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

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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 increase understanding of both ecological and socioeconomical factors 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 publicised, 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 and green areas were posteriorly correlated with marmoset distribution.

Key results. Despite the urbanisation 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 utilisers.

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

Implications. This study showed 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.

Additional keywords: adaptation, geographic distribution, surveys, urban ecology, urban landscape.

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Introduction

Urbanisation 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 urbanisation 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 there have been many studies of birds in these environments (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 such as rats and mice that rely on 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 (Pontes and Soares 2005; Goulart *et al*. 2010). However, primatologists have given little attention to strictly urban environments, despite several species being found within these environments 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 2012). Non-human 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 are often tolerated by the local community because they are seen as key species in this ecosystem or kept as pets (Lee and Priston 2005; McKinney 2011). Likewise, human proximity as a result of habitat fragmentation and urbanisation leads to human–primate interactions, driven by humans, ranging from the illegal pet trade to the consumption of primate bush meat (Bowen-Jones and Pendry 1999; Duarte-Quiroga and Estrada 2003). Surprisingly, even primates' similarity to humans may cause a distorted 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 for the general public has been the risk of disease transmission (Bicca-Marques 2009; Goulart *et al*. 2010; Rodrigues and Martinez 2014). Several initiatives have taken place to protect neotropical primates in Brazil, such as the Urban Monkeys Program for howler monkeys (*Alouatta*) in southern Brazil (Lokschin *et al*. 2007; Jerusalinsky *et al*. 2010), and Urban Marmosets Project in south-eastern Brazil (Goulart *et al*. 2010; Duarte *et al*. 2011, 2012; Duarte and Young 2011). Moreover, marmosets have a good cognitive ability (Huber and Voelkl 2009), making them an interesting model species to study, with urban animals already having 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 affected areas (Mittermeier *et al*. 2013). Presently, their range overlaps several vegetation types such as the Brazilian biodiversity hotspots the cerrado and Atlantic forest (de Vivo 1991; Myers *et al*. 2000), including major Brazilian cities. In the city of Belo Horizonte, *C. penicillata* is the only naturally occurring primate species (Municipality of Belo Horizonte 1992). *Callithrix penicillata* home-range size varies from 2.50 ha to 18.50 ha in its natural environment (da Fonseca and Lacher Jr 1984; Miranda and Faria 2001) and between 1.72 ha and 6.89 ha in an urban environment (dos Santos 2006; Duarte 2007). Its population density ranges from 0.09 to 1.8 individuals per hectare in the wild (Ruiz-Miranda *et al*. 2006; da Fonseca and Lacher Jr 1984); no data are available for urban environment. Group size is from 3 to 15 individuals, with a mean of 6.86 (s.e. 1.41) individuals per group in a natural environment (da Fonseca and Lacher Jr 1984; Miranda and Faria 2001; da Silva and de Faria 2002; Ruiz-Miranda *et al*. 2006); again no data are available for urban environment.

The extent to which this species is adapted to cities is unknown. However, some behavioural characteristics indicate how black-tufted marmosets can 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 the absence of natural predators in an urban environment, 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 can persist in cities (Duarte and Young 2011). Gum-feeding specialisations and behavioural plasticity allow this species to occur in adverse habitats, such as in an urban environment (Stevenson and Rylands 1988; Mittermeier *et al*. 2013; Duarte *et al*. 2012). Although the species possesses dental adaptations for tree gouging, it can feed on many dietary items. In urban parks, it takes advantage of easily 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 2014). However, 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 the following 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 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 they do in their nature habitat; examples include brown bears (*Ursus arctos*) and elk (*Cervus canadensis*) (McKinney 2006).

