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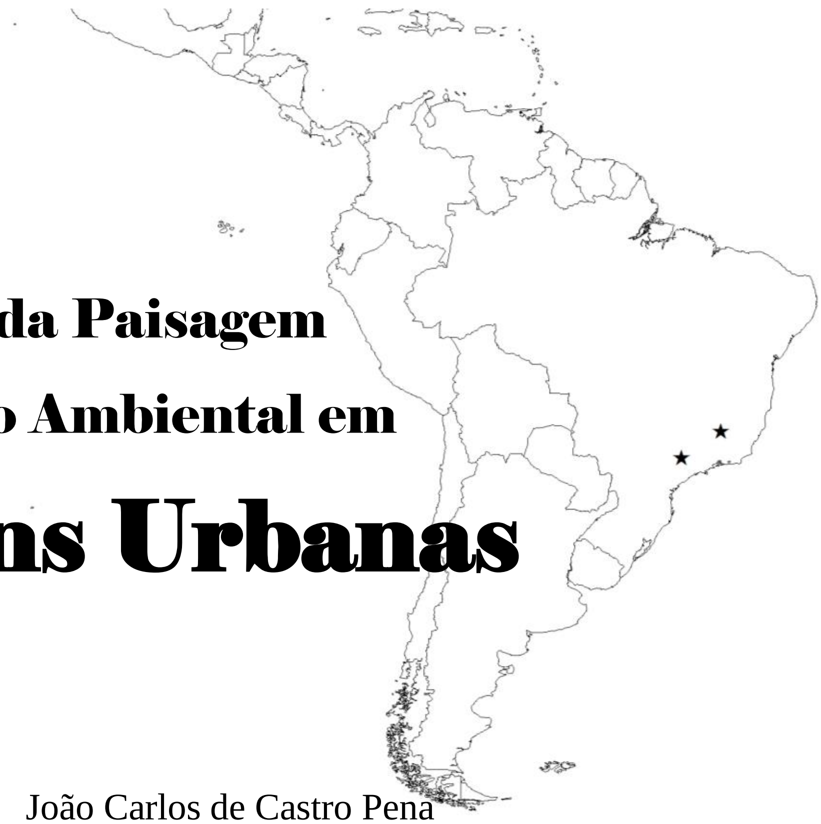
Instituto de Ciências Biológicas
Programa de Pós-Graduação em Ecologia, Conservação e Manejo de Vida Silvestre



Aves, Conectividade da Paisagem e Planejamento Ambiental em Paisagens Urbanas

João Carlos de Castro Pena

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Tese de Doutorado
Aves, Conectividade da Paisagem e Planejamento Ambiental
em Paisagens Urbanas

Thesis
Birds, Landscape Connectivity and Environmental Planning in Urban Landscapes

João Carlos de Castro Pena

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Orientador:
Prof. Dr. Marcos Rodrigues

Co-orientadores:
Prof. Dr. Milton Ribeiro
Prof Dr. Robert. J. Young

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____

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____

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____

Dr. Frederico de Siqueira Neves (UFMG)

____

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____

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"Man is that uniquely conscious creature who can perceive and express. He must become the steward of the biosphere. To do this, he must design with nature"

Ian McHargh

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Programa de Pós-Graduação Em Ecologia, Conservação e Manejo de Vida Silvestre

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Resumo

O papel de paisagens urbanas para a preservação da biodiversidade tem sido cada vez mais reconhecido. Diferentes estudos têm demonstrado que quando a infraestrutura verde é adequadamente planejada e manejada, cidades são capazes de abrigar grande diversidade de espécies e preservar serviços ecossistêmicos essenciais para o bem-estar humano. Entretanto, apesar da rápida expansão de paisagens urbanas neotropicais durante as últimas décadas, elas permanecem pouco estudadas. Assim, os objetivos principais dessa tese foram (1) avaliar os efeitos da urbanização sobre as aves em uma metrópole Neotropical e (2) formular estratégias de manejo e políticas públicas que tenham como objetivo a conservação da biodiversidade urbana e o aumento do bem-estar humano. A hipótese geral é que paisagens urbanas localizadas na região Neotropical são má planejadas e manejadas, e que o filtro ambiental urbano apresenta um forte efeito negativo sobre a comunidade de aves. Entretanto, através da identificação dos efeitos da urbanização sobre a biodiversidade, e os aspectos sócio-políticos que moldam o desenvolvimento e crescimento urbanos, é possível definir estratégias de manejo e planejamento que podem reduzir os efeitos negativos da urbanização sobre organismos humanos e não-humanos. Para alcançar esses objetivos, essa tese foi dividida em quatro capítulos. Para os primeiros três capítulos, a região centro-sul de Belo Horizonte (Minas Gerais, Brasil) foi selecionada como área de estudo, e sua infraestrutura verde foi mapeada e descrita. Posteriormente avaliamos os efeitos de impactos antrópicos e da vegetação urbana sobre a comunidade de aves que habita as ruas e modelamos caminhos de menor custo, com o objetivo de formular redes ecológicas urbanas entre fragmentos de habitat. No quarto capítulo, nós descrevemos a participação acadêmica na formulação de políticas públicas para o novo plano diretor participativo de Rio Claro (São Paulo, Brasil), uma cidade Neotropical de médio porte. A infraestrutura verde da região centro-sul de Belo Horizonte é má planejada e manejada, apresentando uma distribuição desigual pela paisagem. Consequentemente, o filtro ambiental urbano possui um forte efeito sobre a comunidade de aves que ocupa as ruas. O processo de urbanização, principalmente a exposição ao ruído, levaram à redução da riqueza de espécies e dos aspectos funcionais da comunidade. Entretanto, práticas apropriadas de manejo, como a manutenção de árvores largas e o incremento de árvores nativas nas ruas, são capazes de reduzir os efeitos negativos da urbanização sobre aves. Com o uso do conhecimento de especialistas e de caminhos de menor custo nós definimos

redes ecológicas urbanas para aves e identificamos as porções mais permeáveis da paisagem e conectores importantes para a manutenção da conectividade. O processo de votação do plano diretor participativo de Rio Claro foi adiado duas vezes e sua aprovação é incerta. Isso é um indicativo da forte influência política e econômica que existe sobre decisões relacionadas ao planejamento e manejo de paisagens urbanas brasileiras. O planejamento urbano e da paisagem precisam priorizar o bem-estar humano, a sustentabilidade ambiental e a conservação da biodiversidade. Assim, através da identificação dos impactos negativos causados pela urbanização sobre organismos humanos e não-humanos e os aspectos sócio-políticos que modelam o desenvolvimento e crescimento urbanos, nós seremos capazes de construir cidades mais amigáveis e resilientes, socialmente responsáveis e ambientalmente sustentáveis.

Abstract

The role of urban landscapes in biodiversity conservation has been increasingly recognized. Various studies have demonstrated that a properly managed urban green infrastructure can increase species diversity and preserve ecosystem services essential for human well-being. However, despite the rapid expansion of Neotropical urban landscapes in recent decades, they remain understudied. Thus, the main goals of this thesis were (1) assess the effects of urbanization on birds of a largely urbanized city located in the Neotropical region, and (2) to formulate management practices and public policies that aim to increase urban biodiversity conservation and human well-being. The general hypothesis was that Neotropical urban landscapes are poorly planned and managed, and the urban environmental filter has a strong effect on the urban bird community. However, by the identification of the effects of urbanization on biodiversity and the socio-political aspects that shape urban growth and development, it is possible to identify planning and management practices that aim to reduce the negative effects of urbanization on human and non-human organisms. To achieve these goals, this thesis was divided in four chapters. In the first three chapters, the southern region of Belo Horizonte (Minas Gerais, Brazil), was selected as our study area and we mapped and described its green infrastructure. Then, we assessed the effects of human impacts and the urban vegetation on birds

that occupy the streets of the southern region of Belo Horizonte and modeled least cost paths for bird species, in order to formulate an urban landscape network. In the fourth chapter, we described our participation in the formulation of public policies for the new participatory master plan for Rio Claro (São Paulo, Brazil), a medium sized Neotropical city. The green infrastructure of the southern region of Belo Horizonte is poorly planned and managed, being unevenly distributed through the landscape. Consequently, the urban environmental filter has a strong effect on the urban bird community that occupy the streets. The urbanization process, especially the exposure to noise, leads to a reduced bird species richness and community functional aspects. However, appropriate planning and management practices, such as the maintenance of large street trees and the increase in the amount of native street tree species, are able to reduce the negative effects of urbanization on birds. Using expert knowledge and least cost path modeling, we defined an urban landscape network for birds, and identified the most permeable portions of the landscape and important links for the preservation of landscape connectivity. The voting process of the participatory master plan for Rio Claro was delayed twice, and its approval remain uncertain. This is an indicative of the strong political and economic influences over decisions related to environmental planning and management in Brazilian urban landscapes. Urban and landscape planning need to prioritize human well-being, environmental sustainability and biodiversity conservation. Thus, by the identification of urbanization impacts on human and non-human organisms and the socio-political aspects that shape urban growth and development, we will be able to build friendlier and resilient cities, that are socially responsible and environmentally sustainable.

Summary

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Introduction

The expansion of urban landscapes is happening at an accelerated rate. By the year 2050, two-thirds of the human population will live in cities (United Nations, 2014), and about 60% of all the infrastructure intended to improve cities by 2030 has yet to be built (Secretariat of the Convention on Biological Diversity, 2012). Consequently, the number of studies assessing the effects of urbanization on biodiversity worldwide has increased in recent decades (Elmqvist et al., 2013). The results show that, despite the intense negative impacts and high biodiversity loss, properly managed cities have the potential to harbor considerable native fauna and flora and preserve essential ecosystem services for human wellbeing and biodiversity conservation.

However, the knowledge about the effects of urbanization on biodiversity is geographically biased—although Neotropical cities are undergoing one of the most rapid and intense urbanization processes (United Nations, 2014), they remain understudied (Pauchard and Barbosa, 2013). This lack of knowledge is evident in general aspects of urban ecology (Pauchard and Barbosa, 2013), in recurrent topics such as the effects of urbanization on birds (Ortega-Álvarez and MacGregor-Fors, 2011), and in research fields that have recently given more attention to urban landscapes, such as animal movement and landscape connectivity (LaPoint et al., 2015). Following the global trend, Neotropical cities are concentrated within and near highly productive areas such as coastal zones and major riverine systems (McDonald et al., 2013). Although Neotropical cities are highly urbanized, they suffer from some of the world's largest social and economic inequalities, which pose a threat to several biodiversity hotspots (Pauchard and Barbosa, 2013).

During the last ten years, Brazilian urban landscapes have been the subject of an increasing number of studies (e.g.: Duarte et al., 2011; Duarte and Young, 2011; Ottoni et al., 2009; Teixeira et al., 2015). However, most of them compared rural and urban landscapes (e.g.: Bainard et al. 2011) or only assessed the biodiversity inhabiting urban habitat patches or parks (e.g.: Ferreira et al., 2013). Only a few studies explored the effects of urbanization on biodiversity at the landscape level (e.g., Fontana et al., 2011) or the functional aspects of urban biodiversity (Sacco et al., 2015). Brazilian cities are distributed over large latitudinal and longitudinal gradients, being influenced by different climatic, topographic and biotic factors.

Therefore, Brazilian urban landscapes present great opportunities to assess the impacts and processes related to urbanization, such as biotic homogenization (McKinney, 2006).

For the proper function of largely urbanized cities, it is necessary the correct planning and management of different types of infrastructure, such as lighting, transportation and water supply. However, for a health urban environment, it is also necessary to consider ecological aspects and the urban biodiversity. Within cities, the green infrastructure is a multifunctional ecological network, which is responsible for the maintenance of ecological processes and ecosystem functionality (Herzog, 2013). It is comprised by different green elements such street trees, squares, parks and green walls. The green infrastructure is able to preserve and maintain important ecosystem services that is essential for human wellbeing and urban resilience, such as reducing the heat island effect, the level of suspended particulate matter (Vailshery et al., 2013), and respiratory problems (Lovasi et al., 2008). The green infrastructure also has positive effects on urban biodiversity, by the preservation of habitat patches, maintenance of landscape functional connectivity, and ensuring resources for native fauna.

Birds are a highly diverse group of organisms and are used as models to assess the effects of urban landscapes on biodiversity worldwide (Ortega-Álvarez and MacGregor-Fors, 2011). Birds can utilize all the components of urban green infrastructure and they are influenced by the composition and configuration of landscapes (Martensen et al., 2012; Medeiros et al., 2015). Since birds are considered a good indicator of urban ecological integrity (Ortega-Álvarez and MacGregor-Fors, 2009), management practices that have positive influences on birds will also benefit people and other organisms inhabiting urban landscapes. The maintenance of large and old trees and the increase in the amount of native tree species are management practices able to reduce the effects of the urban environmental filter, and increase urban bird species richness, abundance and functional aspects (Ikin et al., 2013; Stagoll et al., 2012; White et al., 2005).

However, for the proper planning and management of urban landscapes, it is necessary that this technical knowledge acquired in universities and research centers become accessible to society, and be applied to help in the formulation of public policies for a more sustainable and resilient urban development. The socio-political infrastructure – socio-political norms, values and relationships that structure the decisions made by public and private actors – creates patterns of behaviors and actions that shape the urban environment (Eakin et al., 2017). Planning and management decisions overemphasize biophysical aspects of urban landscapes, but it is also necessary to consider socio-political influences and vulnerabilities on decisions, such as informal economic and political transactions: clientelism, corruption, or the high influence of specific economic sectors (Eakin et al., 2017). In most Neotropical urban landscapes, the high political instability and fragility, coupled with the serious infrastructural problems (such as housing, poverty and unemployment), reduce the concern about environmental issues. It is necessary a transdisciplinary analysis of urban environmental problems and vulnerabilities. Academia needs to actively transfer its technical knowledge to decision making, considering the socio-political processes shaping urban environmental planning and management. The cosmetic and utilitarian perception of green infrastructure – which consider the urban vegetation as a embellishment element – must be replaced by a multifunctional concept (Hansen and Pauleit, 2014; Herzog, 2016), that is based in a holist view of complex socio-ecological systems, such as urban landscapes.

Considering the large knowledge gap related to Neotropical urban landscapes, the main goals of this thesis were (1) to assess the effects of urbanization on birds of a largely urbanized Neotropical city, (2) and to formulate management practices and public policies that aim to increase urban biodiversity conservation and human well-being. The general hypothesis was that Neotropical urban landscapes are poorly planned and managed, and the urban environmental filter has a strong effect on the urban bird community. However, by the identification of the effects of urbanization on biodiversity and the socioeconomic aspects that shape urban growth and development, it is possible to identify planning and management practices that aim to reduce the negative effects of urbanization on human and non-human organisms.

Thus, to achieve these goals this thesis was divided in four chapters. First, the green infrastructure of the southern region of Belo Horizonte (Minas Gerais, Brazil) – a highly developed urban center in the Neotropical region – was mapped and described, and it was discussed the role of the green infrastructure for urban biodiversity conservation. In the second chapter, it was assessed the effects of human impacts and the urban vegetation on birds that occupy the streets of the southern region of Belo Horizonte. In the third chapter, we simulated, for ten bird species, least cost paths between habitat patches distributed through the southern region of Belo Horizonte. It was assessed the contribution of the different elements of the green infrastructure to the functional connectivity of this urban landscape. In the fourth chapter, it is described the academic participation in the formulation of a master plan for Rio Claro (São

Paulo, Brazil), a medium sized Neotropical city. Civil society and academic representatives joined efforts for a participatory environmental planning that aimed to define public policies and directives for a sustainable urban development and reduce the impacts of mineral extraction on biodiversity and the human population of Rio Claro.

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Chapter 1

The green infrastructure of a highly-urbanized Neotropical city: the role of the urban vegetation in preserving native biodiversity

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Belo Horizonte from Sapucaí

The green infrastructure of a highly-urbanized Neotropical city: the role of the urban vegetation in preserving native biodiversity

João Carlos de Castro Pena, Danilo Marques de Magalhães, Ana Clara Mourão Moura, Robert J. Young, Marcos Rodrigues

Abstract

The composition of the urban vegetation that comprises the green infrastructure of a highly-urbanized Neotropical city was mapped and described in order to assess how it can be used to preserve and maintain urban biodiversity. Supervised classification was used, followed by Map Algebra methodology, to identify the elements that comprise the green infrastructure of the southern region of Belo Horizonte (Minas Gerais, Brazil). Species composition of the street trees community was also assessed. Almost half of the study area is occupied by 12 types of woody and herbaceous vegetation, composed mostly by urban parks and gardens. Forty-one percent of the almost 90,000 street trees is composed by 10 species from which only four are native. These results show that the green infrastructure of this urban landscape is comprised by a large amount of different types of green elements, and has a great potential for biodiversity conservation. However, management strategies are needed such as better planning of the urban afforestation process, increasing street tree species richness. This study is the first step towards a better understanding of how such urban landscape influences local biodiversity.

Keywords: Belo Horizonte; Biodiversity conservation; Map algebra; Rapid eye image; Urban landscape.

Introduction

Urban green infrastructure is an ecological network which restructures the urban landscape, mimicking natural processes to maintain the functionality of the urban ecosystem (Herzog, 2013). It also provides the ecosystem services that are equally necessary for human well-being and biodiversity conservation. Within cities the green infrastructure is comprised by different areas and pervious surfaces, partially or completely dominated by different vegetation types. They include forest patches, green roofs, gardens, grasslands, green walls, street trees, parks and squares with different management types and history of human influences.

