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Good neighbours: distribution of black-tufted marmoset (Callithrix penicillata) in an urban environment

Teixeira, B, Hirsch, A, Goulart, VDLR, Figueiredo Passos, L, Teixeira, CP, James, P and Young, R (2015) Good neighbours: distribution of black-tufted marmoset (Callithrix penicillata) in an urban environment. Wildlife Research. 42 (7). pp. 579-589. ISSN 1035-3712

ABSTRACT

Context

Primates are one of the most charismatic and widely studied vertebrate groups. However, the study of new world primates in green patches within urban areas has been neglected. Such primates have been viewed as a source of human-animal conflict; however, their ecological importance to urban ecosystems and their role in human well-being is poorly understood.

Aims

To understand factors both ecological and socio-economical affecting the distribution, density and group sizes of urban marmosets in a large Brazilian city (Belo Horizonte).

Methods

A map of vegetation cover and land use was produced and employed to investigate the distribution of marmosets. An online questionnaire was extensively publicized, which permitted the public to report the occurrence or not of marmosets near their residences. For sites with low salary levels and low internet availability, face-to-face interviews were conducted. Additionally, field surveys were conducted in 120 green areas identified by spatial analysis as potential areas of occurrence. The human population density, salary levels, green areas were posteriorly correlated to marmosets' distribution.

Key Results

Despite the urbanization and high human population density, green fragments within the city still housed marmoset groups. However, the presence of green areas did not always indicate primate presence. Group presence was significantly related to the size of parks or green areas and negatively related to built-up areas, and human density. Salary levels were related to more forested streets and possibly tolerance. Marmosets were classified as urban adapters (same density in the wild and urban areas).

Conclusions

The human-wildlife conflict with marmoset species was relatively low, due to marmoset avoidance of built-up areas. The interaction of marmoset species and city dwellers was mainly limited to borders of forest fragments, inside city parks and appeared to be human motivated.

Implications

This study shows the importance of public involvement in wildlife studies in urban environments; clarifying the interaction between city dwellers and wild species is essential to mitigate negative interactions.

Keywords: adaptation; *Callithrix penicillata*; geographic distribution; surveys; urban ecology; urban landscape

Introduction

Urbanization profoundly alters an area's biota (Williams *et al.* 2006; Garden *et al.* 2010). Notably, it often induces changes in local vegetation, modifies local climate and results in new food sources being available (Marzluff and Rodewald 2008). The direct and indirect effects of urbanization on wildlife can be to increase or decrease the viability of animal populations by affecting reproduction, survival, immigration and emigration (Waite *et al.* 2007; Marzluff and Rodewald 2008).

Neotropical cities often contain a wide diversity of animal species and many studies of their birds have been undertaken (Mörtberg 2001; Fernández-Juricic 2004; Chace and Walsh 2006; Parsons *et al.* 2006; Stagoll *et al.* 2010; Fontana *et al.* 2011; Ortega-Álvarez and MacGregor-Fors 2011). Despite the growing effort to reduce the gap of knowledge on urban wildlife and an increasing number of studies on birds and mammals, publication rates are still low (Magle *et al.* 2012). Urban mammals include commensal species as rats and mice that rely upon human resources; and synanthropic species, which are exploitative, but independent from human supplies (Baker and Harris 2007). There is evidence of marmosets (*Callithrix)* occasionally exploiting human resources (Goulart *et al.* 2010; Pontes and Soares 2005). However, primatologists have been given little attention to strictly urban environments despite a number of species being found within it throughout the world. For instance, rhesus macaques (*Macaca mulatta*) and hanuman langurs (*Semnopitheaus entellus)* are resistant to deforestation and urban alteration (Waite *et al.* 2007; Chauhan and Pirta 2010; Jaman and Huffman 2013).