The terminology of avoider, adaptor and exploiter in relation to urban animals has recently been called into question (Fischer *et al.* 2015); this new study elucidated the problems with each of the previous three categories. Urban avoiders may be strict avoiders because of perception of poor habitat quality or in low abundance as a result of poor resource availability. The term urban adaptor was criticised for considering only population density and not considering population dynamics (e.g. growth), which may be affected by processes such as ecological traps or despotic distributions. In this context, urban exploiters and adapters could be considered to be members of a single category because their density is due to local resource availability in the urban environment. Fischer *et al.* (2015) proposed three new categories, namely, urban avoiders, urban utilisers and urban dwellers, to define a gradient of responses of animals to urban environments. Urban avoiders are species normally only found within natural environments, but those environments may form part of an urban matrix. Urban utilisers are species that have positive population growth rates in urban environments but that do not breed in them. Finally, urban dwellers are species that have positive population growth rates in urban environments and that breed in them.

Questions concerning the adaptability of the primates to urban environments are, increasingly, important, because the neotropical region is experiencing rapid urbanisation, which results in a loss and fragmentation of natural habitat (Wilson and Forman 1995), but may also create opportunities for some species. Furthermore, high densities of human population increase the intensity of urban impacts, completely displacing those native species that are not adapted to human disturbances (Pauchard *et al*. 2006). 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 the present study were two-fold, namely, 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 × exploiter paradigm (McKinney 2006) or utiliser × dweller paradigm (Fischer *et al*. 2015)), and to investigate the factors (both ecological and socioeconomic) 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 as a result of urbanisation and introduced vegetation. It is limited by latitudes 19°47′S and 20°04′S, and longitudes 43°52′W and 44°04′W, in south-eastern Brazil. The city occupies an area of 33 151 ha and has ~2.40 million inhabitants (IBGE 2010). The municipal area is divided into the following nine administrative regions: Centre-South, North-east, North, North-west, West, East, Barreiro, Pampulha and Venda Nova (Municipality of Belo Horizonte 2009*a*, 2009*b*). Each administrative region has different socioeconomic (i.e. human population density and salary level) and environmental (i.e. vegetation cover and land use) characteristics. All regions have fragments of natural habitats of different sizes surrounded by built-up areas, where endemic marmoset groups are to be found.

Field surveys

Group counts were undertaken within the city boundaries in 120 public and private urban parks and green areas, so as 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 (~1 km h^{-1}) along all the existing trails and the border of the sampled green areas, always between 0700 hours and 1800 hours when marmosets are active (Stevenson and Rylands 1988). All available trails were sampled several times, because marmosets can be cryptic in their habits (Stevenson and Rylands 1988), repeating the visit to each green area from up to 10 times, depending on the size of the area (more visits to larger sites), totalling from 20 to 960 min spent per site.

At intervals of 10 min, playback sessions using *C. penicillata* vocalisations 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®, USA), accepting an estimated position error (EPE) equal or less than 15 m. When the group was seen, the number of individuals was counted, and their age category (i.e. infant, juvenile or adult) and sex noted. Generally, 20 min were spent with each group, during which time a 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 to compare with group densities in the wild. Consequently, we classified the marmoset adaptation to urban environments as exploiters, adapters or avoiders, according to McKinney (2006), or as dwellers, utilisers or avoiders, according to Fischer and colleagues (2015).

Questionnaires

To obtain broader information about the geographical distribution of *C. penicillata* in the private gardens and streets of Belo Horizonte, surveys were conducted through informal interviews, electronic online questionnaires and formal interviews with the city's inhabitants. First, between January 2008 and January 2009, informal semi-structured interviews were applied to residents of the same places as 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 encourage voluntary participation. Electronic forms contained a query (i.e. Have you seen a marmoset in your block?), with a marmoset picture for clarification, and the option of two possible answers, namely, yes or no. Participants were also asked to fill in the street name and number, zip code and neighbouring streets on the right-hand and on the left-hand sides. In Brazil, houses are numbered in accordance with the linear metric system, where the residence receives a number according to its distance (in metres) 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, so as 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 2008), to georeference places informed by the respondents with or without the occurrence of *C. penicillata*.