Investments on green infrastructure result in positive outcomes for the urban population. Such benefits surpass the relatively low initial income necessary for improvements on vegetation (Soares et al., 2011). Urban trees can reduce energy consumption, storm water runoff and pollutants exposure, as well as increase real estate values (Soares et al., 2011). The green infrastructure is also directly important to maintain and preserve biodiversity inside cities. Street trees' species composition influences bird feeding guilds that use street's vegetation (Young et al., 2007) and the amount of native street tree species increases the amount of native bird species within urban parks (Ikin et al., 2013).

Neotropical cities are experiencing one of the most rapid and intense urbanization processes worldwide (UnitedNations, Department of Economic and Social Affairs, 2014). However, little is known about how urban vegetation affects the urban biodiversity and human wellbeing (Keniger et al., 2013). This is a worrisome fact, because Neotropical urban landscapes are often located within and nearby highly biologically productive areas, such as coastal zones and major riverine systems (McDonald et al., 2013). Although highly urbanized, Neotropical cities have some of the world's largest social and economic inequities, which can threaten biodiversity hotspots (Pauchard and Barbosa, 2013). The attempts to solve the serious social and infrastructural problems within these cities are often held disregarding environmental issues; therefore it is necessary to change the perception that separates the ecological factors from other urban problems (poverty, housing, food and unemployment) once these issues interact, and ecological solutions often exist and are viable (Herzog, 2016, 2013).

This study aimed to: (1) map and describe the urban vegetation elements that compose the green infrastructure in Belo Horizonte, a Neotropical urban centre; and (2) investigate how they can be used to preserve native biodiversity within the urban landscape. The knowledge concerning the structure of an urban landscape is the first step to understand how it influences the organisms capable of living and persisting within cities (both human and non-human organisms) and for the appliance of adequate management.

Material and Methods

Study area

Our study area is the southern region of Belo Horizonte city (19W 55' 37", 43S 56' 34") one of the first planned cities in Brazil and Minas Gerais state capital (Figure 1.1). The southern region of Belo Horizonte has 31.7 km², which comprises the oldest part of the city, an area of approximately 9 km², established in 1897 and designed for 200,000 inhabitants. It was conceived under the "garden city" concept, being famous during the first decades after its foundation for the high density of gardens, public squares and leafy streets. In the 1960s, after facing an explosive growth of its population (800,000 inhabitants in 1962), the city suffered intense landscape changes: reducing the quantity and diversity of street trees and gardens for the expansion of the urban infrastructure. The most infamous event was the cutting of hundreds of *Ficus benjamina* L. (Weeping figs) located in one of the main avenues of Belo Horizonte in 963 (Duarte, 2007). Today, Belo Horizonte's landscape comprises an area of approximately 331 km² and its public green infrastructure is composed of scattered green areas, public squares and parks, and street trees composed mainly of exotic species embedded in an urban matrix. This historical background of landscape changes makes this city an interesting model to evaluate the composition of the urban vegetation and how it can be used for biodiversity conservation in the Neotropical region.

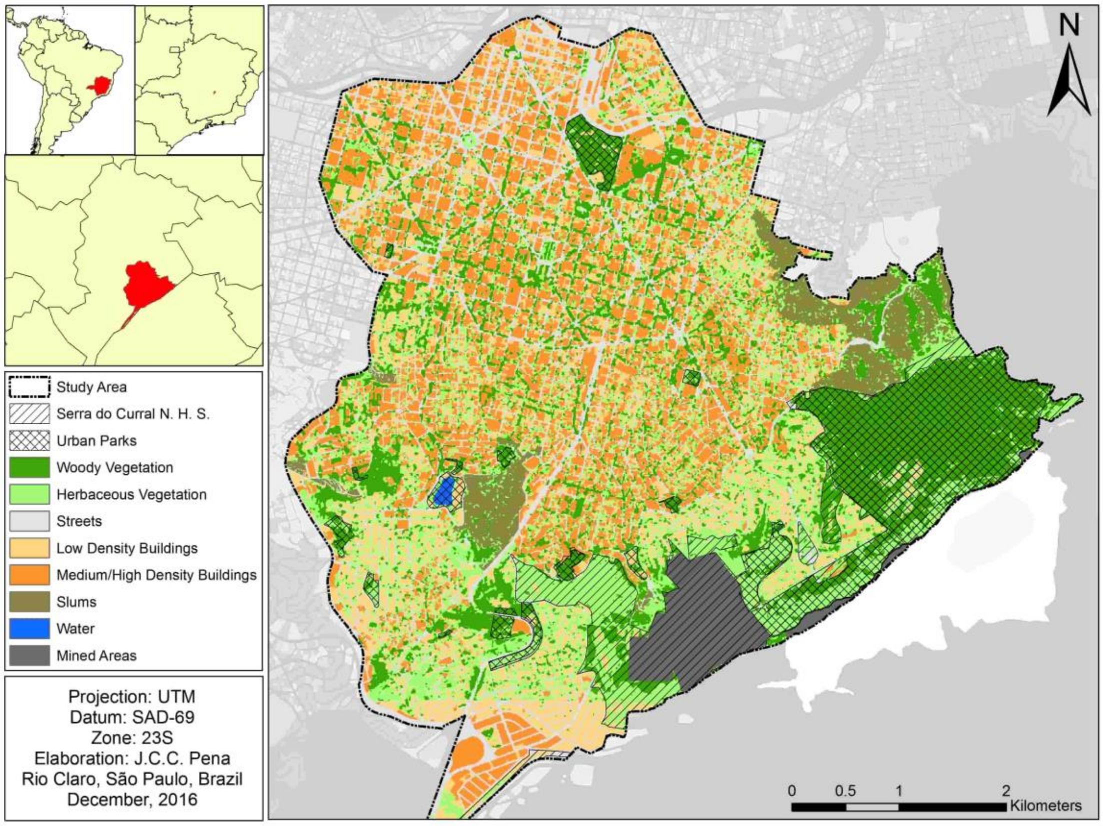

Figure 1.1. Land use type of the southern region of Belo Horizonte (Minas Gerais, Brazil), highlighting the municipal parks and the Serra do Curral National Heritage Site (N.H.S.).

Mapping urban and vegetation features

The identification of the urban and vegetation features of Belo Horizonte's landscape was made by supervised classification of RapidEye's satellite images from the year 2010. This satellite is equipped with REIS (RapidEye Earth Imaging System) sensors, operating in five frequency bands, three in the electromagnetic spectrum of the region known as "visible" (bands 1, 2 and 3); the other frequency bands – Red-Edge (Band 4: 690-730mm) and near infrared (Band 5: 760-850mm) – are used for vegetation monitoring, as they are able to identify changes in chlorophyll content and in plant cell structure, respectively. We used two 25 x 25 km images, with 5m spatial resolution and 12 bits (4096 shades of grey). The method adopted was segmentation followed by definition of classification keys (composed by water, dense vegetation, medium vegetation, herbaceous vegetation and urban components), and the application of MaxVer algorithm (Maximum Likelihood Classification) with accuracy of 85%.

Due to the images' characteristics (spatial and spectral resolution) it was possible to clearly identify the volumetric conditions of the vegetation (dense, medium or herbaceous vegetation) and to separate them from anthropic elements (buildings and roads). Nonetheless, it was not possible to differentiate the urban elements (such as houses, buildings and roads) as well as the different types or uses in green elements that compose the green infrastructure (such as gardens, parks, street trees and squares). To allow this differentiation we adopted the Map Algebra methodology (McHarg, 1969), with the aim of crossing distinct data types and get accurate information on vegetation and urban elements, which is described below.

A land use cover map in vector format of Belo Horizonte from the year 2012 was obtained (Belo Horizonte, 1996). This map allows the identification of each land use type of each lot inside of the city blocks located in the study area (S1.1 Table). It is worth mentioning that this file only has the information within city blocks; that is, in roads, public squares and roundabouts there are no assigned information.

The vector data were converted to raster format to allow greater flexibility in data processing and maintaining a common scale for analysis. In a raster image, each pixel records the description of the elements that compose it (e.g. vegetation type) in the form of a digital numerical value. Thus, during the conversion process a value was assigned to each of the land use types in order to identify them in the Map Algebra process. These values were chosen in a qualitative way; that is, they do not represent any hierarchy of information, only a distinction of classes (S1.1 Table). Some land use types, considered to fall within our interests were grouped into numerical classes (S1.1 Table). Both images were reclassified using the *Reclassify* tool from ArcGIS 10.2 software. The three categories of the supervised classification map were reclassified to values in the range of 1-10 [one for woody vegetation (dense + medium vegetation), two for herbaceous vegetation and 10 for urban elements]. The land use map categories were reclassified to values in the range of 100-1000 (S1.1 Table). Both reclassified maps were then, overlapped. Using the final pixel values, it is possible to know which categories of both maps were overlapped (S1.2 Table). Each numerical final value was replaced by a new land use type name in the final map (Figure 1.1).

As roads, public squares and roundabouts have no assigned information in the land use map, all pixels with values equal to one, two and 10 (values attributed to the supervised classification map) are related to those elements in the final map. Thus, pixels with value equal to one are composed by, for example, street trees and woody vegetation in squares; pixels with value equal to two are composed by, for example, roadside grass, public gardens and squares; pixels with value equal to 10 are composed by streets, avenues and roads.

To assess the contribution of each land use type to the urban landscape, the total number of pixels of each class was multiplied by $25m^2$ (pixel resolution). In this way was possible to know the quantity of herbaceous and woody vegetation composed by parks, street trees, public squares and gardens throughout the landscape.

Composition of street trees' community

Currently, the afforestation process in most Neotropical cities located in countries like Brazil is usually based on a relatively small pool of commonly planted, often exotic tree species (Moro and Castro, 2015; Pauchard and Barbosa, 2013). Furthermore, street tree species composition influences urban biodiversity (Ikin et al., 2013; Young et al., 2007). Therefore, besides assessing the composition and amount of different land use types attributed to the urban vegetation, we also assessed the street tree species community composition.

Information about species and geographic location of all individual street trees in the study area was obtained from Belo Horizonte's Tree Information System (SIIA-BH), which was designed to register information on trees located in public places (Belo Horizonte, 2015). Approximately 90,000 trees were inventoried through the southern region of Belo Horizonte, totalling 475 species. From this database, we evaluated the frequency of the abundances of the street tree species. Among the ten dominant tree species, we identified exotic and native tree species and their relative proportions in relation to the street trees' community.

Results and Discussion

Within the study region, were found 6 different types of herbaceous and 6 different types of woody vegetation distributed in parks, streets and squares, gardens, wastelands, slums and mined areas (Figure 1.1, Table 1.1). The proportion of build-up area is 54.46% of the territory (17.26 km²), which means that almost half of this urban landscape (14.44 km²) is occupied by woody (22.56% - 7,15 km²) and herbaceous vegetation (22.98% - 7.29 km²) (Table 1.1). Parks contained the largest proportion of woody vegetation (38.51% - 2.75km²), followed by street trees and public squares (24.63% - 1.76km²). Although apparently being a considerable amount of vegetation, multiple street segments of the study area are lacking forestry coverage (Figure 1.2A). Gardens represent the largest proportion of herbaceous vegetation (31.10% - 2.27km²), followed by parks (22.15% - 1.61km²) (Table 1.1). Considering gardens, the most relevant different types were distributed in small and medium/height residential buildings, leisure facilities, religious and education institutions, small and medium/height commercial buildings and warehouses (Figure 1.2B). However, despite the large amount of vegetation within this urban landscape and the wide variety of elements, these are concentrated at the southern portion of the study area, dominated by parks and gardens (Figure 1.1, Table 1.1).

Table 1.1. Proportions of woody and herbaceous vegetation found in the southern region of Belo Horizonte (Minas Gerais, Brazil).

		Parks	**Streets/ Squares**	**Gardens**	**Wastelands**	**Slums**	**Mined areas**	**Total**
Woody	**Km²**	2.75	1.76	1.31	0.68	0.35	0.30	7.15
Vegetation	**%**	38.51	24.63	18.38	9.57	4.77	4.14	100
Herbaceous	**Km²**	1.61	1.45	2.27	1.10	0.23	0.63	7.29
Vegetation	**%**	22.15	19.88	31.10	15.11	3.09	8.67	100

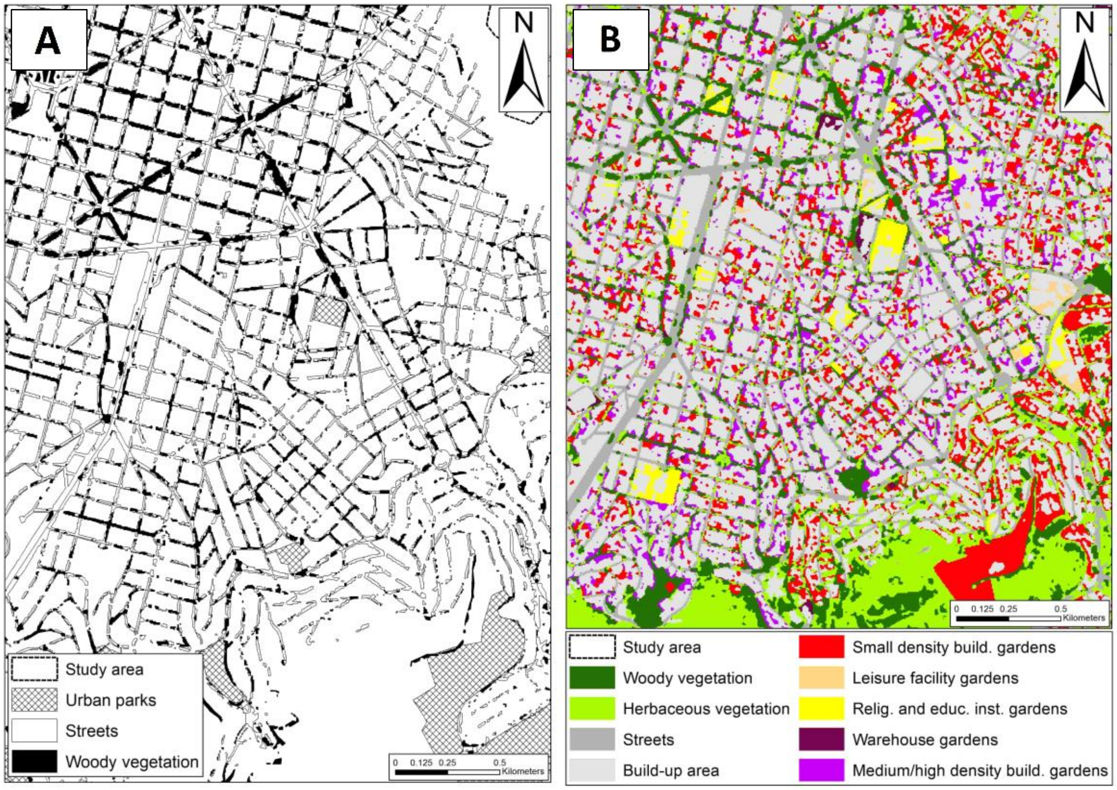

Figure 1.2. A - Woody vegetation (black) distributed through the streets (lines) of the southern region of Belo Horizonte (Minas Gerais, Brazil). The municipal parks are highlighted in checkers. B - Different types of gardens identified through the southern region of Belo Horizonte. The woody and herbaceous vegetation within parks and other public spaces (e.g.: squares and streets) are represented in dark and light green, respectively.

Urban parks are sources of resources for different organisms and are responsible to maintain viable species populations inside and in the vicinity of urban landscapes. Management strategies can be adopted around these protected areas, helping their preservation and in fulfilling their ecosystem functions. A surrounding matrix composed of less urbanized regions and more gardens and green spaces have less negative effects on urban parks (Ikin et al., 2013). Thus, the current characteristics of the landscape surrounding most of the urban parks located at the southern region of the study area should be maintained, such as the concentration of houses and gardens. In fact, gardens can be spatially arranged to maximize total habitat area and minimize isolation between habitat patches (Goddard et al., 2010). In this way, these green elements can be used to increase the urban connectivity, especially between the isolated municipal parks located in the inner city.

Within our study area, gardens harbour a considerable amount of herbaceous and woody vegetation. This is observed in other urban landscapes, despite the current world tendency towards reduction of the proportion of area dedicated to gardens (Cameron et al., 2012). These green elements are mostly influenced by the decisions of their householders (Cameron et al., 2012; Smith et al., 2006), being the vegetation located within gardens highly heterogeneous, promoting great potential for urban biodiversity conservation (Smith et al., 2006). Within our study area it is possible to find different types of gardens, located in city blocks under different land use types (e.g.: schools, private and public gardens and commercial zones), and consequently under different management types and intensities.

To increase gardens' value to biodiversity native plant species must be used during its landscaping. In the Brazilian city of São Luís (Maranhão state), endangered Brazilian tree species, such as *Caesalpinia echinata* Lam. "pau-brasil", are protected within gardens due to the extensive use of native species (Akinnifesi et al., 2010). In Palmas (Brazilian state of Tocantins), the use of native tree species helps in native bird species conservation within the urban landscape (Reis et al., 2012). Gardens will never replace natural and semi-natural environments, but can be a useful complement to these habitats (Cameron et al., 2012), serving as a repository for indigenous species of animals and plants, including those threatened by extinction in nature (Akinnifesi et al., 2010). Considering that each garden has its peculiarities due to the different decisions of their householders, they should be encouraged to adopt strategies that favour the maintenance and preservation of local biodiversity. In this way, the different types of gardens located within the southern region of Belo Horizonte will be able not only to increase the landscape permeability, but also to act as important sources of resources inside of the urban landscape (Smith et al., 2006). Formally protected areas are not the only green infrastructure elements with potential for biodiversity conservation, especially in urban landscapes (Colding et al., 2006).