Primates are responsible for one of the most intense human-wildlife conflicts (Dickman 2013). Nonhuman primates are often classified as crop-raiders causing substantial damage around African and Asian reserves (Lee and Priston 2005; Riley 2007). Crop-raiding also occurs with Neotropical primates, with species such as capuchin monkeys (*Cebus)* and marmosets, however, they often tolerated by the local community; they are seen as key species in their ecosystem or kept as pets (Lee and Priston 2005; McKinney 2011). Likewise, human proximity caused by habitat fragmentation and urbanization leads to human-primate interactions, driven by humans, ranging from the illegal pet trade to the consumption of primate bush meat (Duarte-Quiroga and Estrada 2003; Bowen-Jones and Pendry 1999). Surprisingly, even primates' similarity to humans causes a peculiar perception of them leading to conflicts (Hill and Webber 2010). Particularly in South America, interactions are usually started by humans and are mainly positive; the main concern from the general public has been about the risk of diseases transmission (Bicca-Marques 2009; Goulart *et al.* 2010; Rodrigues and Martinez 2014). Several initiatives have been taking place to protect neotropical primates in Brazil such as the Urban Monkeys Programme for howler monkeys (*Alouatta*) in south Brazil (Lokschin *et al.* 2007; Jerusalinsky *et al.* 2010), and Urban Marmosets Project in Brazilian Southeast (Goulart *et al.* 2010; Duarte *et al.* 2011; Duarte and Young 2011; Duarte *et al.* 2012). Moreover, marmosets have good cognitive abilities (Huber and Voelkl 2009) making them an interesting model species to study, as urban animals are already adapted to human-designed environments (Duarte *et al.* 2012).

Black-tufted marmosets (*Callithrix penicillata*) have the widest geographical distribution of their genus occurring in both natural and impacted areas (Mittermeier *et al.* 2013). Presently, their range overlaps several vegetation types such as the Brazilian biodiversity hotspots the Cerrado and Atlantic Forest (Vivo 1991; Myers *et al.* 2000), which includes major Brazilian cities. In the city of Belo Horizonte it is the only naturally occurring primate species (Municipality of Belo Horizonte 1992). *C. penicillata* reported home range sizes vary from 2.50 ha to 18.50 ha in natural environments (Fonseca and Lacher Jr. 1984; Miranda and Faria 2001) and between 1.72 ha to 6.89 ha in urban environments (Santos 2006; Duarte 2007). Its population density ranges from 0.09 indiv./ha to 1.8 indiv./ha in the wild (Ruiz-Miranda *et al.* 2006; Fonseca and Lacher Jr. 1984) and no data are available for the urban environment. Group size is from three to 15 individuals with a mean of 6.86 (SE 1.41) indiv./group in a natural environment (Fonseca and Lacher Jr. 1984; Miranda and Faria 2001; Silva and Faria 2002; Ruiz-Miranda *et al.* 2006); again no data are available for the urban environment.

The extent to which this species is adapted to cities is unknown. Some behavioural characteristics indicate how black-tufted marmosets adapt to urban environments. They are able to cope with common impacts from urban environments (e.g. noise pollution), and use man-made structures, for example, they travel between green patches using electricity transmission cables (Goulart *et al.* 2010; Duarte *et al.* 2011, Rodrigues and Martinez 2014). In absence of natural predators in urban environments, the proximity of food sources is crucial for home range size and the choice of sleeping sites (Pontes and Soares 2005). Despite this, marmosets are able to cope with non-native predators such as domestic cats and persist in cities (Duarte and Young 2011). Gum-feeding specializations and their behavioural plasticity allow this species to occur in adverse habitats, such as the urban one (Stevenson and Rylands 1988; Mittermeier *et al.* 2013; Duarte *et al.* 2012). While the species possesses dental adaptations for tree gouging, it can feed on many dietary items. In urban parks, they take advantage of easy available diet, by begging for food from visitors (Duarte *et al.* 2012) whose attitudes towards them are mainly positive (Leite *et al.* 2011; Rodrigues and Martinez*l.* 2014). Although, it is not known how their group sizes compare to those encountered in natural environments nor the factors that may affect their distribution in the urban environment.