These spatial data were then combined with the data obtained through surveys of 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, socioeconomic data were not obtained from questionnaires, but were collected from Brazilian Institute of Geography and Statistics (IBGE) and posteriorly applied to geographical analysis.

Cartographic base

The following six cartographic bases in vector format were used: (1) municipal boundaries; (2) cities; (3) urban areas; (4) road network; (5) hydrographical net; and (6) contour lines (GeoMinas 2001; IBGE 2003); topography with 90 m of spatial resolution (CGIAR-CSI 2004); administrative regions of Belo Horizonte, urbanised 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 (de Assis 2008). For the entire cartographic base, we adopted the universal transverse of mercator (UTM) projection, centred on the Zone K23 and on the South American Datum 1969(SAD69).

Map of vegetation cover and land use (MVCLU)

The map of vegetation cover and land use (MVCLU) was prepared by de 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 a spatial resolution of 2.44 m per pixel, from 10 October 2005, 14 June 2006 and 15 July 2006.

Before the interpretation and classification of the QuickBird images, models to assist in this process were generated, such as the normalised difference vegetation index (NDVI) and digital elevation model (DEM). To generate the MVCLU, the technique of contextual interpretation and classification of Bayesian inference was adopted, using the algorithms of Mahalanobis distance and a maximum-likelihood classifier (de Assis 2008). The 10 classes of vegetation cover and land use were the same as used by de 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, Table 2).

de 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 de Assis (2008) (see 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 km^2 (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 discrepancy occurred because of 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 occupied in each of the nine administrative regions of Belo Horizonte was calculated, and then the regional values were summed to obtain the total for the entire municipality. Furthermore, the absolute areas (ha) occupied by the grouped classes of 'green areas along the streets' and 'green areas within the blocks' were calculated separately, because these classes were already pre-established by de 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

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

Class	Class name	Description
01	Native forest	Native dense arboreal vegetation, with closed canopy
02	Planted forest	Planted dense arboreal vegetation, such as eucalyptus monoculture, orchard, or other type of reforestation
03	Cerrado (Brazilian savanna)	Native open vegetation, with disconnected canopy
04	Natural field	Natural field, with sparse shrubs
05	Pasture	Grasses planted as lawn or pasture
06	Bare soil	Area devoid of any vegetation
07	Impermeable area	Constructed area occupied by buildings, houses, parking lots, asphalt and others
08	Hydrographical net	Water streams, lagoons and reservoirs
09	Clouds	Area not classified and occupied by clouds
10	Shadows	Area not classified and occupied by shadows