Through the southern region of Belo Horizonte, each of the 10 most dominant tree species was represented by over 2000 individuals; together, these species accounted for 41% of all 90,000 street trees (Table 1.2). Four are Brazilian native species and six are exotic species. The three most abundant species are *Caesalpinia peltophoroides* Benth. "falso-pau-brasil" ou "sibipiruna" with 6431 individuals, *Syagrus romanzoffiana* (Cham.) Glassman "palmeira-real" 5638 individuals – both native species in Belo Horizonte – and the exotic *Tabebuia rosea* (Bertol.) DC. "ipê-rosa" 3850 individuals, highly used in the urban forestry throughout Belo Horizonte (J.C.C. Pena *pers. obs.*). In general, most species are represented by less than 1000 individuals (Figure 1.3).

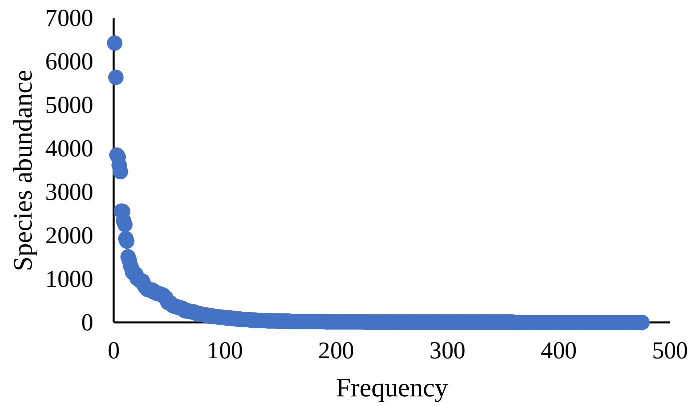

Figure 1.3. Frequency of the abundances of the street tree species through the southern region of Belo Horizonte (Minas Gerais, Brazil). It is possible to observe that most species are represented for less than 1000 individuals.

Table 1.2. The 10 most abundant street tree species distributed through the southern region of Belo Horizonte (Minas Gerais, Brazil), their abundances and original distributions.

Species	**Common name**	**Abundance (%)**	**Native to**
Caesalpinia peltophoroides Benth.	"Falso-pau-brasil" ou "sibipiruna"	6431 (7.22)	Brazil
Syagrus romanzoffiana (Cham.) Glassman	"Palmeira-real"	5638 (6.33)	Brazil
Tabebuia rosea (Bertol.) DC.	"Ipê-rosa"	3850 (4.32)	North and Central America

Dypsis lutescens (H. Wendl.) Beentje & J. Dransf.	"Areca-bambu"	3810 (4.27)	Madagascar
Ligustrum lucidum W.T. Aiton	"Ligustro" ou "alfeneiro"	3623 (4.06)	Asia
Tibouchina granulosa (Desr.) Cogn.	"Quaresmeira"	3470 (3.90)	Brazil
Michelia champaca L.	"Magnólia-amarela"	2563 (2.88)	Asia
Murraya exotica L.	"Murta-de-cheiro"	2552 (2.86)	Asia
Cupressus sp.	"Cipreste-italiano"	2344 (2.63)	Northern Hemisphere
Pachira aquatica Aubl.	"Monguba"	2255 (2.53)	Central and South America (Brazil)

The urban forestry process plays an important role within urban landscapes. Street trees' species composition have influence on bird feeding guilds that use a street's vegetation (Young et al., 2007). The number of trees in the streets (Fontana et al., 2011) and the amount of native species (Ikin et al., 2013) leads to an increase in bird species richness, as there is a greater variety and availability of resources. The current composition of the street tree's community in the study area is a consequence of the preference for a few tree species, manly exotic and with striking flowers. This aesthetic view of the urban forestry process does not consider the landscape functionality. As a consequence, we observe this great dominance of species such as *T. rosea, C. peltophoroides* and *Tibouchina granulosa* (Desr.) Cogn.("quaresmeira") – tree symbol of Belo Horizonte. Furthermore, the great abundance of *Dypsis lutescens* (H. Wendl.) Beentje & J. Dransf. ("areca-bambu") and *Murraya exotica* L. ("murta-de-cheiro") are indicative of a replacement process of trees for shrubby species. Since shrubby and small tree species usually produce less organic material such as fruits and leaves, there is a preference of these species by the human population. The deficient street forestry, the reduced species diversity, the great use of exotic species and the growing use of shrubby species reduces the role of urban forestry, not only in preserving biodiversity, but also in maintaining important ecosystem services, such as the reduction of storm water runoff (Soares et al., 2011). Therefore, an investment in planting of street trees is needed, and the selected species must have the necessary characteristics to increase the functionality of the urban forest. Streets and other urban linear elements can be used to increase the connectivity of the urban landscape. Differentiated management can be used in streets and roads that connect parks and cross less urbanized areas, serving as green urban corridors or linear urban parks, for human – as cyclist and walking tracks – and non-human organisms (Magalhães and Moura, 2013), such as the streets and avenues that connect the urban parks located within central region of the study area.

When properly managed, wastelands, roadside grass and empty spaces between road junctions can provide important ecosystem services within urban landscapes. They can act not only as stepping stones for the movement of animal species, but sources of resources within the urban landscape (Sitzia et al., 2015). In Berlin (Germany), the vegetation structure in wastelands influences the presence of urban birds with 12 species of European conservation concern within these green elements (Meffert and Dziock, 2012). In Belo Horizonte, wastelands and roadside grass can be used as pocket parks to help in the conservation of urban biodiversity and to increase the landscape permeability along with other green elements, such as gardens and parks.

The slums, neglected areas in large cities in developing countries, are a strong example of poor urban planning. Millions of people live in these regions, without basic services and in unhealthy living conditions. This is mostly related due to the spontaneous and irregular occupation of the land due to human migration to urban centres. Thus, the green infrastructure planning rarely is considered in attempts to improve the population's quality of life. Within the slums of our study area (which represented 7.47% of the build-up area), there is a small amount of vegetation, but it was not possible to identify its use due the lack of urban planning. The few forest patches located near and inside the slums are extremely important for slope protection (the regions in which the slums are located in the study area have a pronounced declivity). However, the population does not have direct access to these areas. Thus, we highlight the importance of the green infrastructure in rehabilitation and urbanization projects of slums. In Belo Horizonte's slums, the creation of community gardens and allotments with community participation will enhance their connection with nature, and increase their interest related to conservation issues, their health and well-being. In Stockholm, allotments provide cultivated vegetables and fruits for self-sufficiency and recreation (Colding et al., 2006).

The remaining amount of vegetation within the study area is located within abandoned mines, which also border the largest protected areas. One of the conditions for permitting dolomite extraction was to transform the area into a park after the mine's closure. Today, four years after the end of extraction, no rehabilitation activity has been performed in the area, leaving a portion of the symbol of the city of Belo Horizonte, the Serra do Curral National Heritage Site, completely degraded. Considering the proximity of the Belo Horizonte's mined areas with its inhabitants and with important native habitat patches, it is of utmost importance that these regions are rehabilitated and used for social and environmental purposes. Abandoned mines can be reclaimed for social, economic and even environmental functions.

Conclusions

This study is the first step towards a better understanding of how Belo Horizonte's landscape influences local biodiversity and can be used to guide the use of urban green infrastructure to increase its resilience and functionality. Next steps include the use of landscape metrics and information on biodiversity that inhabits the city to understand the functionality of this urban ecosystem. Although being used since the 1960's, the Map Algebra methodology can be a useful tool for the combination of factors in order to assist in urban planning, especially with digital technology support that favors adjustments and calibrations. Using this procedure, our results show that private properties and street trees harbour a considerable amount of vegetation within this urban landscape, reinforcing the importance of showing to the urban population that biodiversity conservation is not restricted to formally protected areas; therefore, requiring an integrated planning of the green infrastructure. Each of the elements of the green infrastructure has distinct historical uses and different levels of impact, presenting relevant functions within urban landscapes. But to achieve their full potential, it is important a holistic view that considers besides the organisms (human and nonhuman) directly affected by them, the social, environmental and economic roles in which they can be involved.

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Supporting Information

S1.1 Table: Values assigned to the elements of the supervised classification and of Belo Horizonte's land use type map.

Supervised classification	
Supervised Classification	**Value**
Arboreal Vegetation	1
Herbaceous Vegetation	2
Urban Elements	10
Belo Horizonte's land use type map	
City block lot’s use type	**Value**
Parks	100
Wastelands	200
Houses and Mansions	250
Leisure Facilities	300
Educational and Religious Institutions	350
Army	400
Commercial Buildings, Stores and Malls	450
Warehouses	500
Transport Stations	550
Slums	600
Residential Buildings	650
Antennas	700
Industries	750
Water	800
Mined Regions	850
no_data	0

S1.2 Table: Examples of results after the Map Algebra process

Value	Identification
1	Arboreal Vegetation in streets and squares
2	Herbaceous Vegetation in streets and squares
10	Streets and roads
101	Arboreal Vegetation within urban parks
102	Herbaceous Vegetation within urban parks
110	Leisure facilities within urban parks
251	Arboreal vegetation with houses - gardens
252	Herbaceous vegetation with houses - gardens
651	Arboreal vegetation with residential buildings - gardens
652	Herbaceous vegetation with residential buildings - gardens

Chapter 2

Street trees reduce the negative effects of urbanization on birds

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Myiozetetes similis

Street trees reduce the negative effects of urbanization on birds

João Carlos de Castro Pena, Felipe Martello, Milton C. Ribeiro, Richard A. Armitage, Robert J. Young and Marcos Rodrigues

Abstract

The effects of streets on biodiversity is an important aspect of urban ecology, but it has been neglected worldwide. Several vegetation attributes (e.g. street tree density and diversity) have important effects on biodiversity and ecological processes. In this study, we evaluated the influences of urban vegetation - represented by characteristics of street trees (canopy size, proportion of native tree species and tree species richness) - and characteristics of the landscape (distance to parks and vegetation quantity), and human impacts (human population size and exposure to noise) on taxonomic data and functional diversity indices of the bird community inhabiting streets. The study area was the southern region of Belo Horizonte (Minas Gerais, Brazil), a largely urbanized city in the understudied Neotropical region. Bird data were collected on 60 point count locations distributed across the streets of the landscape. We used a series of competing GLM models (using Akaike's information criterion for small sample sizes) to assess the relative contribution of the different sets of variables to explain the observed patterns. Seventy-three bird species were observed exploiting the streets: native species were the most abundant and frequent throughout this landscape. The bird community's functional richness and Rao's Quadratic Entropy presented values lower than 0.5. Therefore, this landscape was favoring few functional traits. Exposure to noise was the most limiting factor for this bird community. However, the average size of arboreal patches and, especially the characteristics of street trees, were able to reduce the negative effects of noise on the bird community. These results show the importance of adequately planning the urban afforestation process: increasing tree species richness, preserving large trees and planting more native trees species in the streets are management practices that will increase bird species richness, abundance and community functional aspects and consequently improve human wellbeing and quality of life.

Introduction

The expansion of urban landscapes is happening at an accelerated rate. By the year 2050, two-thirds of the human population will live in cities (United Nations, 2014), and about 60% of all the infrastructure intended to improve cities by 2030 has yet to be built (Secretariat of the Convention on Biological Diversity, 2012). The replacement of natural habitats by artificial elements – such as houses, buildings and streets – leads to disturbances and negative impacts on different biological taxa. To persist within cities, organisms need to adapt to the direct and indirect effects of environmental changes such as habitat loss and fragmentation, destruction of freshwater resources and introduction of exotic species (McDonald et al., 2013). Therefore, it is necessary to understand how these environmental changes affect the biodiversity and ecological processes essential for maintaining human quality of life and the functioning of urban ecosystems.

Birds are a highly diverse taxon and are sensitive to environmental changes in anthropogenic landscapes (Morante-Filho et al., 2015), wherein some species are more capable than others to occupy urban landscapes (Aronson et al., 2014; Blair, 1996; Chace and Walsh, 2006). Characteristics of the urban vegetation, such as street trees, gardens and natural habitat patches, are important for the maintenance of bird populations in cities (Litteral and Wu, 2012). Actions such as planting native tree species (Ikin et al., 2013), planning an ecological network connecting habitat patches (Hong et al., 2012) and ensuring the availability of resources for native fauna (Young et al., 2007) increase bird species richness, abundance and diversity as well as reducing the negative effects of the urbanization process, such as biotic homogenization (McKinney, 2006).

Despite the considerable amount of information about the effects of urban green elements, the urban matrix (Chace and Walsh, 2006), and roads on birds (van der Ree et al., 2011), little is known about how birds are influenced by disturbances and vegetation characteristics of streets. Traffic volume and the size of the vegetation gap affects the movement of songbirds (Tremblay and St. Clair, 2009) and traffic noise has an influence on antipredator behavior (Meillere et al., 2015), causing changes in song patterns (Arroyo-Solís et al., 2013).

However, when the urban vegetation is properly managed, streets need not be completely negative to urban birds. Species can use street trees to move between urban parks and habitat patches (Fernandez-Juricic, 2000). Streetscapes that contain predominantly native tree species, increase native bird species richness and abundance, and the bird community is more similar to that in natural habitat patches than in streetscapes, which are composed mainly of exotic tree species (White et al., 2005).

Since different bird species can use urban vegetation to different degrees (Litteral and Wu, 2012), such species differences must be taken into consideration when evaluating how urbanization affects bird communities. In recent decades, functional diversity approaches have been widely used to understand the influences of human activities on biodiversity. In general, this can be defined as the range and the value of functional traits (such as body mass and foraging substrate) of a determined community that influence ecosystem functioning (Tilman, 2001), thus incorporating the differences between species. Indices derived from this approach have the potential to reveal the processes that shape communities, and can help in understanding how biodiversity interacts with environmental constraints (Mouchet et al., 2010). The use of different indices has been considered a better strategy to assess all the functional aspects of a community, rather than try to represent them in a single value, such as functional diversity *per se* (Mason et al., 2005; Mouillot et al., 2013). Thus, the union between these indices and taxonomic information about the community makes it possible to identify groups of organisms that are sensitive to anthropogenic disturbances, as well as organisms that are able to live and exploit human-dominated landscapes.

However, knowledge about the effects of urbanization on birds is geographically biased—although Neotropical cities are undergoing one of the most rapid and intense urbanization processes (UnitedNations, Department of Economic and Social Affairs, 2014), they remain understudied (Ortega-Álvarez and MacGregor-Fors, 2011). Following the global trend, Neotropical cities are concentrated within and near highly productive areas such as coastal zones and major riverine systems (McDonald et al., 2013). Although Neotropical cities are highly urbanized, they suffer from some of the world's largest social and economic inequalities, which pose a threat to several biodiversity hotspots (Pauchard and Barbosa, 2013).

Considering the importance of understanding biodiversity in urban ecosystems, particularly on streets, this study aimed to assess how human impacts and urban vegetation –

represented by characteristics of street trees (canopy size, tree species richness and the proportion native tree species) and characteristics of the landscape (amount of vegetation and distance to parks) – influence bird species inhabiting the streets of a largely urbanized Neotropical city. We hypothesized that the negative effects of urbanization on birds (Chace and Walsh, 2006) from human impacts will have the strongest effect on taxonomic data and functional diversity indices of the urban bird community, followed by the characteristics of street trees (we expected this patterns since birds are highly influenced by the availability of resources – such as food and nesting places (Concepción et al., 2015)) and then the characteristics of the landscape (Fig. 2.1A). We also hypothesized that variables related to human impacts and the distance to parks will have negative influences on the taxonomic data and functional diversity indices (Fig. 2.1B), while the remaining characteristics of urban vegetation will have positive influences (Fig. 2.1C). Finally, we hypothesized that when urban vegetation and human impacts are considered in the same model, the former will influence positively the taxonomic data and functional diversity indices, despite the strongest negative effect of the human impacts (Fig. 2.1D). However, we expected that the distance to parks will negatively affect the urban bird community (Fig. 2.1E).

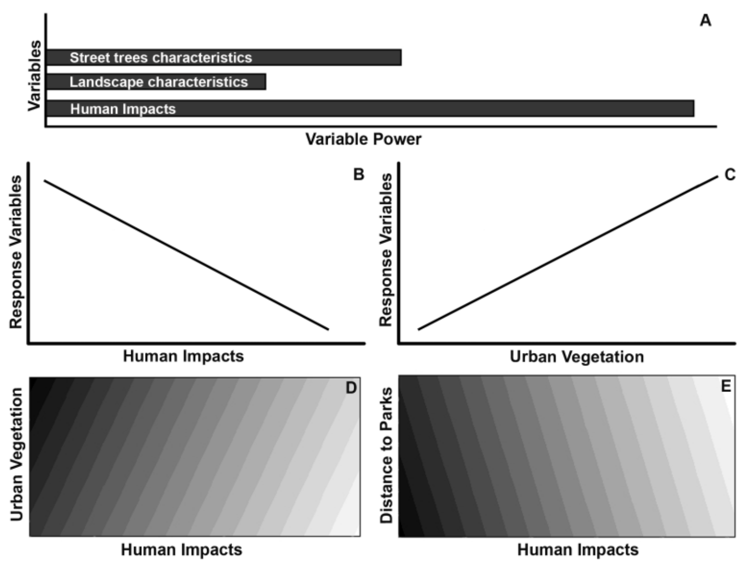

Figure 2.1: Fig. 1: Hypothesis of the effects of the urban vegetation (street trees and landscape characteristics) and human related variables on the urban bird community inhabiting streets. In Figures 1C and 1D, darker colors represent higher response variables values (taxonomic data and functional diversity indices).