Animal species can be classified into one of three categories in relation to their adaptation to the urban environment: adapters, avoiders and exploiters (McKinney 2006). Rats (*Rattus* sp.) and house sparrows (*Passar domesticus*), both urban exploiters, are perhaps the most well-known of urban species, they live at densities higher than those found of their wild counterparts. Urban adapters are species that live at the same density in the urban environment and their natural habitat; examples include meso-predators such as red foxes (*Vulpes vulpes*) and birds such as crows (Corvidae). Finally, urban avoiders are species that live at a much lower density in the urban environment than in their nature habitat; examples include brown bears (*Ursus arctos*) and elk (*Cervus canadensis*) (McKinney 2006).

Questions about the primates' adaptability to urban environments are, increasingly, important since the Neotropical region is experiencing rapid urbanization, which results in natural habitat loss and fragmentation (Wilson and Forman 1995), but perhaps it also creates opportunities for some species. Furthermore, high human population densities increase the intensity of urban impacts, displacing completely those native species not adapted to human disturbances (Pauchard *et al.* 2005). In Brazil, for example, more than 85% of the human population lives in large urban centres and the trend is for this number to increase (IBGE 2010).

The aims of this study were twofold: to investigate how well a small primate species, the black tufted marmoset (*C. penicillata*), adapts to the urban environment through measures of group size and density (i.e. Adapter x Exploiter paradigm); and to investigate the factors (both ecological and socio-economic) that affect its spatial distribution in such an environment.

Materials and Methods

Study site

The city of Belo Horizonte is situated in the transition zone of the two Brazilian hotspot biomes, the Cerrado and the Atlantic Forest (Myers *et al.* 2000; IBGE 2010); however, the environment is highly altered due to urbanization and introduced vegetation. It is limited by latitudes 19°47'S and 20°04'S, longitudes 43°52'W and 44°04'W, in southeast Brazil. The city occupies an area of 33 151 hectares with approximately 2.40 million inhabitants (IBGE 2010). The municipal area is divided into nine administrative regions: Centre-South, Northeast, North, Northwest, West, East, Barreiro, Pampulha, and Venda Nova (Municipality of Belo Horizonte 2009a; Municipality of Belo Horizonte 2009b). Each administrative region has different socio-economic (i.e. human population density and salary levels) and environmental (i.e. vegetation cover and land use) characteristics. All regions have fragments of natural habitats with different sizes and surrounded by built-up areas where endemic marmoset groups are to be found.

Field Surveys

Group counts were undertaken within the city's boundaries in 120 public and private urban parks and 'green areas' to investigate the presence and group sizes of *C. penicilata*. These areas were chosen by spatial analysis (see *Map of Vegetation Cover and Land Use*), when their size was ≥1.5 ha, which may represent an area sufficient to support a group of marmosets.

During the field surveys two or three observers walked slowly (approximately 1 km/h) along all the existing trails and the border of the sampled green areas, always between 07:00-18:00 hrs when marmosets are active (Stevenson and Rylands 1988). All available trails were sampled several times, as marmosets can be cryptic in their habits (Stevenson and Rylands 1988), repeating the visit to each green area from up to ten times depending on the area's size (more visits to larger sites), totalling from 20 to 960 min per site.

At intervals of 10 min, playback sessions using *C. penicillata* vocalizations were used to facilitate the detection of individuals (Bezerra *et al.* 2010). Once a group was seen or heard, its location was marked with a GPS device (GPS Garmin Etrex Vista®), accepting an Estimated Position Error (EPE) equal or less than 15 m. When the group was seen, the number of individuals was counted, their age category (i.e., infant, juvenile or adult) and sex noted. Generally, 20 minutes were spent with each group, during which time note of any physical characteristic of the group members was made, such as a mark or wound on the body, to avoid repeated counting of a group. The data obtained were used to calculate the density of marmosets in the city and compare with group densities in the wild. Consequently, we classified the marmoset's adaptation to urban environments as exploiters, adapters or avoiders, according McKinney (2006).

