
Molossidae	*Molossus molossus*			X	X				X						30
Total			362	155	120	114	95	143	177	79	45	65	53	82	1490

3.2. Microhabitat factors

The first four factors were selected from the PCA accounting for 75% of the variability in microhabitat matrix (Table 2). The first factor (PC1) was positively correlated with number of stems < 11 m height, number of stems < 0.2 m d.b.h., number of stems < 0.4 m d.b.h., and richness vegetal species, describing urban parks rich in plants species and with both, short-size and thin-diameter trees. PC2 was positively correlated with number of stems > 31 m height; this component could be considered as an indicator of urban parks with large-size tree (*tree height*). The third factor (PC3) was positively correlated with the number of stems 11 - 21 m height and number of stems 0.6 - 0.8 m d.b.h., reflecting parks with high number of both short-size and medium-diameter tree trunks. Finally, the fourth factor (PC4) was positively correlated with the shutter aperture, thus, PC4 explained urban parks with few light. We decide to exclude from the multiple regression analysis PC3, as its unclear interpretation could darken our results.

3.3. Influence of park area

Park area was associated with isolation distance (r = - 0.553 p = 0.005), urbanization (urban index: r = 0.493 p = 0.014; commercial land use: r = - 0.433 p = 0.035; protection land use: r = 0.689 p = 0.000; amount of pedestrian: r = - 0.580 p = 0.003) and with parks rich in vegetation with short-size and thin-diameter tree (PC1: r = 0.896 p = 0.000).

Table 2 Loadings of variables on first four principal components after varimax rotation on the microhabitat matrix. Bold values indicate high loadings on that axis

	Correlations			
Variable	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Number of stems < 11 m height	**0.829**	0.118	0.085	0.070
Number of stems 11 - 21 m height	-0.089	0.287	**0.881**	-0.130
Number of stems 21 - 31 m height	0.137	0.426	0.473	-0.365
Number of stems 31 - 41 m height	0.008	**0.930**	0.098	-0.220
Number of stems 41 - 51 m height	0.560	**0.763**	-0.089	0.181
Number of stems > 51 m height	0.183	**0.864**	0.137	0.029
Openness	0.300	-0.641	0.131	-0.444
Number of tree species	**0.693**	-0.098	-0.418	-0.364
Percentage of pavement	-0.497	-0.307	0.373	0.518
Number of stems < 0.2 m d.b.h.	**0.855**	0.026	0.118	-0.006
Number of stems 0.2 - 0.4 m d.b.h.	**0.928**	0.141	-0.018	0.100
Number of stems 0.4 - 0.6 m d.b.h.	0.446	0.031	0.510	0.137
Number of stems 0.6 - 0.8 m d.b.h.	0.127	-0.088	**0.930**	0.149
Number of stems 0.8 - 1 m d.b.h.	-0.333	0.654	0.518	-0.121
Number of stems > 1. m d.b.h.	-0.629	0.356	-0.340	0.028
Shutter aperture	0.296	-0.033	-0.002	**0.764**
Number streetlight	-0.199	0.107	-0.019	0.217
Eigenvalue	4.522	3.944	2.594	1.647
% Variance	26.598	49.799	65.057	74.745

The park size was strongly correlated with the bats assemblage, having a positive impact on both species richness ($r^2 = 0.482$ $F1,22 = 22.434$ $p < 0.0001$) and abundance ($r^2 = 0.507$ $F1,22 = 24.659$ $p < 0.0001$) (Fig. 2). A positive influence of the park area with lesser significance and correlation in the relationship abundance-area was found for both nectarivores ($r^2 = 0.167$ $F1,22 = 5.621$ $p = 0.027$) and insectivores ($r^2 = 0.129$ $F1,22 = 4.422$ $p = 0.047$), rather than to frugivores ($r^2 = 0.379$ $F1,22 = 15.02$ $p < 0.001$). The omnivore guild was not used in this and further analyses because of its small sample size.

3.4. Relationships among independent variables and urban bats

The multicollinearity effect was thought slight because of the low Pearson correlation coefficient ($r < 0.9$) between the variables involved, the model stability as a collinear variable was incorporated and eliminated, and the tolerance values. Therefore, the analysis went on without taking remedial measures, in spite the harmful impact of multicollinearity on the regression models.