Material and Methods

Study area

The study area was the southern region of Belo Horizonte city (W 19º 55' 37", S 43º 56' 34") one of the first planned cities in Brazil and the Minas Gerais state capital (Fig. 2.2). The southern region of Belo Horizonte covers 31.7 km², which includes the oldest part of the city (est. 1897), an area of approximately 9 km². According to the land use/land cover map developed by Pena et al. (2016), almost half of the study area is occupied by arboreal and herbaceous vegetation, concentrated at the southern portion of the study area within urban parks (Fig. 2.2). The rest of the landscape is composed of scattered green areas and public squares, and street trees composed mainly of exotic species (Pena et al., 2016). In our study area, it is possible to find Cerrado and Atlantic Forest remnants, as well as *campos rupestres* (rocky fields) and *campos de altitude* (high altitude fields) patches, typical mountain grasslands, located in the higher portions of the city (1300 to 1400 meters a.s.l.), which are located in the southern part of our study area (Fig. 2.2).

Point counts selection and bird community data

We selected 60 point count locations (Bibby et al., 2000) distributed in streets through the southern region of Belo Horizonte. Point selection aimed to represent the variation of the influences of the streets and arboreal and herbaceous vegetation within the study area. We sampled points that, within a 50 meters radius, have large amounts of arboreal and herbaceous vegetation but low street density, as well as points within the city center, with high street density, and small amount of herbaceous or arboreal vegetation (S2.1 Text, S2.1 Fig.). Point counts were at least 200 meters away from each other.

We conducted a pilot study to define the number of visits and the duration of the point counts, and we observed that three 20-minute visits were sufficient to obtain information about bird species richness in the streets of the study area. Fieldwork started 30 minutes after sunrise and extended during the first three hours of daylight on days with favorable weather (sunny and non-windy days). To define the point sampling order, the first point count was randomly selected. After 20 minutes of sampling, the observer walked to the next nearest sample point. This process was repeated during the first three hours of the day. Point counts were conducted only on working days to avoid great variation in people and vehicles in circulation.

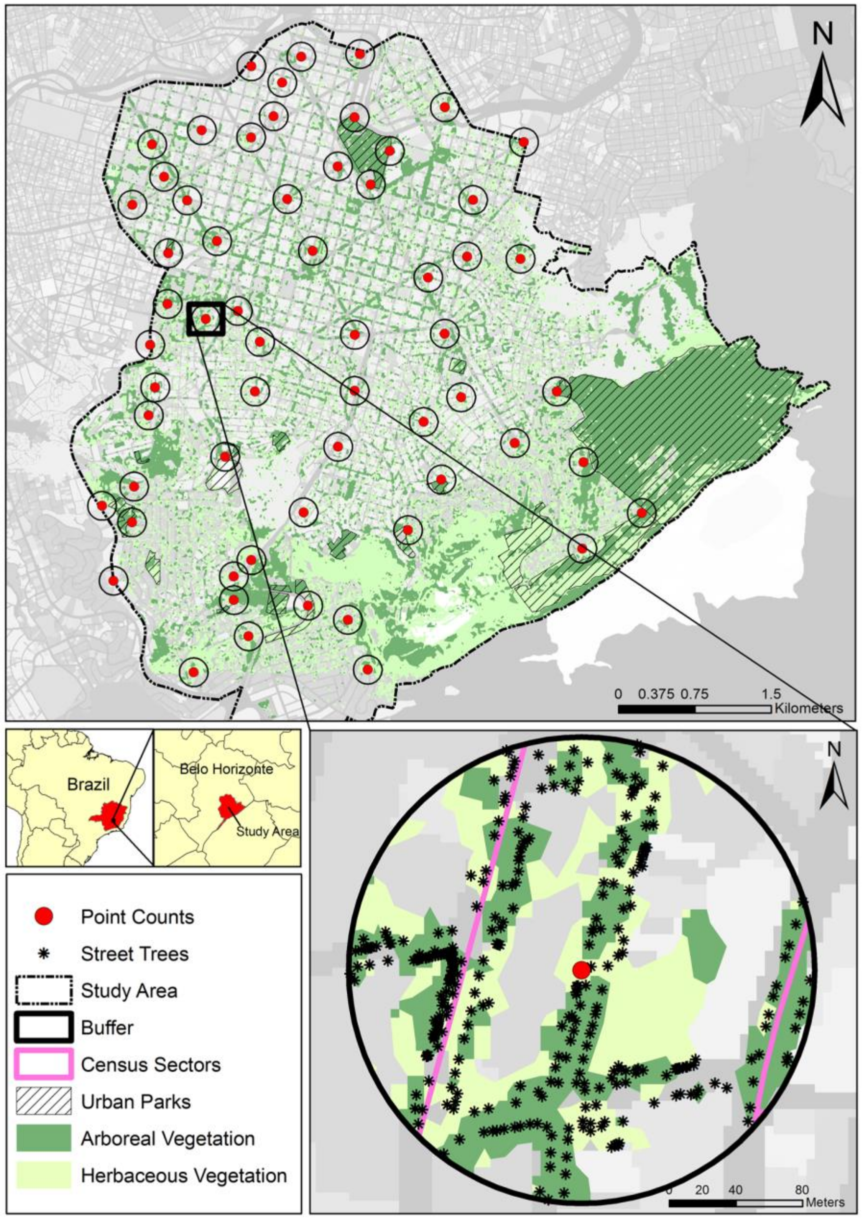

Figure 2.2: Southern region of Belo Horizonte (Minas Gerais, Brazil), with the point count locations where birds were observed on the streets of the study area. The circles represent 140m radius buffers around each sampling point. Urban vegetation elements and census sectors are highlighted within one of the 140m radius buffers. Arboreal and herbaceous vegetation data was obtained from Pena et al. (2016).

Point counts were conducted by one trained ornithologist (J.C.C. Pena) between September 2014 and January 2015. This period coincides with birds' breeding season, during which different migratory species visit Belo Horizonte (Rodrigues and Dias, 2009; Sick, 1997). All bird species (breeding and non-breeding birds) within a 50 m radius around the center of the point count were recorded visually or acoustically and counted. Monospecific flocks were considered to be up to a number of 20 individuals. The following behaviors were recorded: flying, resting or performing activities (e.g.: feeding, nesting). Birds suspected of being captive or pets were not included.

To analyze the effects of human impacts and urban vegetation on the urban bird community, we only considered species and individuals registered resting, feeding or nesting in the point count locations. Therefore, we excluded from our analysis species and individuals that were recorded only flying – they could be only moving through the urban landscape – and singing – they could be within an urban park or habitat patch nearby the point count. Thus, our analysis was limited to species that actually use the urban landscape. Individuals which were observed only flying or singing were recorded for inventory purposes only.

Response Variables

We used two taxonomic variables – species abundance (S_{Abund}) and richness (S_{Rich}) – and two functional diversity indices – Rao's Quadratic Entropy (RaoQ) and Functional Richness (FRic) as response variables. FRic represents the amount of functional space occupied by species in a community (Mouchet et al., 2010). It is independent of species abundance, being a representation of functional trait space filled by the community (Villéger et al., 2008). Low functional richness indicates that some of the resources potentially available to the community are unused (Mason et al., 2005). RaoQ incorporates species relative abundances and pairwise functional differences between species (Botta-Dukát, 2005). This index is an indirect measure of functional evenness, since the higher the value of RaoQ, the greater the dissimilarity between species, hence high functional evenness. To calculate the functional diversity indices aquatic species (we registered only one individual of great egret *Ardea alba*) and species that were not fully identified were not considered.

To calculate the functional diversity indices, we constructed a matrix containing two continuous traits and three categorical (fuzzy) traits (Table 2.1). The selected functional traits represent bird phenotypic characteristics which are influenced by environmental changes (Luck et al., 2012). Data for the functional traits were collected from published literature (Del Hoyo et al., 2004; Sick, 1997; Wilman et al., 2014).

Table 2.1: Functional traits used to calculate the functional diversity indices for the bird community inhabiting the streets of the southern region of Belo Horizonte, Minas Gerais, Brazil.

Trait category	Trait	Type of variable
Morphological	Body mass	Continuous
Reproductive effort	Clutch size	Continuous
Nesting substrate	Tree nester Shrub nester Primary excavator Secondary excavator Ground nester Brood parasite	Categorical
Foraging substrate	Ground Upper/medium foliage Lower foliage Air	Categorical
Diet	Mammals Amphibians Birds Carrion Invertebrates Fruits Seeds Flowers/néctar	Categorical

Prior to calculating the functional diversity indices, we converted the fuzzy variables to proportional variables (Pavoine et al., 2009). This was done using the prep.fuzzy function of the R (RCoreTeam, 2015) package ade4 (Dray et al., 2014). Subsequently, the trait matrix was converted to a distance matrix using the dist.ktab function. This final matrix was used to calculate the functional diversity indices in R using the function dbFD of the FD package (Laliberté et al., 2014).

Predictor variables

The information about human impacts and street trees and landscape characteristics were extracted from a buffer defined around the 60 point counts (Fig. 2.2). The buffer radius definition aimed to find a balance between the size of the area and the amount of information about the urban landscape. Thus, we used the average variety function of the zonal statistics tool of ArcGIS 10.4.1 software to evaluate the amount of information of the land use/ land cover map (Pena et al., 2016) within buffers of different sizes (50 to 180m radius). We observed that 140m radius buffer size was the most informative (Fig. 2.2, S2.2 Fig.). Therefore, instead of using the 50m radius used to collect information about the urban bird community, we decided to use the 140m radius buffer to extract the following eight predictor variables (Table 2.2), since it provided more information about this urban landscape. For more information about the predictor variables definition see S2.2 Text.

Table 2.2: Predictor variables selected to assess the influences of human impacts and urban vegetation on taxonomic data and functional diversity indices of the bird community inhabiting the streets of Belo Horizonte (Minas Gerais, Brazil).

Variable category	Variable
Human impacts	Exposure to noise
	Human population
Trees characteristics	Proportion of the abundance of native street tree species
	Steet tree species richness
	Average diameter of street trees canopy
Landscape characteristics	Average arboreal patch size
	Average herbaceous patch size
	Average distance to parks

The human impact related variables were exposure to noise and the number of inhabitants (Table 2.2). A decibel meter (model Instrutherm DEC-490) was used to measure the sound pressure level at each point count location simultaneously with the bird sampling data. The decibel meter was calibrated (model Instrutherm CAL-4000) every day before data collection. An Equivalent Continuous Sound Level (L_{eq}) index was calculated each sampling day for each point count, and the exposure to noise was measured through the calculation of the average L_{eq}. This index is a measure of the overall level of exposure to sound in the environment. The human population (H_{pop}) inside each buffer was estimated through data from the population census of the Brazilian Institute of Geography and Statistics from the year 2010 (IBGE, 2010). The proportion of people living inside of the area of the census sectors that overlapped the area of each buffer was calculated (Fig. 2.2).

The landscape characteristics were the average arboreal patch size (Arb_{patch}), the average herbaceous patch size ($Herb_{patch}$), and the average distance to parks ($Dist_{parks}$) (Table 2.2). Vegetation patches were comprised by clusters of pixels that were composed of arboreal or herbaceous vegetation in the land use/land cover map of the study area (Pena et al., 2016) (Fig. 2.2). The average distance to parks for each point count was calculated using average Euclidian distance from all urban parks located within the study area (Fig. 2.2).

The characteristics of street trees were the average diameter of the trees' canopies (T_{canopy}), tree species richness, (T_{rich}), and the proportion of the abundance of native tree species (T_{native}) (Table 2). This information was acquired from Belo Horizonte's Tree Information System (SIIA-BH), which was designed to register information on street trees to promote the creation of a management tool (BeloHorizonte, 2015). Belo Horizonte municipal government consider these trees to be part of its ecological, landscape and cultural patrimony (BeloHorizonte, 2015). Approximately 90,000 street trees of 475 species were inventoried and georeferenced through the southern region of Belo Horizonte. We extracted only the street trees that were located within the 140m radius buffers around the point counts (Fig. 2.2).

Statistical analysis

We generated Generalized Linear Models (GLMs) between the response variables (species abundance, species richness, FRic and RaoQ) and the predictor variables. First, we performed a sensitivity analysis through the src function in R – a sensitivity package – to identify the influence of each predictor variable on the response variables; those predictor variables explaining less than 5% of variation were excluded from following analyses (S2.3 Fig). Therefore, each response variable has a distinct set of candidate models, composed of the most relevant combinations of predictor variables (S2.1 Table, S2.3 Fig). Most models were univariate, but we also compared multivariate additive models combining human impacts with landscape and street trees characteristics. To verify if the models were better than would be expected by chance, we included a null model representing the absence of effect of predictor variables. For the functional diversity indices, GLMs were generated with Gaussian distribution. For species richness and species abundance, Poisson distribution was used. Average arboreal patch size, average herbaceous patch size and human population were log-transformed.

We used a competing model selection approach to select the most plausible models (Burnham and Anderson, 2002). For each model, we calculated Akaike's information criterion for small sample sizes (AICc), and the difference in AICc between each model and the model with the lowest AICc (ΔAICc). Models with ΔAICc < 2.0 were considered to have substantial support (Burnham and Anderson, 2002), and then equally plausible. Furthermore, predicted relationships between response variables and the predictor variables included in the models with the lowest AICc value were plotted. Considering all combinations, we generated 15 candidate models for species richness, 8 models for FRic and 12 models for species abundance and RaoQ (S2.1 Table). Statistical analyses were carried out using the R packages AICcmodavg, MuMin, sensitivity and vegan (Mazerolle, 2016; Oksanen et al., 2016; Pujol et al., 2016).

Results

Seventy three bird species were registered [almost 20% of all species registered in Belo Horizonte territory, which includes wetlands and natural habitat patches such as Atlantic Forest and Cerrado remnants – (Melo-Júnior et al., 2013)], distributed in 26 families and 12 orders (Table 2.3). The most diverse family in terms of number of species was Tyrannidae, which represented almost 30% of the observed species (Table 2.3). The number of species registered in each point count location varied between 1 to 25 ($\bar{x}$=12.75, sd±4.47); 3143 individuals were counted, and varied from 2 to 143 per point count ($\bar{x}$=52.38, sd±30.93). The point count with a single species was excluded from our analysis, as it was not possible to calculate the functional diversity indices.

Table 2.3: Bird species observed resting or performing behaviors (such as nesting or feeding), and the total number of individuals (abundance) and number of point counts in which they were observed through the streets of the southern region of Belo Horizonte (Minas Gerais, Brazil). Scientific names and taxonomic order according to Piacentini et al. (2015).

Order	Family	Species	Frequency	Abundance
Pelecaniformes	Ardeidae	*Ardea alba*	1	1
Cathartiformes	Cathartidae	*Coragyps atratus*	1	1
Accipitriformes	Accipitridae	*Rupornis magnirostris*	1	2
Columbiformes	Columbidae	*Columbina talpacoti**[#]	45	423
		*Columba livia**	30	357
		Patagioenas picazuro[#]	46	216
		Patagioenas cayennensis	1	4
Cuculiformes	Cuculidae	*Piaya cayana*	12	18
		Crotophaga ani	1	2
Strigiformes	Strigidae	*Athene cunicularia*	1	1
Apodiformes	Trochilidae	*Eupetomena macroura*	43	93
		Anthracothorax nigricollis	1	1
		Chlorostilbon lucidus	1	1
		Amazilia lactea	13	21
		Trochilidae sp.	2	2
Piciformes	Picidae	*Picumnus cirratus*	3	3
		Colaptes campestris	1	1
		Colaptes melanochloros	2	2
Falconiformes	Falconidae	*Caracara plancus*	4	5
		Milvago chimachima	4	6

		Falco sparverius	2	2
Psittaciformes	Psittacidae	*Psittacara leucophthalmus*	6	37
		Forpus xanthopterygius	6	33
		Brotogeris chiriri	14	152
Passeriformes	Thamnophilidae	*Thamnophilus caerulescens*	1	1
	Furnariidae	*Furnarius rufus*	16	43
	Tyrannidae	*Camptostoma obsoletum*	1	4
		Elaenia flavogaster	9	25
		Serpophaga subcristata	3	10
		Myiarchus ferox	2	3
		Myiarchus tyrannulus	3	4
		Pitangus sulphuratus[#]	46	193
		Machetornis rixosa	10	16
		Myiodynastes maculatus	2	2
		Megarynchus pitangua	10	21
		Myiozetetes similis	30	72
		Tyrannus melancholicus[#]	53	251
		Tyrannus savana	4	6
		Empidonomus varius	25	57
		Colonia colonus	2	4
		Myiophobus fasciatus	1	1
		Fluvicola nengeta	7	11
		Lathrotriccus euleri	1	1
		Knipolegus lophotes	1	1
		Satrapa icterophrys	1	1
		Xolmis cinereus	4	6
	Hirundinidae	*Pygochelidon cyanoleuca*	3	15
		Progne tapera	1	3
	Troglodytidae	*Troglodytes musculus*	10	18
	Turdidae	*Turdus leucomelas*	26	62
		Turdus rufiventris	2	2
		Turdus amaurochalinus	29	54
	Mimidae	*Mimus saturninus*	16	51
	Passerellidae	*Zonotrichia capensis*	2	7

Parulidae	*Geothlypis aequinoctialis*	1	2
	Basileuterus culicivorus	2	4
Icteridae	*Chrysomus ruficapillus*	1	10
	Molothrus bonariensis	19	33
Thraupidae	*Tangara sayaca*	41	125
	Tangara palmarum	12	25
	Tangara ornata	1	2
	Tangara cayana	14	37
	Sicalis flaveola	8	39
	Hemithraupis ruficapilla	1	2
	Volatinia jacarina	6	23
	Dacnis cayana	2	4
	Coereba flaveola	42	142
	Sporophila collaris	1	1
	Sporophila nigricolis	1	3
	Sporophila sp.	2	5
Fringillidae	*Euphonia chlorotica*	5	12
Estrildidae	*Estrilda astrild*	8	76
Passeridae	*Passer domesticus**	39	268

*** Most abundant species**

 # Species most frequently observed throughout the point count locations

The most abundant species was the ruddy ground-dove *Columbina talpacoti* (423 individuals; 13% of all individuals), followed by two exotic species, the rock dove *Columba livia* (357 individuals; 11%) and the house sparrow *Passer domesticus* (268 individuals; 8.5%) (Table 2.3). Summed they represented 33% of all registered individuals. Most species (64 species, 87%) were represented by less than 100 individuals (Table 2.3). The tropical kingbird *Tyrannus melancholicus* was the most widely observed species in 88% of the point counts, followed by the Picazuro pigeon *Patagioenas picazuro*, the great kiskadee *Pitangus sulphuratus* and the ruddy ground-dove, which were recorded at c.a. 75% of the point counts (Table 2.3). Most species were observed in few point counts, there were 42 species (58%) registered in less than five point counts (Table 2.3).