Questionnaires

To obtain broader information about the geographical distribution of *C. penicillata* in the private gardens and streets of Belo Horizonte, surveys were conducted with the city dwellers through informal interviews, electronic online questionnaires and formal interviews. First, between January 2008 and January 2009 informal semi-structured interviews were applied to residents of the same places visited to survey *C. penicillata*, and this information was georeferenced with the aid of a GPS device. Second, a structured electronic online questionnaire was published at the same time period with the goal of asking people to respond, spontaneously, about the occurrence or not of *C. penicillata* in their street (the online questionnaire was divulged through newspaper, magazine, radio and television articles and by emailing associates). Questionnaires and interviews were as brief as possible, aiming to map possible occurrences of marmosets in Belo Horizonte and to incentive voluntary participation. Both were formed as follows. Electronic forms contained a query (Have you seen a marmoset in your block?) with a marmoset picture for clarification and two possible answers: Yes or No. Also, fields to fill in the street name and number, zip code and neighbouring streets on the right and on the left side. In Brazil, houses are numbered in accordance with the Linear Metric System, where the residence receives a number according to its distance (in meters) from the beginning to the end of the street. Unfortunately, sometimes these numbers are allocated unevenly. For this reason, the name of the first perpendicular street (corner) on the right and on the left was requested; to obtain a greater precision when the information provided by the residents was georeferenced. Third, between June 2008 and January 2009, 141 interviews with the citizens of Belo Horizonte were conducted, using the same questions as in the electronic online questionnaire. These questionnaires targeted people from poorer neighbourhoods, who may have only limited access to the Internet. In the second and third case, the first street on the right and on the left were located through Google Earth 3.0 (Google 2009) and through GPS Trackmaker® Professional v. 4.2 (Ferreira Jr. 2008) to georeference places informed by the respondents with or without the occurrence of *C. penicillata*.

These spatial data were then joined with the surveys in parks and green spaces in the data analyses to provide a more complete picture of marmoset distribution in the city of Belo Horizonte. To avoid bias, socio-economic data was not obtained from questionnaires, but collected from Brazilian Institute of Geography and Statistics (IBGE) and posteriorly related to geographical analysis.

Cartographic base

Six cartographic bases in vector format were used: municipal boundaries, cities, urban areas, road network, hydrographical net and contour lines (IBGE 2003; GeoMinas 2001); topography with 90 m of spatial resolution (CGIAR-CSI 2004); administrative regions of Belo Horizonte, urbanized area, streets and avenues, squares and urban lots (Municipality of Belo Horizonte 2008); and a map of

Vegetation Cover and Land Use (MVCLU), green areas along the streets and green areas within the blocks (Assis 2008). For the entire cartographic base we adopted the UTM (Universal Transverse of Mercator) projection, centred on the Zone K23 and on the SAD69 (South American Datum 1969).

Map of Vegetation Cover and Land Use (MVCLU)

The map of vegetation cover and land use (MVCLU) was prepared by Assis (2008) together with the Assistant Secretary for the Environment of Belo Horizonte (SMAMA), using five QuickBird satellite images of 11 bits, with five bands and spatial resolution of 2.44 m/pixel, from the dates October 10, 2005, June 14, 2006 and July 15, 2006.

Before the interpretation and classification of the QuickBird images models to assist in this process were generated, such as the NDVI (Normalized Difference Vegetation Index) and DEM (Digital Elevation Model). To generate the MVCLU the technique of contextual interpretation and classification of Bayesian inference was adopted, using the algorithms of Mahalanobis distance and maximum likelihood classifier (Assis 2008). The 10 classes of vegetation cover and land use were the same as used by Assis (2008); although the names of some classes were modified (Table 1) to better meet the objectives of our study with arboreal primates (Fig. 1 and Table 2).