The urbanization and microhabitat were related to urban bat assemblage among the three considered variables. The urbanization was a negative significant predictor in multiple regression models which included the species richness (Table 3); the commercial (strong influence) and residential uses, and traffic volume (strong influence) decreased the number species in urban parks. Overall abundance was associated only with the microhabitat (PC1) so urban parks rich in plant species with numerous small-size (< 11 m height) and thin (< 0.4 m d.b.h.) trees explained the increase in number of urban bats.

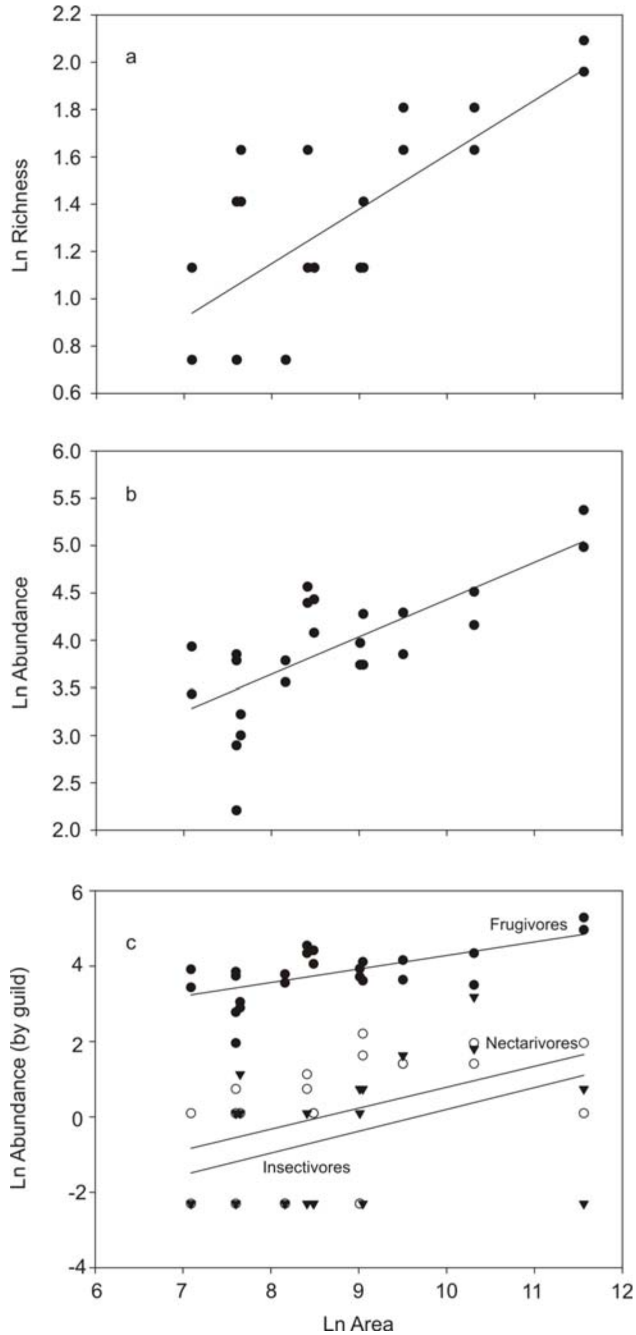

Fig. 2 Relationships between park area and urban bats in Bucaramanga city. a) Richness, b) Abundance, c) Abundance by guild (●) Frugivores, (○) Nectarivores, (▼) Insectivores

Table 3 Multiple stepwise regression models of species richness and abundance with independent variables (no using urban index). Significance level: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Dependent variable	***F***	***df***	***p***	***r^2***	**Urbanization**				**Microhabitat**
					Commercial	**Residential**	**Protection**	**Traffic**	**PC1**
Richness	13.343	6,17	0.000	0.763	-0.674**	-0.511*		-0.450**	
Abundance	7.037	4,19	0.001	0.512					0.659**
Frugivores	7.707	3,20	0.001	0.467	0.405*				0.532**
Insectivores	11.313	4,19	0.000	0.642	-1.333***	-0.662**	-0.558**		
Nectarivores	3.370	7,16	0.021	0.419		-0.963*			

The frugivores increased in urban parks with predominant commercial land use and parks mainly rich in plant species with small-size and thin-diameter trees (Table 3). Abundance of insectivorous bats was mainly affected by commercial activities; while the insectivores were negatively associated to commercial, residential, and protection ones together. Nectarivorous guild was negatively related with parks located in areas with high proportion of residential use.