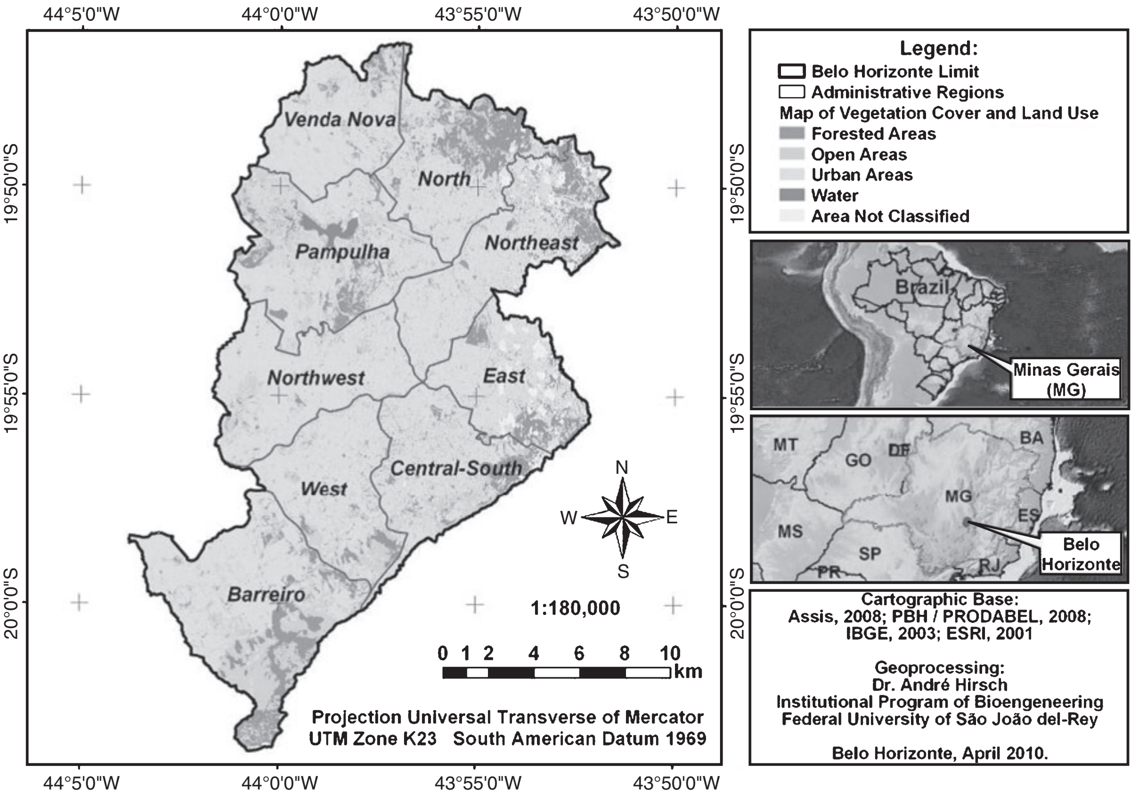

Fig. 1. Reclassified map of vegetation cover and land use (MVCLU) in Belo Horizonte municipality, Brazil, modified from de Assis (2008).

Table 2. Description of the regrouped classes of vegetation cover and land use in the municipality of Belo Horizonte, Brazil, adopted for this study, modified after de Assis (2008) (see Table 1)
See Table 1 for explanation Class codes (01–10)

Regrouped class	Class name	Description
01 + 02 + 03	Forested areas	Dense arboreal vegetation
04 + 05 + 06	Open areas	Typical grassland with sparse shrubs, or grasses planted as lawn or pasture, or without buildings
07	Urban areas	Constructed area occupied by buildings, houses, parking lots, asphalt, and others.
08	Water	Water streams, lagoons and reservoirs
09 + 10	Area not classified	Area not classified and occupied by clouds or shadows

chosen because it was approximately the size of a city block (100 × 100 m). Then, the absolute area (ha) of each class of vegetation cover and land use for all of the 614 electronic questionnaire responses was calculated. The same was done for each 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. 2).

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 fewer than five 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).

So as to verify which variables are determinant to the occurrence of marmosets in an urban environment, we employed a generalised 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 proportions of forested, open and urban areas. We used pairwise interactions to eliminate predictors based on the Akaike's information criterion (AIC) numbers, 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