Assis (2008) used object oriented modelling techniques, based on NDVI, to verify the occurrence of vegetated areas along the streets and within the blocks. Continuing on from this stage, a more detailed spatial overlap between the MVCLU and other layers of information was performed, such as streets, squares and urban lots obtained from Municipality of Belo Horizonte (2008). Thereafter, the classes of 'green areas along the streets' and 'green areas within the blocks' were obtained, both containing information from the Classes 01, 02, 03, 04 and 05 described by Assis (2008) in Table 1.

Data Analyses

Spatial Analyses

All spatial analyses were generated through the Spatial Analyst Module of ArcGIS (ESRI 2002), following previously established techniques (Hirsch 2003; Teixeira *et al.* 2006; Coelho *et al.* 2008; Landau *et al.* 2008). As a reference, the area of the polygon of Belo Horizonte municipality was considered equal to 33 151 ha or 331.51 km² (IBGE 2003; Municipality of Belo Horizonte 2008), although this value is different from that calculated for the maps of 'green area along the streets' and 'green areas within the blocks'. This difference occurred due to the accuracy associated with scanning the original maps and when they were converted from vector to raster format or vice versa.

The absolute area (ha) that each of the 10 classes of vegetation cover and land use occupies in each of the nine administrative regions of Belo Horizonte was calculated, and then the regional values were summed to obtain the total of the entire municipality. Furthermore, the absolute area (ha) occupied by the grouped classes of 'green areas along the streets' and 'green areas within the blocks' were calculated separately, since these classes were already pre-established by Assis (2008) and contained merged information from classes 01, 02, 03, 04 and 05, which were impossible to separate (Table 1).

Another technique employed was to generate buffer zones with a radius of 100 m around the points where the questionnaire answers were obtained and around the polygon of the areas visited in the field surveys. The radius value of 100 m was chosen because it approached the size of a city block (100 x 100 m). Then, the absolute area (ha) of each class of vegetation cover and land use for all of the 614 electronic questionnaires responses was calculated. The same was done by type of record at the places visited in the field (N = 120). When the points of the questionnaire answers or the places visited in the field fell within 200 m of each other, the buffer zones were collapsed and the adjacent areas were summed and treated as a single buffer zone. For this reason, the number of buffer zones generated is fewer than the original number of sampled areas. In other words, this resulted in 154 buffers zones with answers 'Yes' and 268 with answer 'No'. Thus, there remained 43 visited places with the presence of *C. penicillata* and 61 places without its presence (Fig. 2a and 2b).

Statistical Analyses

The classes of vegetation cover and land use observed within areas (i.e. buffer zones) where the questionnaire answers were obtained and around the surveyed areas were analysed by Chi-square tests. To meet the assumptions of the test, when a category had <5 counts in a cell, it was eliminated from the analysis. Therefore the degrees of freedom are not always the number of categories minus one. In the case of statistically significant results ($P<0.05$), standardised residual analyses were conducted to determine where significant differences were occurring (Siegel and Castellan, 1988).

In order to verify which variables are determinant to the occurrence of marmosets in an urban environment we employed a Generalized Linear Model (GLM) with a negative binomial distribution and a logarithmic link function. The response variable was the count of individuals verified by 43 field surveys. In a full model, we included the following six predictors: size of parks or green areas, human density and salary levels at the nine administrative regions, and the proportion of forested, open, and urban areas. We used pairwise interactions to eliminate predictors based on AIC numbers (Akaike's information criterion), using a statistical significance level of 0.05. The three following explanatory variables were selected: size of parks or green areas; human density; and the proportion of urban areas. The overall model fit was tested with the Likelihood ratio test, which supported a negative binomial model ($P<0.05$).

To investigate further effects of socio-economic factors on marmoset distribution and spatial composition we checked if there is a correlation between Salary Levels and the proportion of green areas along streets employing the Spearman rank correlation test.