RaoQ and FRic index scores were generally low, varying from 0.042 to 0.161 and from 0.001 to 0.409, respectively. Exposure to noise was included in all the best ranked models (Table 2.4), negatively affecting species richness, species abundance, FRic and RaoQ (Table 2.4, Figs 2.3 and 2.4). The univariate model containing exposure to noise was the most plausible model for species richness (wAICc = 0.292), FRic (wAICc = 0.390) and RaoQ (wAICc = 0.419) (Table 2.4, Fig. 2.3). Five different patterns were found in the multivariate models with the exposure to noise (Fig. 2.4). In general, the street trees and landscape characteristics had positive effects on the response variables, even with the negative effects of the exposure to noise (Table 2.4, Fig. 2.4). However, average distance to parks had positive effects on RaoQ (Fig. 2.4C) and the average size of the canopy of street trees had negative effects on FRic (Fig. 2.4D), contradicting our expectations. The remaining models of FRic, RaoQ and species richness presented similar patterns to the ones shown in Figs 2.4A, 2.4C and 2.4E, respectively (S4 Fig.). Human population and the average herbaceous patch size did not contribute to explaining patterns in the response variables (S2.1 Table).

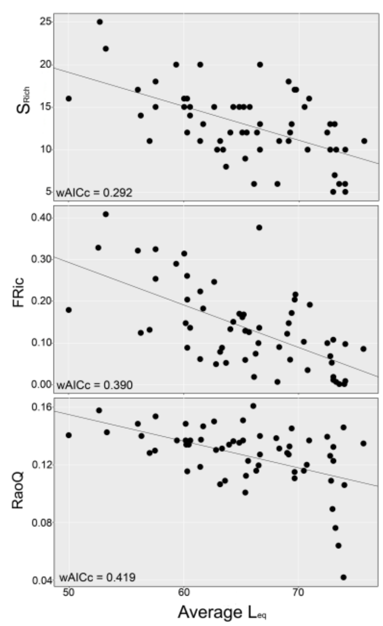

Figure 2.3: Best ranked univariate models, showing the negative influence of the exposure to noise (Average Equivalent Continuous Sound Level - L_{eq}) on species richness (S_{Rich}), functional richness (FRic) and Rao's Quadratic Index (RaoQ), of the bird community inhabiting the streets of Belo Horizonte (Minas Gerais, Brazil).

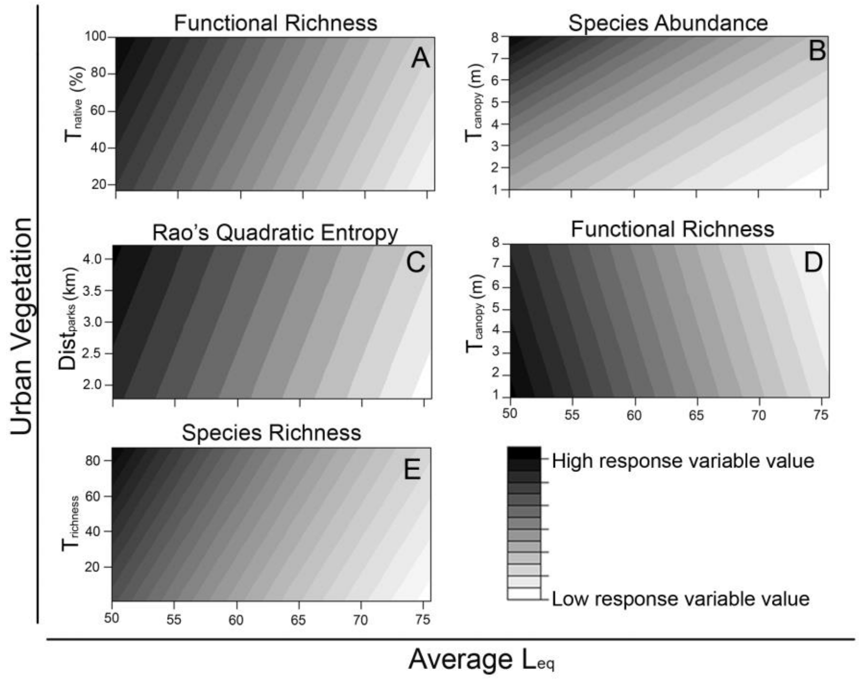

Figure 2.4: Patterns obtained in the multivariate models assessing the effects of the exposure to noise (Average Equivalent Continuous Sound Level - L_{eq}) and urban vegetation variables on the taxonomic data and functional diversity indices of the bird community inhabiting the streets of Belo Horizonte (Minas Gerais, Brazil). T_{native}: proportion of the abundance of native street tree species; T_{rich}: street tree species richness; T_{canopy}: average diameter of street trees canopy; $Dist_{parks}$: average distance to parks.

Table 2.4: Best ranked models (AICc > 2.0) showing the influences of the exposure to noise (Average Equivalent Continuous Sound Level - L_{eq}) and vegetation variables on taxonomic data and functional diversity indices of the urban bird community inhabiting the streets of the southern region of Belo Horizonte, Minas Gerais, Brazil.

Response Variable	Model	ΔAICc	wAICc	Slope sign
S_{Ric}	$\sim L_{eq}$	0	0.292	-
	$\sim L_{eq} + T_{native}$	0.158	0.270	-
	$\sim L_{eq} + Arb_{patch}$	1.034	0.174	-
	$\sim L_{eq} + T_{rich}$	1.211	0.159	-
S_{Abund}	$\sim L_{eq} + T_{canopy}$	0	1	-

FRic	$\sim L_{eq}$	0	0.390	-
	$\sim L_{eq} + Arb_{patch}$	0.835	0.257	-
	$\sim L_{eq} + T_{native}$	1.458	0.188	-
	$\sim L_{eq} + T_{canopy}$	1.732	0.164	+
RaoQ	$\sim L_{eq}$	0	0.419	-
	$\sim L_{eq} + Dist_{parks}$	1.350	0.213	-
	$\sim L_{eq} + Arb_{patch}$	1.422	0.206	-
	$\sim L_{eq} + T_{canopy}$	1.932	0.160	-

S_{Rich}: species richness; S_{Abund}: species abundance; FRic: functional richness; RaoQ: Rao's Quadratic Entropy; T_{native}: proportion of the abundance of native street tree species; T_{rich}: street tree species richness; T_{canopy}: the average diameter of street tree canopy; Arb_{patch}: average arboreal patch size; $Dist_{parks}$: average distance to parks.

Discussion

Street trees reduced the negative effects of the exposure to noise on the urban bird community inhabiting the streets of a Neotropical city. Urban areas with higher proportion of native street tree species and higher street tree species richness had a greater number of bird species and higher functional richness, even with the negative effects of the exposure to noise. Regions with larger trees had a greater number of birds across all species and less dominance of functional traits. Therefore, the urban bird community was more influenced by characteristics of street trees than characteristics of the landscape.

The lack of influence of the average herbaceous patch size is probably related to the reduced amount of native open habitat patches through this landscape. The majority of herbaceous vegetation patches were composed of cultivated lawns, squares and gardens, and utilized by open habitat generalist species such as the shiny cowbird (*Molothrus bonariensis*), the cattle tyrant (*Machetornis rixosa*) and the saffron finch (*Sicalis flaveola*). These species are commonly found in Belo Horizonte and other urban landscapes in southeastern Brazil (Rodrigues and Dias, 2009; Sick, 1997). Moreover, human population was not significant in any of the most plausible models, indicating that even in highly populated and dynamic urban centers it is possible to find a considerable amount of native biodiversity.

Effects on species and taxonomic variables

On the streets of the southern region of Belo Horizonte it was possible to find 20% of all bird species recorded in the city's territory (Melo-Júnior et al., 2013). To persist within the urban matrix, bird species need to adapt to an intense interaction with humans and different environmental impacts (Chace and Walsh, 2006). Therefore, only few species – defined as "urban exploiters" and "suburban adapters" (Blair, 1996) – will be able to exploit the reduced amount of resources and stressful conditions of streets. The environmental filter caused by the urbanization process (Meffert and Dziock, 2013; Sandström et al., 2006), makes the most sensitive species locally extinct and generalist species, especially omnivorous species become dominant (Clergeau et al., 1998). However, bird communities have different responses to urbanization worldwide. While in temperate urban landscapes urban bird communities are composed mostly of omnivorous and seed eaters (Blair and Johnson, 2008; Chace and Walsh, 2006; Clergeau et al., 1998; Jokimäki et al., 2016; Lindsay et al., 2002), in Neotropical urban centers (as observed in Belo Horizonte), omnivorous and insectivorous species are dominant (de Toledo et al., 2012; Ortega-Álvarez and MacGregor-Fors, 2009; Ponço et al., 2013; Reis et al., 2012). Urban bird communities are shaped by the availability of resources (Clergeau et al., 1998). Unlike temperate urban landscapes, warmer temperatures of most Neotropical cities probably allow for larger populations of insects and the presence of a larger number of insectivirous birds species. Different groups of arthropods are abundant in urban landscapes, such as generalist ground arthropods, plant-feeding arthropods and generalist pollinating arthropods (Faeth et al., 2005). Domestic wastes also provide opportunities for insectivorous birds to feed on insects such as flies and mosquitoes (Gatesire et al., 2014). Furthermore, the high diversity of tyrant flycatchers (Tyrannidae) in Neotropical cities (de Toledo et al., 2012; Fontana et al., 2011; Ortega-Álvarez and MacGregor-Fors, 2009; Ponço et al., 2013; Reis et al., 2012), probably have a positive effect on the larger number of insectivorous species that occupy Neotropical urban landscapes.

The negative effects of the exposure to noise on urban birds has been evaluated in many studies (Fontana et al., 2011; Meillere et al., 2015; Tremblay and St. Clair, 2009). However, our study is the first to assess, at the landscape level, how the exposure to noise influences the bird community occurring in the streets of an urban landscape. Noise intensity can be considered as a proxy for other negative effects within streets: the higher the exposure to noise, the greater the impacts associated with urbanization, and therefore, the smaller the number and abundance of bird species able to occupy streets. Our results show that, in addition to helping species conservation within protected areas (Ikin et al., 2013, 2012), the appropriate planning and management of the urban afforestation process – such as increase the number of large and native tree species in the streets – is able to mitigate the negative effects of the urbanization on birds that occupy the urban matrix. Urban bird species richness is positively influenced by the amount of native street tree species (Ikin et al., 2013; Reis et al., 2012; Shackleton, 2016; Threlfall et al., 2016; White et al., 2005). This is related to birds' preferences for native tree species as nesting sites (Shackleton, 2016) and the availability of resources, such as arthropods, which is higher in native trees (Bhullar and Majer, 2000). Larger trees increase canopy complexity and provide critical resources for the native fauna inhabiting urban landscapes, such as a large contribution to flower, fruit and seed production and provision of cavities (Lindenmayer et al., 2014). Therefore, large trees have a strong positive effect on different taxa, increasing species abundance and richness, and are considered keystone ecological structures in urban landscapes (Le Roux et al., 2014; Lindenmayer et al., 2014; Stagoll et al., 2012; Threlfall et al., 2016). Furthermore, trees also can act as sound barriers causing sound to disperse and dissipate (Fan et al., 2010).

The reduced influence of the distance to urban parks on bird species richness and number of individuals is probably related to the high efficiency of the local avifauna in exploring this urban landscape – the most frequent species in our landscape were native bird species, such as the ruddy ground-dove, the great kiskadee and the Picazuro pigeon. Bird species inhabiting streets may efficiently move through the landscape, perceiving the urban matrix as a *continuum* of habitats, and are influenced by local conditions such as the characteristics of street trees (Young et al., 2007). However, species composition change with the distance to urban parks, and this is confirmed by the functional diversity results.

Effects on functional diversity indices

Community's functional aspects presented low values across the streets of the southern region of Belo Horizonte, which corroborates the results for the taxonomic richness. Probably, the resources available across the landscape are low (Mason et al., 2005), filtering species that have specific ecological requirements. Most bird species found in this study are omnivorous, feeding on invertebrates and/or using human-made structures as nesting substrates, leading to a reduction in the community's functional richness. This result is confirmed through the low RaoQ index scores, showing that species with similar functional traits are dominant. The urbanization process leads to a reduction in the amount of bird species' traits, particularly in traits related to resource use and nesting substrate (Concepción et al., 2016; Jokimäki et al., 2016). However, our results are in accordance with another study, in which the increase in the amount of arboreal vegetation led to an increase in the community's functional aspects (Schütz and Schulze, 2015). The increase in the proportion of native street tree species influence the presence of a larger amount of bird feeding guilds in urban landscapes (Ikin et al., 2013; White et al., 2005), and consequently had positive influences on community's functional richness.

Urban landscapes have large quantities of resources for a portion of the avifauna with similar functional traits (Concepción et al., 2016; Jokimäki et al., 2016) – which is related to the general low functional richness and RaoQ index scores. Since synanthropic species are negatively influenced by the amount of habitat within urban landscapes (Litteral and Wu, 2012), urban areas with more available habitat will allow the presence of species with functional traits related to the most preserved areas, leading to changes in the functional diversity indices. The average canopy size of the street trees increases community's RaoQ and leads to a reduction in the community's functional richness. Probably, the increase in canopy size reduces the richness and abundance of a larger number of species that have functional traits related to more urbanized areas; the increase in number of birds, probably, is related to an increase in the abundance of fewer species, which have functional traits related to more preserved areas. This process increases community's functional evenness with a lower number of functional traits. The proximity to parks can reduce the total number of individuals for many bird species, which have functional characteristics related to the more urbanized areas (Concepción et al., 2016, 2015). However, species that need a greater amount of habitat, probably, are favored, reducing taxonomic evenness without changing the taxonomic and functional richness, consequently reducing RaoQ. Therefore, despite the bird community inhabiting streets being composed mostly of species adapted to the conditions related to the urbanization process, it is possible to increase the number of species with functional traits related to most preserved environments.

Conclusions

We demonstrated that the urban environmental filter has negative effects on urban avifauna. However, human impacts can be mitigated by the appropriate planning and management of urban vegetation, especially related to the urban afforestation process. The maintenance of large trees, increasing street tree richness and planting of a larger amount of native tree species are management practices able to increase urban biodiversity and ecosystem functionality within the urban matrix.

"We need nature as much in the city as in the countryside" was written by Ian McHarg in 1969 in his book *Design with nature* (McHarg, 1969). Fifty years later, we still need to learn how to enhance, preserve and live with biodiversity within urban landscapes. With the current planning and management practices, Belo Horizonte is only able to retain 20% of its rich and diverse bird community within the urban matrix. Therefore, we need to change the current focus on a purely aesthetic and utilitarian view of the urban afforestation process (Moro and Castro, 2015); decisions must consider the functionality of the urban landscape and the green elements as interconnected units (Herzog, 2016, 2013). Considering that bird species can be used as indicators of urban ecological integrity (Ortega-Álvarez and MacGregor-Fors, 2009), planning and management practices, especially those related to street trees identified here and in other studies (e.g.: Fontana et al., 2011; Ikin et al., 2013; Jokimäki et al., 2016; Reis et al., 2012; Stagoll et al., 2012; White et al., 2005; Young et al., 2007) are able to reduce the negative effects of urbanization on biodiversity and consequently enhance human wellbeing and quality of life.

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Supporting Information

S2.1 Text: Point counts' selection

To evaluate the influence of the urbanization on the bird community inhabiting the streets of the southern region of Belo Horizonte, the selection of sampling points aimed to consider the maximum possible interactions between urban features and the remaining arboreal and herbaceous vegetation. Thus, we adopted the methodology described below.