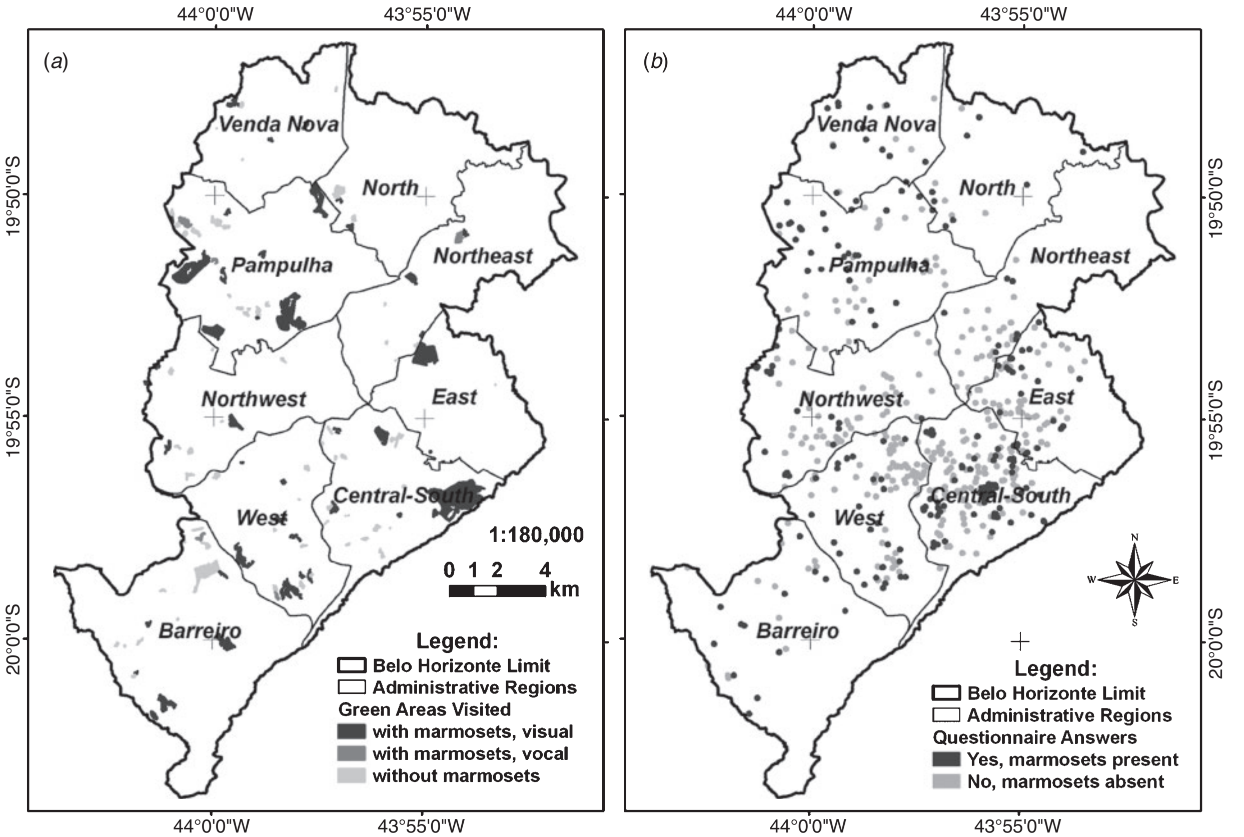

Fig. 2. Areas sampled to obtain the geographic distribution of *Callithrix penicillata* in Belo Horizonte, Brazil. (*a*) Green areas visited during the field survey, and (*b*) places from which answers to the questionnaires were obtained.

the likelihood-ratio test, which supported a negative binomial model ($P < 0.05$).

To investigate further effects of socioeconomic factors on marmoset distribution and spatial composition, we checked whether there was a correlation between the salary level and the proportion of green areas along streets, by 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 (Minitab Inc.).

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* was seen in 43 surveyed areas and vocalisations were heard in a further five locations (Fig. 2*a*, *b*). In total, 90 groups, consisting of 247 adults, 156 juveniles and 69 infants, plus 53 undefined individuals (because of obtaining only a brief view), were observed. Green areas with marmosets had 1–16 groups, with a mean of 2.09 (s.e. ± 0.45) groups per site. An average group was composed of 2.73 (s.e. ± 0.21) adults, 1.74 (s.e. ± 0.181) juveniles and 0.79 (s.e. ± 0.43) infants. Each group had a mean of size of 5.83 (s.e. ± 0.43) individuals per group and a mean density of 3.14 (s.e. ± 0.59) individuals per hectare.