Statistical analyses were performed using R (R Core Team 2014), the package "MASS" (Venables and Ripley 2002), and Minitab 16.

Ethical note

There was no ethics committee established at the Pontifical Catholic University of Minas Gerais at the time of this research. Despite this, we had the consent from all respondents and complied with all respective Brazilian laws.

Results

Marmoset group sizes and densities

Of the 120 places visited, *C. penicillata* were seen in 43 surveyed areas and vocalizations were heard in a further five locations (Fig 2a, b). A total of 90 groups consisting of 247 adults, 156 juveniles and 69 infants plus 53 undefined individuals (due to only obtaining a brief view) were observed. Green areas with marmosets had one to 16 groups, with a mean of 2.09 (SE ± 0.45) groups per site. An average group was composed of 2.73 (SE ± 0.21) adults, 1.74 (SE ± 0.181) juveniles, and 0.79 (SE ± 0.43) infants. Each group had a mean of size of 5.83 (SE ± 0.43) indiv./group and a mean density of 3.14 (SE ± 0.59) indiv./ha.

Factors affecting marmoset spatial distribution

Regarding the marmoset distribution reported from questionnaires, we obtained a total of 935 respondents, in which 614 where correctly filled in and able to be used. The occurrence of marmosets reported showed that the classes of vegetation cover and land use in the buffer zones of the places with the answers 'No' (i.e. absence) were significantly different from the expected values (X^2 = 34.90; df = 3; P<0.001). The standardized residual analysis shows that 'forested areas' and 'open areas' occurred less than expected where the answers were 'No' (P<0.05). In contrast, the class 'Urban Area' was proportionally higher at places where the answers were 'No' (P<0.05). Consequentially, the presence of marmosets from questionnaires corroborates the association of marmosets with green areas.

Furthermore, the proportion of classes of vegetation cover and land use of each administrative region had no influence on 'Yes' (i.e. presence) or 'No' (i.e. absence) responses regarding the occurrence of *C. penicillata*. No administrative region had correlations for forested areas and 'Yes' (N = 9; r_s = -0.377; P>0.05) or 'No' (N = 9; r_s = -0.067; P>0.05), in open areas and 'Yes' (N = 9; r_s = 0.151; P>0.05) or 'No' (N = 9; r_s = -0.067; P>0.05), and urban areas and 'Yes' (N = 9; r_s = 0.176; P>0.05) or

'No' (N = 9; r_s = -0.067; P>0.05). Thus, marmoset groups were evenly distributed in green areas in the city.

The best negative binomial regression model inferring the variation in abundance of *C. penicillata* in an urban environment resulted in three significant predictor variables: constructed areas in the buffer zone of marmoset occurrence, size in hectares of parks or green areas in the buffer zone, and human density at the administrative region of the surveyed area. Non-significant (P>0.05) variables excluded from the full model based on AIC values were: Salary levels, Forested and Open areas in the buffer zone. The number of individuals tends to decrease with the increase of constructed areas (95% CI: -0.001 – -0.0005) and with the increase of Human Density (95% CI: -0.0003 – -0.0001). In contrast, the abundance of marmosets is positively related to the size of parks and green areas (95% CI: 0.0145 – 0.0253) (Table 3).

Effect of socio-economic factors on marmoset spatial distribution

Concerning socio-economic factors, there was no effect of Salary Levels on marmoset abundance.. However, the human density had a negative effect on marmoset distribution (Table 3). Despite the fact of no influence of wage, Salary Levels in each administrative region had a strong positive correlation with the proportion of green areas along its streets (N = 9; r_s = 0.917; P<0.01), which represent a factor impacting on marmoset spatial distribution.