From the land use/land cover map [1] in raster format, we extracted, independently, the pixels containing information on built-up area, arboreal vegetation, herbaceous vegetation, and streets. In each of the four maps, the intensity in which each pixel is influenced by each variable was evaluated through a moving window with 50m radius (half of the size of a city block in Belo Horizonte – 100m). Thus, we obtained four maps classified in values between zero and one. Pixels with values closer to zero are related to a low influence of that land use type (indicating, for example, low influence of arboreal vegetation), and pixels with values closer to one are related to a high influence of that land use type (high influence of streets or build-up area, for example). The average intensity of the streets' map moving window is 0.29, arboreal map moving window is 0.40, herbaceous map moving window is 0.41 and build-up area map moving window is 0.54.

We then used the R software to assess the degree of correlation between streets and build-up area and the vegetation features (as the variables did not have a normal distribution, we used the Spearman coefficient). The built-up area map showed a high degree of correlation (0.64 $p < 0.05$) compared to the streets map (0.34 $p < 0.05$), therefore, it was excluded from our analysis. Thus, the three remaining moving window maps were reclassified to categorical values representing intensities of influence: streets 1 – 4; arboreal vegetation: 10 – 40; herbaceous vegetation: 100 – 400. Then the map algebra process was used to sum these three maps, and it was obtained a final map containing 20 categories of interactions between the three land use types (S1 Fig.).

In this final map were randomly created 10,000 points, from which we selected 3 points in each of the categories of land use interactions. These points were distributed throughout the

streets of the study area and were at least 200 meters away from each other (S1 Fig.). The distribution of points between and in the same category aimed to achieve the greatest latitudinal and longitudinal range within the study area. Points located nearby or within risk areas (such as irregular occupations/slums) were not selected. The selected 60 point counts were distributed in regions with large amounts of arboreal and herbaceous vegetation but with low streets density, as well as within the city center, with
high streets density, and small amount of herbaceous and arboreal vegetation (S1 Fig.). All spatial analyzes were carried out using Grass GIS 6.4 software.

S2.2 Text: Definition of predictor variables

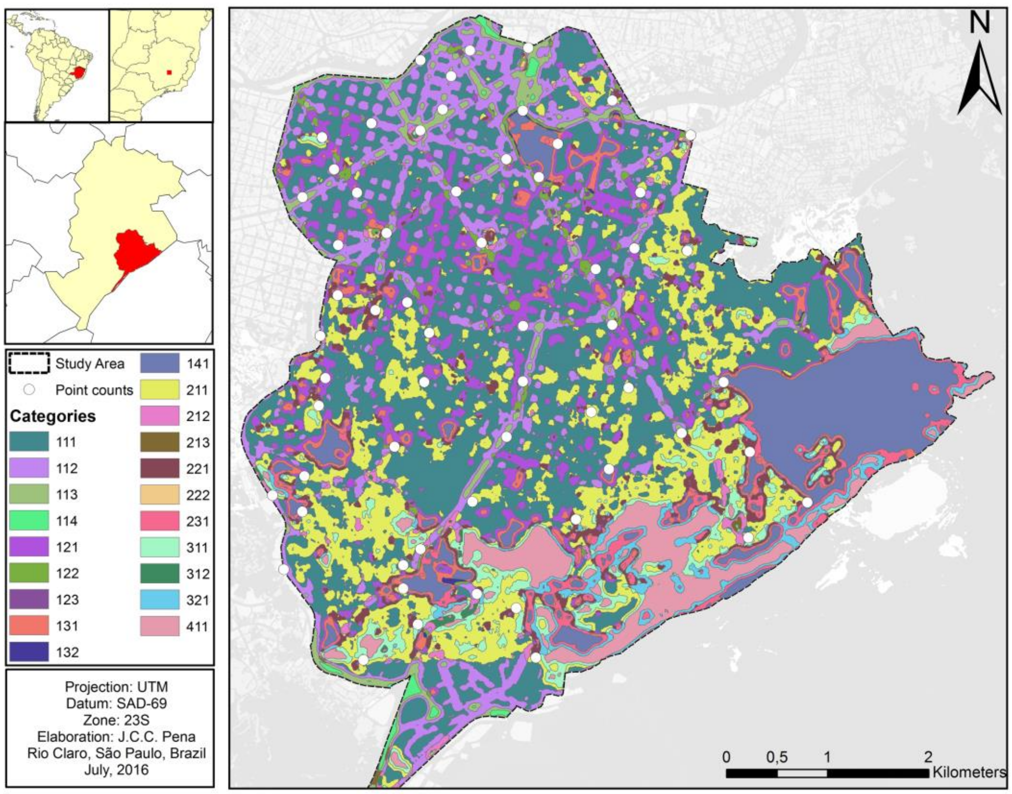
We selected 17 variables that we considered to be highly influential on the bird community inhabiting the streets: average distance to parks; human population size; average Equivalent Continuous Sound Level; average building height; proportion of vegetation within the buffer; the average arboreal patch size; the average herbaceous patch size; the average size of the canopy of the street trees; diversity of street trees (Shannon index); street tree richness; street tree abundance; the number of native street tree species; the proportion of native street tree species; the abundance of native street tree species; the proportion of the abundance of native street tree species; the abundance of fleshy fruit trees in the streets; the abundance of flowering trees in the streets.

A Principal Component Analysis (PCA) was performed to reduce the number of variables on principal component axes that retained as much variability as possible of our predictor variables. We retained the eight predictor variables described in the main text, that were highly correlated with the first four principal components. These four PCA axes explained 76% of landscape variance.

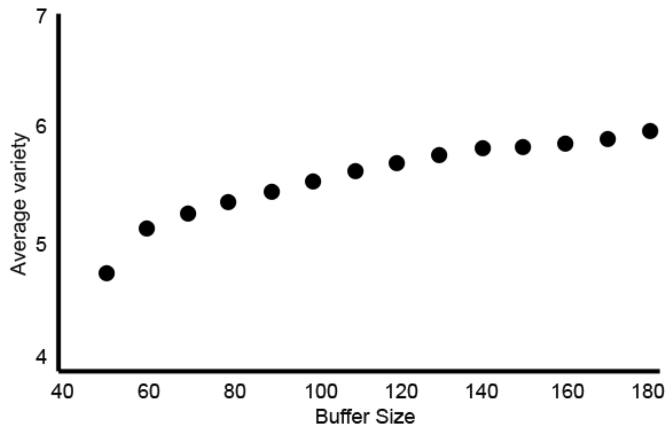
S2.1 Table: Candidate models defined for the response variables related to the bird community inhabiting the streets of the southern region of Belo Horizonte (Minas Gerais, Brazil), highlighting models with ΔAICc < 2.0.

Response variable	Candidate Model	k	ΔAICc	wAICc
S_{Rich}	**$\sim L_{eq}$**	**2**	**0.000**	**0.292**
	$\sim L_{eq} + T_{native}$	**3**	**0.158**	**0.269**
	$\sim L_{eq} + Arb_{patch}$	**3**	**1.034**	**0.174**
	$\sim L_{eq} + T_{rich}$	**3**	**1.211**	**0.159**
	$\sim L_{eq} + Dist_{parks}$	3	2.047	0.105
	$\sim T_{rich}$	2	14.226	< 0.001
	$\sim H_{pop} + T_{rich}$	3	16.303	< 0.001
	$\sim Arb_{patch}$	2	22.774	< 0.001
	$\sim T_{native}$	2	22.874	< 0.001
	~null	1	23.153	< 0.001
	$\sim Dist_{parks}$	2	24.232	< 0.001
	$\sim H_{pop} + Arb_{patch}$	3	24.764	< 0.001
	$\sim H_{pop} + T_{native}$	3	24.979	< 0.001
	$\sim H_{pop}$	2	25.287	< 0.001
	$\sim H_{pop} + Dist_{parks}$	3	26.453	< 0.001
S_{Abund}	**$\sim L_{eq} + T_{canopy}$**	**3**	**0.000**	**1.000**
	$\sim L_{eq} + Dist_{parks}$	3	35.421	< 0.001
	$\sim L_{eq} + Arb_{patch}$	3	68.819	< 0.001
	$\sim L_{eq}$	2	68.919	< 0.001
	$\sim H_{pop} + Dist_{parks}$	3	98.160	< 0.001
	$\sim Dist_{parks}$	2	101.464	< 0.001
	$\sim H_{pop} + T_{canopy}$	3	129.930	< 0.001
	$\sim T_{canopy}$	2	132.318	< 0.001
	~null	1	148.887	< 0.001
	$\sim H_{pop}$	2	149.107	< 0.001
	$\sim H_{pop} + Arb_{patch}$	3	150.546	< 0.001
	$\sim Arb_{patch}$	2	150.739	< 0.001
FRic	**$\sim L_{eq}$**	**3**	**0.000**	**0.390**
	$\sim L_{eq} + Arb_{patch}$	**4**	**0.835**	**0.257**
	$\sim L_{eq} + T_{native}$	**4**	**1.458**	**0.188**
	$\sim L_{eq} + T_{canopy}$	**4**	**1.732**	**0.164**
	$\sim T_{canopy}$	3	23.735	< 0.001
	~null	2	26.731	< 0.001
	$\sim Arb_{patch}$	3	26.860	< 0.001
	$\sim T_{native}$	3	28.158	< 0.001
RaoQ	**$\sim L_{eq}$**	**3**	**0.000**	**0.419**
	$\sim L_{eq} + Dist_{parks}$	**4**	**1.350**	**0.213**

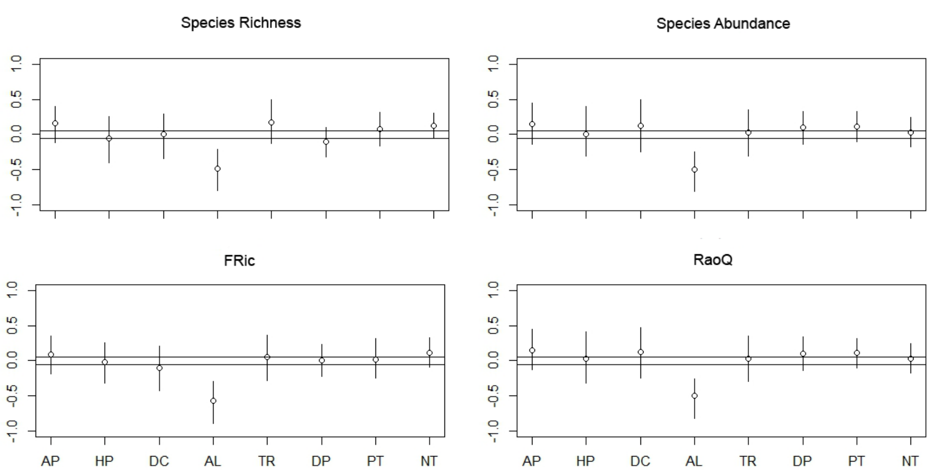
~L_{eq} + Arb_{patch}	**4**	**1.422**	**0.206**
~L_{eq} + T_{canopy}	**4**	**1.932**	**0.160**
~null	2	13.059	0.112
~Arb_{patch}	3	13.825	0.076
~T_{canopy}	3	14.655	0.050
~$Dist_{parks}$	3	15.058	0.041
~H_{pop}	3	15.137	0.039
~H_{pop} + Arb_{patch}	4	15.660	0.031
~H_{pop} + T_{canopy}	4	15.687	< 0.001
~H_{pop} + $Dist_{parks}$	4	17.163	< 0.001



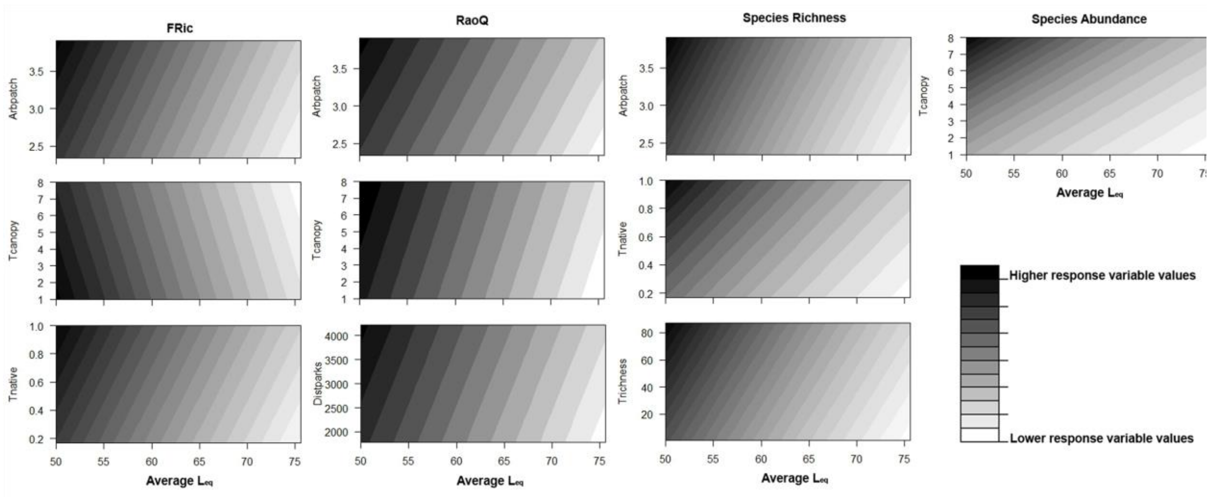
S2.1 Figure: The 60 point counts selected within 20 categories of influences of herbaceous and arboreal vegetation and streets through the southern region of Belo Horizonte (Minas Gerais, Brazil).



S2.2 Figure: Variation of the average variety of land use types of the southern region of Belo Horizonte (Minas Gerais, Brazil) within buffers with different sizes.



S2.3 Figure: Sensitivity analysis performed for species richness, species abundance, functional richness (FRic) and Rao's Quadratic Entropy (RaoQ) of the bird community inhabiting the streets of the southern region of Belo Horizonte. Only predictor variables located outside the range of 0.05 and -0.05 (black lines) were considered. It is possible to observe the large effect of the exposure to noise on the taxonomic and functional aspects of the urban bird community. AP: average arboreal patch size; HP: average herbaceous patch size; DC: average size of the canopy of street trees; AL: average Equivalent Continuous Sound Level; TR: street tree richness; DP: average distance to parks; PT: human population; NT: proportion of the abundance of native tree species in the streets.



2.4 Figure: Multivariate additive models showing the influences of urban environmental variables on taxonomic data and functional diversity indices of the bird community inhabiting the streets of the southern region of Belo Horizonte (Minas Gerais, Brazil). S_{Ric}: Species richness; S_{Abund}: Species abundance; FRic: Functional richness; RaoQ: Rao's Quadratic Index; L_{eq}: Average Equivalent Continuous Sound Level; T_{native}: proportion of the abundance of native street tree species; T_{rich}: street tree species richness; T_{canopy}: the average diameter of street tree canopy; Arb_{patch}: the average arboreal patch size; $Dist_{parks}$: the average distance to parks.

Chapter 3

Defining urban landscape networks for birds using least cost path modeling and expert knowledge

Manuscript to be submitted to the journal Landscape and Urban Planning

Amazilia lactea and *Tillandsia streptocarpa*

Defining urban landscape networks for birds using least cost path modeling and expert knowledge

João Carlos de Castro Pena, Milton C. Ribeiro, Robert J. Young, Marcos Rodrigues

Abstract

When properly elicited, the unpublished knowledge gathered from experts can be a good source of information on cases where data are unavailable or incomplete. Functional connectivity in urban landscapes is an emergent area, and currently only a few studies have been published. This study aimed to, using *expert knowledge,* assess landscape functional connectivity and define a landscape network for bird species within a largely urbanized South American city (Belo Horizonte, Minas Gerais, Brazil). Based on the knowledge of 16 experts, we defined resistance surfaces (i.e. affecting bird movement) through use of an analytical hierarchy process for 10 bird species (7 forest and 3 open habitat species). We assessed the consistency between expert answers. Using the new LS Corridors software, least cost paths were simulated for the selected bird species between habitat patches. We assessed the frequency in which each land use type was considered during the simulations and the spatial correlation between the least cost paths of each bird species. Experts were consistent in their opinions about resistance values for land use types. Simulated paths were highly correlated; therefore, we were able to identify landscape networks for bird species' groups (i.e. forest and open habitat). Woody and herbaceous vegetation of gardens were found to be important during our simulations; therefore, this land use type is important for the maintenance of functional connectivity of this urban landscape. Expert knowledge and least cost paths can help in the identification of the most permeable areas of urban landscapes for bird species, as well as habitat patches and links that can be important for the maintenance of landscape functional connectivity. Therefore, these tools can be used in the management and planning of the urban green infrastructure.

Keywords: Belo Horizonte, functional connectivity, leas cost paths, LSCORR, resistance surfaces

Introduction

Within highly fragmented landscapes that have a reduced amount of natural habitat available, their configuration and structural connectivity will determine the maintenance of species' populations (Andrén, 1994; Antongiovanni and Metzger, 2005; Fahrig, 2003). However, it is also necessary to consider landscape functional connectivity, which is related to a species' willingness to cross different land use types between habitat patches (Arroyo-Rodríguez and Mandujano, 2009). This is even more evident within urban landscapes, in which matrix components can act as barriers for the movement of different species (Chace and Walsh, 2006). To overcome this issue, it is necessary to increase matrix permeability considering a species` ability to use and explore natural, semi-natural and human-made structures.