Richness was mainly affected by the urban index, once included in the multiple regression analysis for reduce the multicollinearity, reflecting which urban parks with lower urbanization level increased richness (Table 4). This coincides with that above mentioned. A lesser degree parks plant rich (PC1) were associated significantly to the richness of bats. The microhabitat PC1 influenced mainly on the overall abundance as the previous regression analysis. The first factor of the microhabitat data was a relatively strong positive predictor of fruit-eater bats; insectivores were mainly influenced by urban index (positive relation), so urban parks with lower urbanization level and short-size trees (PC2 inverse) explained the abundance of this guild; and abundance of nectarivorous bats decreases as the light increases in the park.

4. DISCUSSION

Cosson et al. (1999) avoided to sample bats in forests during full moon, since decrease the bat activity (see Lang et al. 2006). However, some of our results show that abundance and richness of urban bats not respond this phenomenon, after controlling the variables independent of the urban park (abundance: ANOVA one-way $F_{3, 24} = 1.719$ $p = 0.189$; richness: ANOVA one-way $F_{3, 24} = 1.716$ $p = 0.190$).

Table 4 Multiple stepwise regression models of species richness and abundance with independent variables (using urban index). Significance level: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Dependent variable	F	df	p	r^2	Urban Index	Microhabitat		
						PC1	PC2	PC4
Richness	11.689	4,19	0.000	0.650	0.529**	0.380*		
Abundance	8.239	3,20	0.001	0.486		0.844***		
Frugivores	6.715	3,20	0.003	0.427		0.783***		
Insectivores	6.097	2,21	0.008	0.307	0.501**		-0.429*	
Nectarivores	2.857	3,20	0.062	0.195				0.403*

Similar to Brazilian cities (see Bredt and Uieda 1996; De Knegt et al. 2005; Perini et al. 2003) urban bats assemblage in Bucaramanga are dominated by a few abundant species (see biotic homogenization in Mckinney 2006). The high proportion of capture of *A. lituratus*, *A. jamaicensis,* and *G. soricina* were attributed to their generalist condition, benefited from the availability of roost and food (e.g., *Ceiba pentandra*, *Bauhinia* sp., *Mangifera indica,* and *Terminalia catapa*) in urban environments (Alberico et al. 2005; Bredt and Uieda 1996; De Knegt 2005; Esberárd et al. 1999; Perini et al. 2003). The remaining species of frugivorous bats, *P. helleri*, *S. ludivici,* and *C. perspicillata*, were restricted to La Flora park. *C. perspicillata* and *S. ludovici* prefer consume plants in second growth areas, such as *Piper* and *Solanum* (Sánchez 2001) found in La Flora park, but not often used in the arborization of streets and green areas in Bucaramanga. *Ficus* sp. and

Cecropia sp. are the preferred diet of *P. helleri* (Ferrell and Wilson 1991). *Ficus* sp. is commonly found in urban areas so that favor the presence of *P. helleri. P. lineatus* likely refuges in the city periphery, as *P. helleri* does, (e.g., La Flora park), including rural areas (Sánchez 2001) or, not concordantly to our results, in buildings and trees in urban areas (Bredt and Uieda 1996). *P. discolor* could benefit from the plants in the city (Perini et al. 2003) though it was scarsely captured in this work. That low number could be explained by lower population densities, more unstable population dynamics, and more extinction-prone for fragmentation than those at lower trophic levels, as Henle et al. (2004) predicted.

M. molossus was the most frequent insectivorous species, exploiting urban roost such as human constructs, as well as insects attracted by the streetlamps (Alberico et al. 2005; Avila-Flores and Fenton 2005). *R. io* was captured in several parks, but there is no record in other urban localities, unless Sampedro-Marín *et al.* (2007) were wrong when reported *R. tumida* in populated areas in Sucre (Colombia), provided that Genoways and Baker (1996) restricted this species to Central America. *M. nigricans* and *S. leptura*, were captured in less than half of the total number of parks, maybe by sampling bias (see Kalko 1998); despite their limited distribution, these species may use eaves and walls of buildings and houses (Alberico et al. 2005; Esberárd et al. 1999).