Factors affecting the spatial distribution of marmosets

Regarding the questionnaires about marmoset distribution, we obtained a total of 935 responses, of which 614 were correctly filled, so as to enable them to be used. The reported occurrence of marmosets 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 ($\chi^2 = 34.90$; d.f. = 3; $P < 0.001$). The standardised residual analysis showed that 'forested areas' and 'open areas' occurred less frequently than expected where the answer was 'no' ($P < 0.05$). In contrast, the frequency of occurrence of the class 'urban area' was proportionally higher at places where the answer was '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 in 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 correlation between forested areas and 'yes' ($n = 9$; $r_s = -0.377$; $P > 0.05$) or 'no' ($n = 9$; $r_s = -0.067$; $P > 0.05$), between 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 between 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 the following 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 level, and 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 to –0.0005) and with the increase in the density of human population (95% CI: –0.0003 to –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 socioeconomic factors on the spatial distribution of marmosets

Concerning socioeconomic factors, there was no effect of salary level on marmoset abundance. However, the density of human population had a negative effect on marmoset distribution (Table 3). Despite the fact of no influence of wage, salary level 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 is a factor that has an impact on the spatial distribution of marmosets.

Discussion

Analysing our results using McKinney's (2006) avoider–exploiter continuum in our study site, the place of *C. penicillata* on this continuum depended on local resources, principally trees. Superficially, our study species appears to be an urban exploiter because it is found in urban environment 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 Figs 1, 2*a*, 2*b*). Thus, if only treeless areas of the city had been studied, the conclusion would have been that our study species is an urban avoider. Finally, if a mean density for the city were used, the conclusion would, probably, have been that our study species is an urban adaptor. 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 but where they sit on this depends on the distribution and quantity of key resources at a local level. Re-analysing our results using the new terminology developed by Fischer and colleagues (2015), our results made much more biological sense and this terminology provided more insights into the conservation requirements for urban marmosets. In this terminology, our species is an urban utiliser because it requires natural habitat to breed.

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

Variable	Coefficient or model summary	Standard error	P
Intercept	5.3331	0.8612751	<0.001
Urban	–0.0012042	0.0003896	<0.001
Size of parks or green areas	0.0194066	0.0026719	<0.001
Human density	–0.000193	0.0000435	<0.001
2 × log-likelihood	–240.519		
Deviance	189.79		
Degrees of freedom	42		
Akaike information criterion	250.52		

Both the presence and size (increasing) of green spaces or parks positively affected the distribution of *C. penicillata* in the urban environment of Belo Horizonte, whereas human density and urban areas had a negative impact. 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). Few studies have investigated correlations between the layout of the urban matrix and biological diversity (Hodgkison 2006). 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 subnatural 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 is positively influencing the geographic distribution of *C. penicillata* in Belo Horizonte. This alone is a good reason to encourage architects and urban planners take into account the kind of urban space that 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 Pisarski 1994; Magle *et al*. 2012). Studies with vertebrates have shown that different species could have different responses to the urbanisation process (McKinney 2006; Fischer *et al*. 2015). Whereas 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 were 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 urbanisation influences species densities is unsurprising, but the nature of a species' response to urbanisation can vary spatially (Evans 2010). Ecological studies have provided ample evidence that different species perform diverse ecological functions, such as, 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 because function is reinforced across scales (Peterson *et al*. 1998).

Our study confirmed the suggestion of a previous study relating to marmosets in Belo Horizonte (Goulart *et al*. 2010) that a regional-scale analysis of land cover in relation to marmoset presence is too coarse a level because of 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 level did not show any clear influence on the distribution of *C. penicillata*; this was also previously found in relation to complaints made about *C. penicillata* 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 socioeconomic variables in animal behaviour and distribution.

The use of spatial analysis to select potential sites in an urban environment was 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 are 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 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 targeting only *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 and 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, owing to marmoset avoidance of built-up areas. The interaction of marmoset species and city dwellers was mainly limited to borders of forest fragments and inside city parks, and appeared to be human motivated. *Callithrix pencillata* is an urban utiliser, although it is able to exploit highly urbanised areas for food and other resources, it still requires natural habitat for reproduction. Thus, our study supports the usefulness of the new terminology developed by Fischer and colleagues (2015).

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