Landscape functional connectivity within urban landscapes is still an emergent area with little consolidated knowledge (LaPoint et al., 2015); this deficiency is especially present in highly biodiverse countries such as Brazil (LaPoint et al., 2015), where only one study has been published so far (Da Silveira et al., 2016). This lack of knowledge, together with highly heterogeneity and complexity of urban landscapes makes it difficult to assess the influences of all land use types on urban landscapes functional connectivity. However, human and non-human organisms have been interacting within urban landscapes for centuries, especially in cities located in the Old World (Elmqvist et al., 2013). Therefore, a large amount of latent knowledge can be used to help in understanding the effects of urbanization on functional connectivity within urban landscapes.

When properly elicited, the unpublished knowledge acquired by experts through experience can be considered as a good source of information, especially when data is unavailable or incomplete (Drescher et al., 2013; Perera et al., 2012a). We consider as experts in this study, practitioners who gained experience through years of training and applying their technical knowledge in scientific research (*expert practitioners* – Drescher et al., 2013; Perera, Drew, & Johnson, 2012), who are well recognized by their peers (McBride and Burgman, 2012). In landscape ecology, experts are often invited to provide insights and information to help in different decisions related to, for example, definition of resistance surfaces to assess landscape functional connectivity and identify possible ecological corridors (Li et al., 2010).

Least cost path modelling is based on a resistance surface (a raster image of a Geographic Information System, also called friction or permeability surface), used to represent the difficulty of an organism to move through the different land used types of a landscape (Etherington and Penelope Holland, 2013). Cells with higher resistance values possess species-specific factors (such as mortality risk, energetic costs or behavioural aversion) that hinder or reduce the species ability to move through the landscape (Etherington and Penelope Holland, 2013). Least cost path approaches have been widely used to assess landscape connectivity in different contexts (Correa Ayram et al., 2016), including urban landscapes (LaPoint et al., 2015).

The definition of priority areas for conservation or for the implementation of ecological networks is a difficult task. This is especially true in urban landscapes where urban expansion and development is often favored over the creation or preservation of green spaces. Therefore, within urban landscapes, the defined corridors must be multifunctional, allowing different species to move between urban habitat patches (Teng et al., 2011). In this context, birds have been used as models to assess functional connectivity in urban landscapes in different parts of the world (e.g.: Nichol et al., 2010; Teng et al., 2011; Unfried et al., 2012). Bird species are influenced in distinct ways by the structure of urban landscapes (Litteral and Wu, 2012). Further, birds can be used as indicators of urban ecological integrity (Ortega-Álvarez and MacGregor-Fors, 2009). Therefore, urban landscape networks defined for birds will also favored the movement of other organisms through the urban landscape.

In this study, we applied a new tool to simulate least cost paths and formulate urban landscape networks for bird species in a Brazilian city. Our aims were (1) to assess landscape functional connectivity, identifying possible paths between urban habitat patches; (2) assess the spatial congruence between bird species groups; and (3) assess how the different land use types are explored during the possible paths. We expected a high correlation and spatial congruence between species, which is related to the configuration and low permeability of urban landscapes. Street trees have an important role in connecting habitat patches within urban landscapes (Fernandez-Juricic, 2000) and positively influence urban birds (Pena et al., 2017), thus we predicted that street trees would be the land use type thar will contribute most for the increase in urban matrix permeability, and consequently, for the definition of urban landscape networks.

Material and Methods

Study area

The study area was the southern region of Belo Horizonte city (W 19º 55' 37", S 43º 56' 34") one of the first planned cities in Brazil and the Minas Gerais state capital (Fig. 3.1). The southern region of Belo Horizonte covers 31.7 km², which includes the oldest part of the city (est. 1897) an area of approximately 9 km². Almost half of the study area is occupied by woody and herbaceous vegetation; however, habitat patches are embedded in a highly developed urban matrix, and are poorly connected due to a deficient urban afforestation process (Pena et al., 2016) (Fig. 3.1).

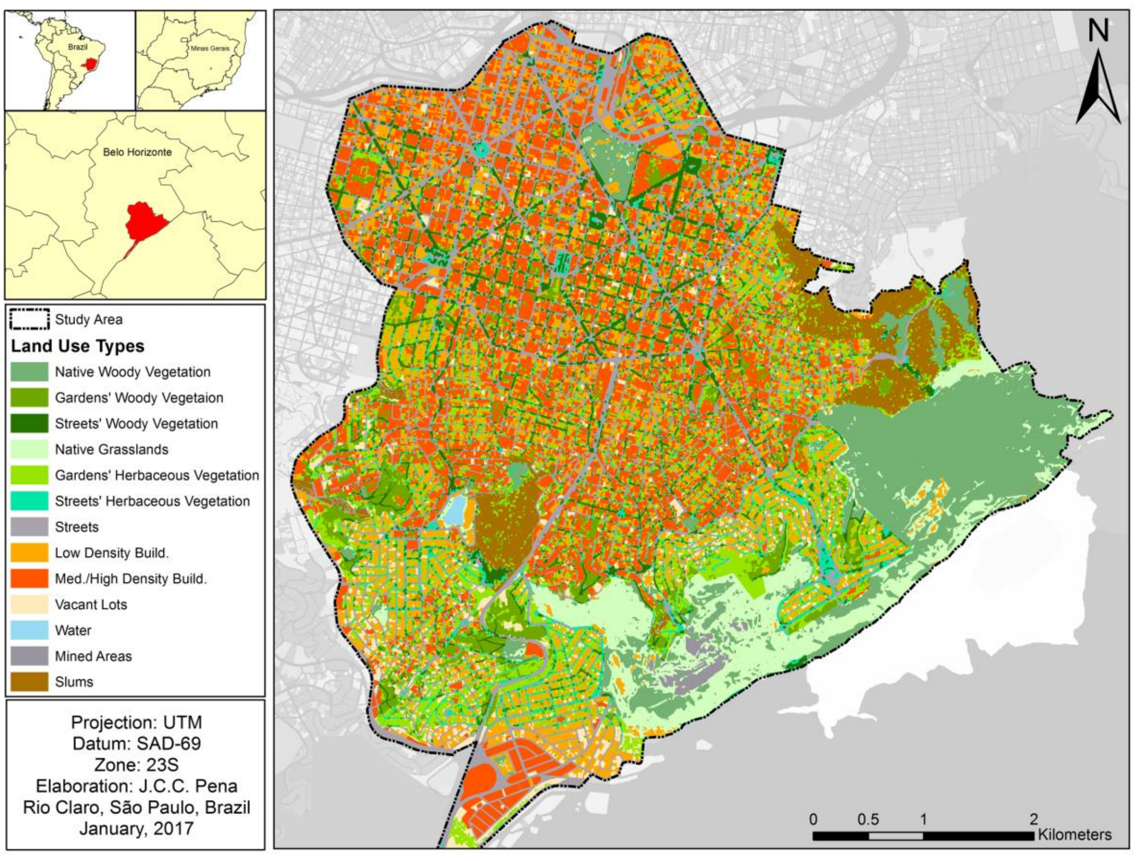


Figure 3.1: Land use types of the southern region of Belo Horizonte (Minas Gerais, Brazil). Modified from Pena et al. (2016).

Selected bird species

We selected 10 bird species that have different feeding habits and nesting and habitat requirements (Table 3.1). These species were selected from a list of 73 bird species observed in 60 point counts distributed throughout the streets of the study area (Pena et al., 2017). Since our goal was to design an urban landscape networks for birds, we selected species that are influenced by the landscape composition and configuration and species which would be favoured by the increase in landscape permeability. Therefore, we selected species that were observed in between 20 and 50% of the point counts, thereby removing from our analysis rare and highly synanthropic species (Table 3.1) (Pena et al., 2017).

Table 3.1. Bird species that were selected for the formulation of urban landscape networks through the southern region of Belo Horizonte (Minas Gerais, Brazil) and the frequency in which they were observed in the streets of the study area. Source: Pena et al., 2017.

Species	Family	Common name	% Point Counts
Amazilia lactea	Trochilidae	Sapphire-spangled emerald	22
Brotogeris chiriri	Psittacidae	Yellow-chevroned parakeet	23
Empidonomus varius	Tyrannidae	Variegated flycatcher	42
Furnarius rufus	Furnaridae	Rufous hornero	27
Molothurs bonariensis	Icteridae	Shiny cowbird	32
Mimus saturninus	Mimidae	Chalk-browed mockingbird	27
Myiozetetes similis	Tyrannidae	Social flycatcher	50
Piaya cayana	Cuculidae	Squirrel cuckoo	20
Tangara cayana	Thraupidae	Burnished-buff Ttanager	20
Turdus leucomelas	Turdidae	Pale-breasted thrush	43

Land use types

The urban landscape of the southern region of Belo Horizonte is highly heterogeneous (see description by Pena et al., 2016). Therefore, with the aim to assess the effects of a highly complex and heterogeneous urban matrix on landscape functional connectivity, we selected 13 land use types from the map developed by the authors, which we believe have influence on the movement of bird species. They are represented by different types of woody and herbaceous vegetation patches – landscape elements that increase matrix permeability – and human made structures, which can reduce or hinder species movement (Table 3.2). The land use types are represented by patches of different sizes and configuration (Fig. 3.1), and occupy different proportions of the southern region of Belo Horizonte (Table 3.2).

Eliciting expert knowledge to define resistance surfaces

We used a questionnaire to collect information about the influences of the different urban land use types on the movement of bird species (S3.1 Text). For each of the selected bird species, we asked experts to attribute values between 1 and 100 for each of the 13 land use types. Land use types with values closer or equal to 1 would have low resistance to the movement of bird species; land use types with values closer or equal to 100 would hinder the species ability to move through the landscape. We considered as experts, practitioners who gained experience through years of training and applying their scientific knowledge on Brazilian ornithological and ecological research and who are well recognized by their peers (S3.2 Text)(McBride and Burgman, 2012). A list of 55 experts was obtained through personal recommendation from direct peers of our research team (members of the Ornithological Lab from Universidade Federal de Minas Gerais and from the Spatial Ecology and Conservation Lab from Universidade Estadual Julio de Mesquita Filho). We assessed their *curriculum* using the National Counsel of Technological and Scientific Development (CNPq) platform (www.lattes.cnpq.br) to trace a profile. We confirmed that all suggested experts are biologists, with experience in ornithology. Almost all experts have a graduate degree, and the majority also have a PhD in environmental or related sciences. Therefore, all of them were invited to answer our questionnaire (S3.1 Text). We assessed the correlation between the average, median and mode of resistance values attribute by all experts for each species (S3.2 Text). We also made a T test to assess if the variance of resistance values attributed for each land use type for each species is statistically different between all researches (S3.2 Text). For land use types of which the variance was statistically different, we performed a second round of interviews (S3.2 Text).

To reduce inaccuracy and subjectivity of expert opinions, and assess the consistency of the obtained answers (Drescher et al., 2013), we defined the resistance values using an analytical hierarchy process (AHP; Saaty 1980). AHP is a multi-criteria decision-making method for judging the relative weights of different factors in a model. We decided to use the average resistance value attributed by the experts to rank the land use types during the analytical hierarchy process, since the correlation between average, median and mode was high (S3.2 Text). We ranked the land use types for each species using their relative average resistance values attributed by the experts. We then constructed matrices of pairwise comparisons of land use types for each species, and resistance values were summarized in terms of their relative value (Table 3.3). A consistency index was calculated for each species, in which values below 0.1 indicate that expert answers are consistent; whereas values above 0.1 indicate inconsistency, thus it would be necessary a re-assessment to reduce variability (Saaty, 1980).

Table 3.2: Land use types selected for the definition of resistance surfaces to model urban landscape networks for birds and their proportions through the southern region of Belo Horizonte (Minas Gerais, Brazil).

Land use Types		% Study Area
Woody Vegetation	Native	7.49
	Garden	4.08
	Street	15.94
Herbaceous Vegetation	Native	7.00
	Garden	8.21
	Street	13.34
Human Made Structures	Streets	13.92
	Vacant Lots	2.90
	Low Density Buildings	11.67
	Medium/High Density Buildings	12.05

	Slums	2.52
Other	Mined Areas	0.44
	Water	0.44

Modelling landscape networks

To model least cost paths, it is necessary to select habitat patches to be used as *sources* and *targets* of species movement (see Ribeiro et al 2017). Thus, we selected ten woody and ten herbaceous vegetation patches distributed throughout the landscape (S3.1 Figure) as our list of potential sources and targets for least cost path simulations. All selected woody vegetation patches are represented by municipal parks and almost all are composed by Atlantic Forest remnants. However, only four herbaceous vegetation patches are composed by natural and semi-natural open habitat remnants. They are located at the southern portion of the study area, and are composed by *campos rupestres* (rocky fields) and *campos de altitude* (high altitude fields) patches (Fig. 3.1). Thus, we selected the largest squares, green areas and cultivated lawns to be the six remaining herbaceous vegetation patches as sources and targets. These habitat patches are utilized by different native open habitat bird species (Pena et al., 2017). Woody vegetation patches were used as sources and targets for the movement of bird species for which Atlantic Forest remnants received the lowest resistance values (forest bird species). Paths for open habitat bird species (for which natural grasslands received the lowest resistance values) were modelled using the herbaceous vegetation patches.

Least cost paths were modelled using the new GRASS GIS extension *Landscape Corridor* (LSCORR – Ribeiro et al., 2017). This software allows the simulation of multiple functional paths between large sets of sources and targets at once, representing alternative routes, which minimize the costs of movement through the landscape. Therefore, LSCORR is ideal for the definition of urban landscape networks. We performed 100 simulations for each pair of sources and targets (45 possible combinations) for each for the 10 bird species, totaling 45,000 simulations. LSCORR allows the addition of stochasticity in the simulations – the *Variability* parameter – which we defined as being equal to 10 (Ribeiro et al. 2017).

An output for each species is provided in raster format, the Route Selection Frequency Index (RSFI), containing all the simulated paths and the frequency in which each pixel is considered during the simulations. Pixels with high RSFI indicate the best potential routes between habitat patches. High RSFI values indicate areas (pixels) that are more likely to be used as corridors according to species requirements included in the resistance surface and should therefore receive special attention (Ribeiro et al., 2017).

Statistical analysis

We used the RSFI raster image to extract the land use types that were overlapped by the paths simulated for each bird species. We then built histograms to compare the frequency in which each land use type is crossed by the simulations for each bird species.

We also assessed the spatial congruence of the simulated paths between species. First, we calculated the Euclidian distance between paths simulated for each species in the RSFI using GRASS GIS 7.0.5 software:

$$\mathrm{Sp}X = \mathrm{EucSp}X$$

Where Sp*X* is the RSFI for the species *X*, and EucSp*X* the Euclidian distance calculated for the RSFI of the species *X*. We then used the following equation:

$$\mathrm{Sp}X\_\mathrm{Sp}Y = \mathrm{EucSp}X * \mathrm{Sp}Y$$

Where Sp*Y* is the RSFI for the species *Y*. This process returns a raster image containing in each cell, the number of pixels that are located between the simulated paths of the species X. The lower the cell value, the closer is a path simulated for the species *Y* to a path simulated for the species *X*. We constructed histograms to assess the frequency of the number of pixels that contain each Euclidian distance value which separated paths between all bird species. Since we used different patches as sources and targets for each group of bird species, we assessed the spatial congruence only between forest bird species and between open habitat bird species. We also assessed the Pearson correlation between the Euclidian distance maps between forest bird species and between open habitat bird species.

Results

Expert opinions presented high consistence for all species and lower resistance values were attributed to the land use types most similar to species natural habitats (S3.1 Table). From the list of 55 experts, only 16 answered our questionnaire. Using AHP we demonstrated that expert opinions presented high consistence in defining resistance values for almost all land use types for bird species (S3.1 Table). Only woody and herbaceous vegetation of gardens for *Piaya cayana* presented low congruence between expert answers (S3.2 Text). Thus, with the aim of reducing the inconsistency between expert answers, we assessed which researches provided answers that were outside the interval between the 1st and 3rd quartiles for each land use type. We then sent an e-mail for each expert containing their respective opinions and the mode and average values of expert answers for the land use type. In this e-mail, we asked whether they would like to change their opinions. We invited 10 experts for the second round of interview and only five answered our request. All experts changed their answers for values closer or equal to the average resistance value. Considering the high consistency obtained during the AHP, and the reduced number of experts that answered our e-mail (S3.1 Table, S3.2 Text), we decided to use these final answers to formulate the resistance map for *P. cayana*.

Lower resistance values were attributed to the land use types most similar to species natural habitats (S3.1 Table). Therefore, forest bird species paths mostly crossed woody vegetation patches, while open habitat species paths mostly crossed herbaceous vegetation patches (Fig. 3.2). Native habitats were highly explored during the simulated paths, and gardens were the most explored land use type within the urban matrix (Fig. 3.2). For some species, the woody vegetation of streets was as much explored as human made structures, such as medium/high density buildings (Fig. 3.2). As we expected, simulated paths presented high correlation (Fig. 3.3) and were spatially congruent between birds of each species group (Figs. 3.4 and 3.5). This is evident when observing the best potential paths identified by the pixels that were most frequently selected during the simulations (Figs. 3.4 and 3.5).