The guild of frugivorous bats was dominant, followed by nectarivorous, insectivorous, and omnivorous bats, in contrast to the insectivorous dominancy in other urban areas of Colombia (Alberico et al. 2005, Sampedro-Marín et al. 2007). This difference is probably due to those authors sampled close to anthropogenic structures, favorite roost sites for the insectivorous Molossidae and Vespertilionidae (Esberárd et al. 1999). Similar to other Neotropical bat assemblages (see Kalko 1998), frugivorous bats were the most diverse and abundant, probably coinciding with greater distribution and abundance of both food and refuges in Bucaramanga city. The low capture of Vespertilionidae, Molossidae, and Emballonuridae in the area of study could be due to sampling techniques bias (Kalko 1998).

The park area was the most important predictor of bat assemblage, being associated significantly with some independent variables, as expected among most of these variables due to their implicit associations produced by a typical fragmentation process, applied to urban environments (see Fahrig 2003; Mckinney 2002; Soulé et al. 1992). Significant association of area with the isolation, urbanization, and PC1 (i.e., plant richness) limited the results resolution when the independent variables were significant. Nonetheless, individual claims should be cautiously taken for each one since the results may indeed be area-dependent.

The positive influence of the area on richness and abundance of bats has been documented in fragmented forest habitat (e.g., Cosson et al. 1999; Gorrensen and Willig 2004). While comparative studies on bats in urban parks are lacking, our findings are largely congruent with results from studies on birds which have been also reported (see Chace and Walsh 2006; Fernández-Juricic and Jokimäki 2001). The impact of area on bats can be associated with at least two, likely interacting, factors: i) minimum species-specific area requirements because small parks might not offer a level of resources suitable for fulfilling requirements of most urban bat species. We found that this can be supported; significantly positive association between the area and PC1, suggests that increase in the park size enhance plant richness, as well as the insect availability increased proportionally to the park size (see Avila-Flores and Fenton 2005), and, therefore, increase in the park area can lead to greater resource availability and diversity for phytophagous and insectivorous bats; and ii) edge effect, being higher in small parks reducing the availability and quality of habitat in the inside of the parks by the influence of the urban matrix (Alberti et al 2001), as observed in urban birds (see Fernández-Juricic 2001).

Isolation distances of parks to large island do not appear to be important for bats. Data from recapture among parks confirm the relatively large dispersion distances of some species in the urban area (e.g., *A. lituratus* and *A. jamaicensis*, see Handley et al. 1991). Fernández-Juricic (2000b) noted the wooded streets are used by birds as vegetation corridors connecting urban parks within a matrix of concrete. Bucaramanga has an extensive network of wooded streets; we supposed that these could serve as bridges between parks and green areas, facilitating the movement of some bats in the inner city.

The two regression models were in most cases consistent in their responses. Insectivorous abundance added the correlation with microhabitat when the UI was included; similarly, nectarivores modified their answer when the same variable was included. The response consistency can vary because of the multicollinearity among the urban variables.

Characteristics related to urbanization influenced negatively species richness; however, caution should be take because most urban characteristics are correlated there is not certainty about the relative influence of each feature (exclusive of the other) on bats.

Decreasing richness from the increasing urbanization has been common in both tropical and temperate zones (Avila-Flores and Fenton 2005; Bredt and Uieda 1996; Chace and Walsh 2006; Hourigan et al. 2006; Kurta and Teramino 1992). In Bucaramanga, areas with high proportion for commercial activities coincide with high vehicle and people flow (downtown area), in contrast to residential areas that have a minor anthropogenic disturbance; usually these areas are subjected to drastic physical changes in available habitat (Mckinney 2002); pollution, erosion, reduction of native vegetation, and addition of new structural elements, such as non-native trees, ornamental vegetation, and human buildings (secondary fragmentation in Soulé et al.1992) (Alberti et al. 2001; Mckinney 2002), leading to the replacement of many species by a smaller number of successful species that thrive in urbanized habitats (Mckinney 2006).