Discussion

C. penicillata is on an avoider-exploiter continuum in our study site and its place on this continuum depends upon local resources, principally trees. Superficially our study species appears to be an urban exploiter because it is found at densities higher than in the wild environment (McKinney 2006). However, this ignores the fact that if there are no trees in an urban area the probability of encountering the species is low (see Figures 1, 2a and 2b). Thus, if only treeless areas of the city had been studied the conclusion would be that our study species was an urban avoider. Finally, if a mean density for the city was used the conclusion would, probably, be that our study species was an urban adapter. In fact, what the data show is that the idea of three categories of animals in relation to urban adaptation does not always function (McKinney 2006): probably many animal species are on an avoider-exploiter continuum and where they sit on this depends upon the distribution and quantity of key resources at a local level.

Both the presence and size (increasing) of green spaces/parks positively affected the distribution of *C. penicillata* in the urban environment of Belo Horizonte, whereas human density and urban areas had negative impacts. The quality of an arboreal patch has a significant impact on the number of marmosets present in a park or green area. Thus, even in an urban environment, this primate shows a strong affiliation with larger forested areas, why it does not use three dimensional structures in the city to substitute for trees is unknown (see Duarte *et al.* 2012). There has been an explosion of research focusing on how the marked ecological differences between rural areas and urban areas influence the traits of conspecific populations (Evans 2010). Relatively few studies have investigated correlations between the layout of the urban matrix and biological diversity (Hodgkison 2005). Further investigations are needed, but observations suggest the importance of trees as sleeping sites (Duarte and Young 2011) where there is a trade-off between protection against predators and access to food sources (Pontes and Soares 2005).

The remaining areas of natural and semi-natural vegetation in cities are essential for the maintenance of biodiversity (Mörtberg and Wallentinus 2000). In addition, lightly managed or unmanaged urban parks and recreation areas can retain large remnants of sub-natural habitats serving as important contributors to the conservation of native biodiversity within a large metropolis (Shwartz *et al.* 2008). As was demonstrated through our research, the size of parks and green areas visited are positively influencing the geographic distribution of *C. penicillata* in Belo Horizonte. This alone is a good reason to make architects and urban planners take into account the kind of urban space, which exists around established and planned natural areas before the construction of new buildings (Marzluff and Rodewald 2008).

Birds, mammals and terrestrial invertebrates are the most studied taxa in urban environments (Luniak and PisarskiI 1994, Magle *et al.* 2012). Studies with vertebrates showed that different species could have different responses to the urbanization process (McKinney 2006). While birds as mobile species are more sensitive to variations in the vegetation structure, mammals seems more sensitive to local disturbances (Croci *et al*. 2008). The size of fragments has been shown in our study as the principal factor to increase the marmoset abundance, which can be also critical to other local species; however, even small patches of woodlands are important refuges for different urban species (Soga *et al.* 2014). The fact that urbanization influences species densities is unsurprising, but the nature of a species' response to urbanization can vary spatially (Evans 2010). Ecological studies have provided ample evidence that different species perform diverse ecological functions, for example, pollination, dispersal, and disturbance (Hooper *et al.* 2005; Alberti 2008). Species that use similar resources may exploit different ecological scales; this is a form of ecological resilience as function is reinforced across scales (Peterson *et al.* 1998).

Our study confirms the suggestion of a previous study relating to marmosets in Belo Horizonte (Goulart *et al.* 2010) that a regional scale of analysis of land cover in relation to marmoset presence is too coarse a level due to the heterogeneous nature of regions. For example, within the same region neighbourhoods of low density housing can be adjacent to densely packed 'shanty towns' (Goulart *et al.* 2010). Salary Levels did not show any clear influence on the distribution of *C. penicillata*, this was previously found in relation to complaints made about them by the public (Goulart *et al.* 2010). But again this may also reflect the heterogeneous mix of social classes at the regional level in the city. The application of a fine scale is desirable in urban wildlife studies and is a key factor to understand the influence of socio-economic variables in animal behaviour and distribution.