The frugivore abundance had a bimodal increase in two mutually exclusive park scenarios: with high proportions of commercial land use and rich in plant species. Toward the downtown areas, *A. lituratus* and *A. jamaicensis,* generalists frugivores often caught were benefiting of the plant species used in the city (Bredt and Uieda 1996; De Knegt 2005; Perini et al. 2003). These bats utilize the *Terminalia cattapa* and *Mangifera indica* more abundant towards areas with a higher level of disturbance in the city, whereas the “habitat specialist” frugivores and lesser extent generalists were favored by parks with a high diversity of plant resources (PC1) toward the suburbs. Nevertheless, the urbanization effect on furgivores does not seem very consistent, because the response was not sustained in the regression model that includes urban index.

Insectivorous bats increases toward few urbanized parks in Bucaramanga city; these result should be taken cautiously because the maximum sampling height was 7.5 m biasing the capture technique and perhaps causing errors or inconclusive relationships between them and the independent variables. In spite, Poveda et al. (1988) observed *Molossus molossus* flying 15 m over the ground in rural Medina

(Cundinamarca), and Emballonuridae around a 10 m building by northern urban Bogotá (pers com.).

Kurta and Teramino (1992) coincide in the negative impact of the urbanized areas, offering roosts and food only a few species of insectivorous bats (Alberico et al. 2005). However, Avila-Flores and Fenton (2005) monitored increases in activity of insectivorous bats around disturbed environments by using acoustic methods.

Nectarivorous bats were negatively influenced by the residential uses about the urban parks; nectarivores such as *G. soricina*, with generalized food and habitat requirements (Alvarez et al. 1991; Lemke 1984) which might allow them to take advantage of the urban environment, are affected by urbanization because of the urban park littleness in highly residential areas, and consistently highly abundant in large patches (Gorrensen and Willig 2004).

The richness of plant species was the microhabitat variable that had a greater impact on assemblage; however, the amount of light in the urban park was also important at guild-level. Kurta and Teramino (1991) and Sánchez (2001) have suggested the positive relationship between vegetal diversity and bat assemblage. The species richness, overall abundance, and frugivore abundance were associated to the PC1, though this result may be area- or urban-dependent. Species of trees and shrubs, ornamentals and exotic used in arborization of sidewalks and parks, such as *Mangifera indica*, *Terminalia cattapa*, and species of *Ficus*, for example, attract frugivorous bats, and species of *Bauhinia* and *Calliandra*, attract nectar-feeding bats. The insectivorous bats can be also benefited by insect richness increased from plant richness (Haddad et al. 2001).

Nectar-bats were negatively associated to increasing light inside the parks. Elköf (2005) and Fure (2006) suggest that the visual cues are important for frugivorous and nectarivorous bats, because they can use brightness and spectral composition differences to find different food items. *G. soricina* can respond to light increments to avoid the disorientation by bright light while foraging in low light (Fure 2006; Winter et al. 2003). The artificial light seems to be the only light source affecting *G. soricina* in urban environments, as Lemke (1984) noted that the amount of moonlight had no detectable effect on its food habits.

Our results suggest that only a few species with flexible roost and food requirements can tolerate heavy levels of urbanization, dominate the urban landscape. Park size had a strong influence on the assemblage of bats; but changes in species richness and abundance in parks with the same area are explained by differences in the level of urbanization around and/or microhabitat inside the park. In general, urban development characteristics in Bucaramanga not allow identifying the effects of each of these variables, exclusive of the other, on bats; so that area, urbanization, and microhabitat can synergistically influence the urban assemblage. In a range of scenarios, small parks built in areas with high levels of disturbance and low-richness plant, maintain a fauna of bats poor both in number of species and individuals; on the other hand, large parks (e.g., > 10,000 m^2), in areas with low proportions of commercial and residential land uses, low traffic volume (e.g., < 30 cars by a period two minutes) and amount of pedestrian (e.g., < 20 pedestrian by a period two minutes), and high plant richness (e.g., seven plant species) can maintain a rich fauna, composed of species both generalists and habitat specialists. The isolation of the parks to La Flora Park does not seem to influence the bat assemblage. Bat movements along wooded streets and identification of differential responses to urbanization by bat species must be studied since they are essential to understand the processes involved in assemblage.

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