The use of spatial analysis to select potential sites in an urban environment has been found suitable to find marmoset groups and might be employed for other species. As a limitation, this approach might exclude sporadic sites or green areas used as corridors between fragments. However, public involvement was a reasonable solution to avoid sampling problems from spatial analyses. In fact, the involvement of citizens has been shown successful in many ecological studies (Silvertown 2009). This is especially relevant to the study of urban environments and to improve the assessment of non-wild areas (Dickinson *et al.* 2010). Internet tools are a potential communication channel and crucial to involve the public on urban wildlife studies (Mulder *et al.* 2010). Although, internet access is widespread in Brazil, it might be limited in poor areas. Using informal interviews was a suitable way to tackle this limiting factor, which allowed consistent sampling throughout the city. How the marmosets came to adopt an urban lifestyle is an interesting question: did they invade the city looking for opportunities or were they swallowed-up by urban development. Old maps and satellite images of the city suggest they were swallowed up by urban expansion; however, some of the city's borders do connect to their natural habitat (Fundação João Pinheiro 1997; IBGE 2003).

With the results obtained here, it will be possible to estimate the potential distribution of *C. penicillata* in the urban landscape of Belo Horizonte. Thus, we will be able to propose how to implement a management program for the conservation of green urban areas, not only targeting *C. penicillata* in Belo Horizonte, but also other mammal species living in large metropolitan areas, such as opossums (Souza *et al.* 2012), squirrels, and potentially others. The methodological approach used in our study, based on complementary techniques (field surveys, electronic online questionnaires, interviews, map of vegetation cover and land use, georeferenced data and spatial analysis) could be adapted for research on other species of arboreal/terrestrial vertebrates found in urban environments around the world.

Biodiversity conservation is a response to anthropogenic impacts on ecosystems, and as such depends on a good understanding of the motivations and drivers of human behaviours that lead to such impacts (Fuller and Irvine 2010). Implementing solutions to the biodiversity crisis will depend on interdisciplinary research efforts as well as systems of implementation that can trade off ecological value and benefits to human wellbeing (Polasky *et al.* 2008). Ecology, sociology and geography of the landscape are areas that should be linked to a deeper understanding of the processes occurring in urban areas.

Human-wildlife conflict with marmoset species is relatively low, due to marmoset avoidance of built-up areas. The interaction of marmoset species and city dwellers was mainly limited to borders of forest fragments, inside city parks and appeared to be human motivated. *Callithrix pencillata* on the urban avoider-exploiter continuum are more towards the exploiter end when in areas of a city that contains sufficiently large forest fragments, and the avoider end in areas without forest fragments. Thus, their classification is location dependent, and varies according to the quantity and distribution of urban forest fragments at a local level.

Acknowledgements

The authors are grateful to Municipal Prefecture of Belo Horizonte and to Assistant Secretary for the Environment of Belo Horizonte (SMAMA) for their logistical support. BT was supported by a CAPES postgraduate scholarship during this study. VDLRG was in receipt of a CAPES postgraduate scholarship Proc. 1213-13-0. LFP was in receipt of a CAPES postgraduate scholarship Proc. 6060-13-7. RJY received financial support from FAPEMIG and CNPq. We are grateful to three anonymous referees for their comments on this manuscript.

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Figures

Fig. 1. Reclassified map of vegetation cover and land use (MVCLU) of Belo Horizonte municipality, Brazil modified from Assis (2008).

Fig. 2. Areas sampled to obtain the geographic distribution of *Callithrix penicillata* in Belo Horizonte, Brazil. a) Green areas visited during the field survey, and b) Places from which answers to the questionnaires were obtained.

Tables

Table 1. Description of the classes of vegetation cover and land use of the municipality of Belo Horizonte, Brazil adopted by Assis (2008).

Table 2. Description of the regrouped classes of vegetation cover and land use of the municipality of Belo Horizonte, Brazil adopted in this study, modified after Assis (2008) (see Table 1).

Table 3. Negative binomial regression model for abundance of black-tufted marmoset (*Callithrix penicillata*) in an urban environment.