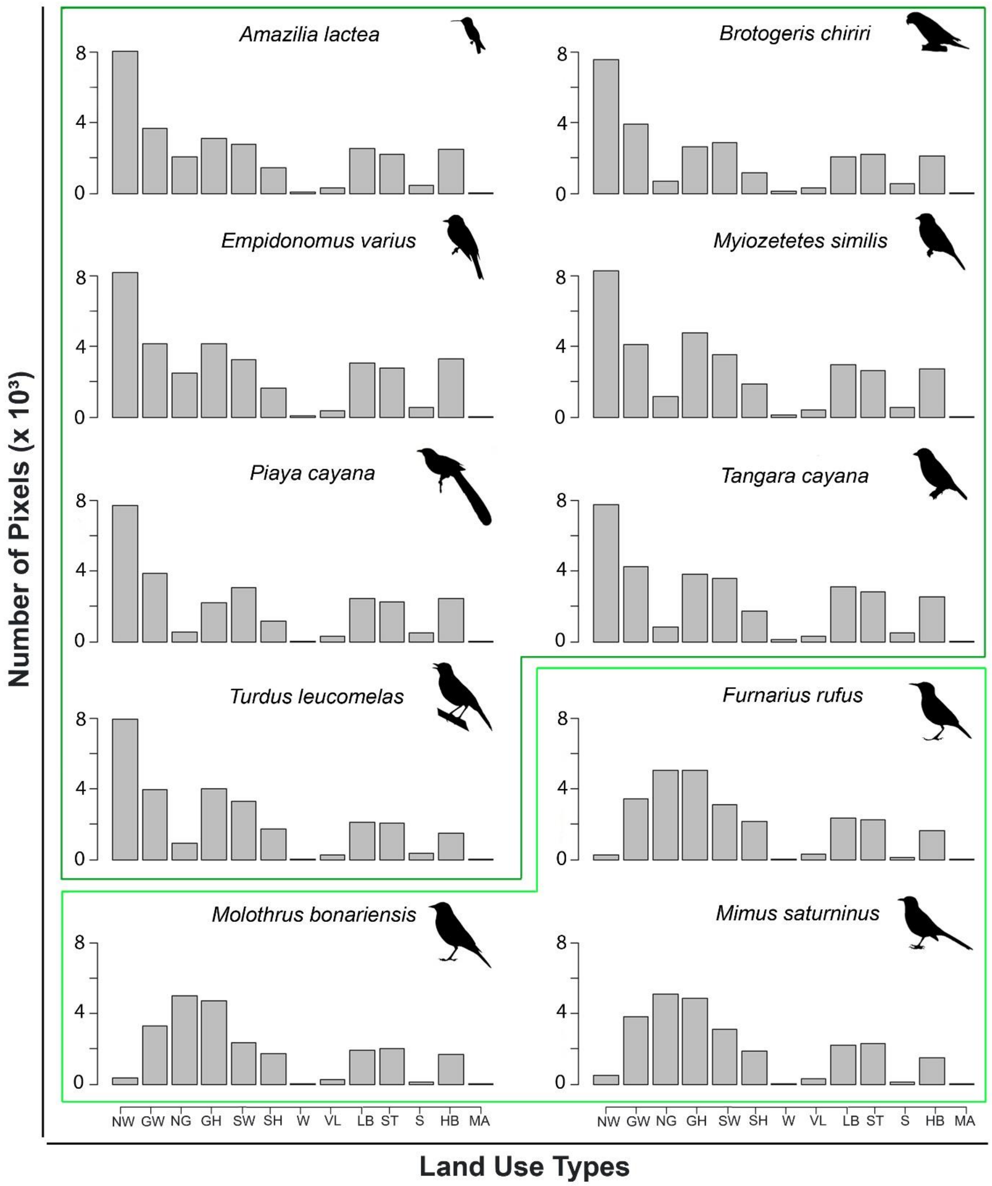


Figure 3.2: Frequency in which each land use type is crossed during the simulated least cost paths for bird species trough the southern region of Belo Horizonte (Minas Gerais, Brazil). Forest bird species and open habitat bird species are highlighted by dark and light green, respectively. NW: Native woody vegetation; GW: Woody vegetation in gardens; NG: Native grasslands; GH: Herbaceous vegetation in gardens; SW: Woody vegetation in streets; SH: herbaceous vegetation in streets; W: Water; VL: Vacant Lots; LB: Low density buildings; ST: Streets; S: Slums; HB: Medium/high density buildings; MA: Mined areas.

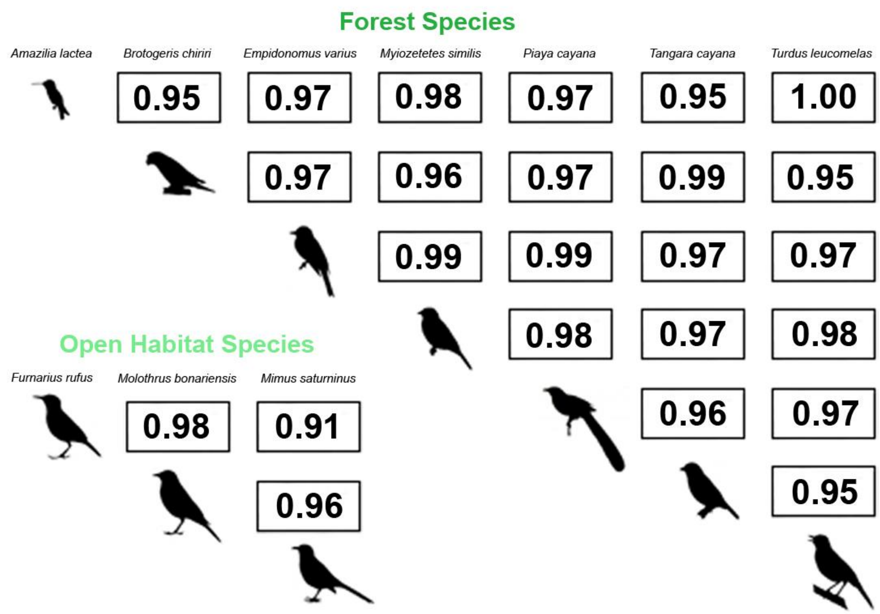


Figure 3.3: Correlation matrix resulted from the comparisons between the Euclidian distance maps formulated from the least cost paths (LSCORR outputs) for forest bird species and for open habitat bird species. Correlation analysis was performed only between birds within the same species group.

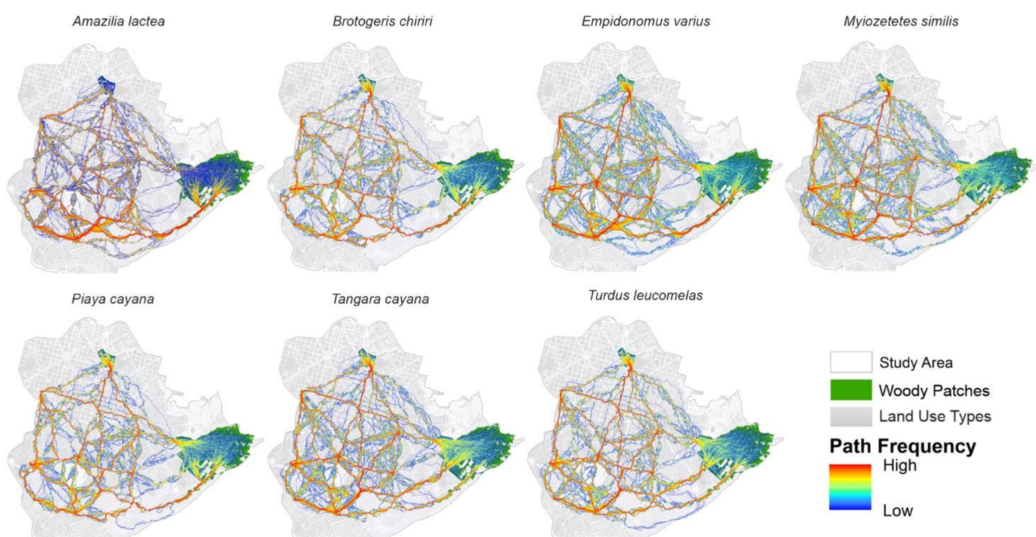


Figure 3.4: Landscape networks simulated for forest bird species through the southern region of Belo Horizonte (Minas Gerais, Brazil). Warmer colors represent the pixels most frequently selected.

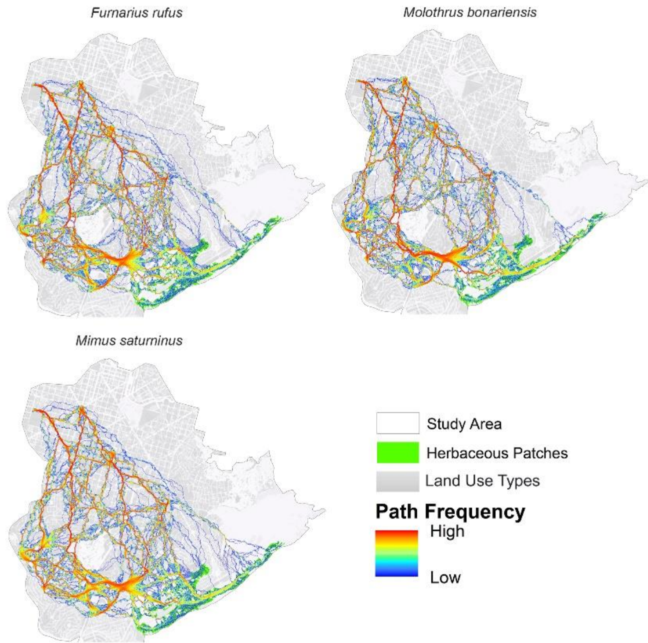


Figure 3.5: Landscape networks simulated for open habitat bird species through the southern region of Belo Horizonte (Minas Gerais, Brazil). Warmer colors represent the pixels most frequently selected.

Discussion

We applied least cost path modelling for the first time within a Brazilian urban landscape. We demonstrated that the simulated paths were highly correlated and spatially congruent between forest bird species and between open habitat bird species. This is related to the lowest resistance values attributed by the experts to urban vegetation elements. Thus, least cost paths avoided pixels that represented land use types that have higher costs for the movement of bird species, such as buildings and mined areas. On the other hand, natural habitat patches, woody and herbaceous vegetation of gardens were the most frequently land use types crossed by the simulated paths. The high congruence is also related to landscape structure: within urban landscapes, human made structures such as medium/high density buildings, hinder species ability to move between habitat patches. Consequently, in the southern portion of the study area – where there is concentrated natural habitat patches, low density buildings and gardens (Pena et al., 2016) – we observed that some of the best potential paths traced nearly straight lines between habitat patches. Whereas, in the most urbanized portion of the study area – least permeable portion of the landscape – the best potential paths suffered a bottleneck effect, following avenues and streets. This was observed even with the variability that we added to the model, which increased the number of alternatives for species movement. This influence of landscape structure on least cost paths, probably, increased the accuracy of our model in identifying the best potential routes between habitat patches.

Experts were statistically consistent in their opinions related to the effects of urban land use types on the movement of bird species. Thus, this unpublished knowledge can be considered a good source of information to assess the influences of urbanization on landscape functional connectivity. Using AHP – an elicitation method widely utilized to make applied decisions (Saaty, 2008) – we were able to develop resistance surfaces that represent the costs of different bird species to move through this complex urban landscape. Few experts were willing to contribute to our research. As mentioned by Perera et al. (2012), there is a tradeoff between the quality of the obtained information and the ability to retain the attention of experts during all elicitation process. Thus, expecting a reduced amount of information, we decided not to do the preparation stage of the elicitation process to maximize expert participation (Perera et al., 2012). However, using the AHP, we observed that, although gathered mostly in only one round of interview, the consistency between expert answers was high.

The use of qualitative judgements is questionable, especially when objectivity is desirable (Saaty 2008). This is, probably, one of the reasons for the small fraction of experts that answered our questionnaire (S3.2 Text). However, expert knowledge allows the incorporation of complex habitat relationships into resistance surfaces (Zeller et al., 2012). Urban matrices are highly heterogeneous and dynamics, making it difficult to obtain information, *in situ*, about the influences of all urban land use types on species movement. Therefore, when the process is repeatable and transparent, and a proper elicitation method is incorporated, expert knowledge can be a practical and reliable source of information to improve our knowledge about understudied ecological processes and landscapes (Drescher et al., 2013; Perera et al., 2012a; Saaty, 2008).

The selected birds species differ in nesting and foraging behaviour and diet (Del Hoyo et al., 2004; Wilman et al., 2014), which probably have influence on species willingness to cross determined land use types (Arroyo-Rodríguez and Mandujano, 2009; Harris and Reed, 2002). The inclusion of behavioral decisions, probably, would have improved our model (LaPoint et al., 2013). The absence of a validation method to determine whether the expert opinions were efficient in describing natural patterns (Johnson et al., 2012), were another limitation of our model. Nevertheless, by confronting multipaths modeled for multiple species, the model was internally validated (Rykiel, 1996). The high congruence between paths of birds from the same species group is an indicative that we were efficient in identifying the most permeable areas and land use types of the landscape.

Multipath modelling can be an important tool to helping in planning and managing the urban green infrastructure. Using our model, it is possible to identify the best potential paths for the formulation of landscape networks for the movement of forest and open habitat bird species. The high congruence, especially between the best potential routes, indicate that obtained networks could improve landscape functional connectivity for a large amount of bird species. Possible routes, such as streets and avenues, can be used as green urban corridors or linear urban parks, for human – as cyclist and walking tracks – and non- human organisms (Magalhães and Moura, 2013). We were also able to obtain information about vegetation patches that are important for the maintenance of landscape functional connectivity (Nichol et al., 2010; Teng et al., 2011). In this study, not only vegetation patches used as sources and targets during our simulations proved to be important links between habitat patches for all bird species, but it is possible to identify other vegetation patches that can be used as stepping stones for species movement through these landscape networks.

Our model was also able to identify which land use types can be used to increase landscape functional connectivity. Native habitat patches were the most frequently explored land use types. However, this is related to the first section of the paths that crossed patches used as sources and targets. LSCORR randomly select a pixel within the selected patches as a starting point for the simulations. Gardens proved to be important elements for the maintenance of landscape functional connectivity, being highly explored by the two groups of species. These components of the urban green infrastructure are utilized by different organisms that occupy urban landscapes (e.g.: bees - Fetridge, Ascher, & Langellotto, 2008; birds - Reis, López-Iborra, & Pinheiro, 2012; beetles - van Heezik et al., 2016). The high heterogeneity of gardens vegetation, influenced by local conditions and management decisions of their householders (Cameron et al., 2012), promote great opportunities to use gardens in favour of urban biodiversity conservation (Smith et al., 2006). In fact, gardens can be spatially arranged to maximize total habitat area and minimize isolation between habitat patches (Goddard et al., 2010), and are used by species to move through urban landscapes (Vergnes et al., 2013). Therefore, householders should be encouraged to adopt environment friendly strategies in landscaping of private gardens. Finally, although not being the most frequent land use type in the simulated paths, streets vegetation proved to be important to connect habitat patches within the most urbanized and least permeable portion of the landscape. Therefore, considering the positive effects of street trees on landscape permeability (Fernandez-Juricic, 2000; Oprea et al., 2009), urban ecosystem services (Armson et al., 2013; Vailshery et al., 2013) and on biodiversity (Pena et al., 2017; Ikin et al., 2013; White et al., 2005), it is necessary a better planning of the urban afforestation process considering the functionality of urban landscapes.

Conclusions

Using expert knowledge and least cost paths we efficiently modelled landscape networks for forest and open habitat bird species. Using this tool, we were able to assess how different land use types potentially affect species movement. The definition of landscape networks for multiple species through the simulation of multipaths, allows the identification of important links and stepping stones between habitat patches and the land use types that can be used to improve landscape functional connectivity. Thus, least cost paths can be used as a tool to help in green infrastructure planning and management. Ecological networks must be multifunctional and consider, not only urban landscape functional and structural connectivity, but also social and environmental aspects that can be favoured by the improvement of landscape functionality and ecosystem health.

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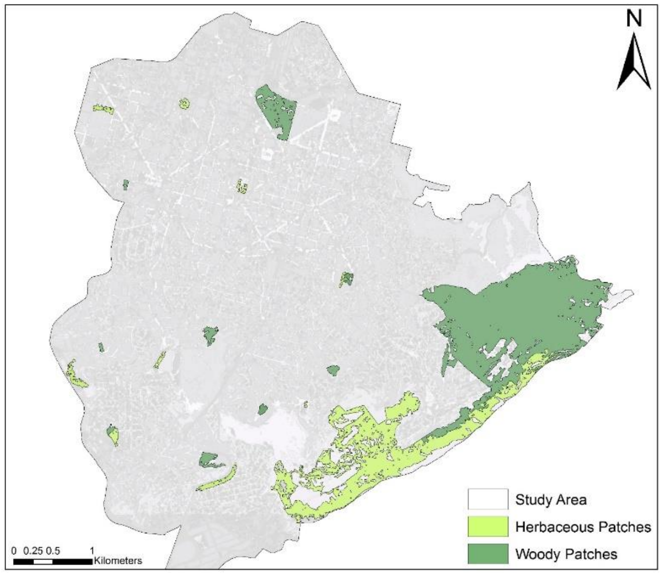
Supporting Information

S3.1 Table: Final resistance values defined through the analytical hierarchy process (AHP) and attributed for each land use type, and their respective consistency index for each of the selected bird species inhabiting Belo Horizonte (Minas Gerais, Brazil).

	Native Wood	Native Herb.	Garden Wood	Garden Herb;	Street Wood	Street Herb.	Vacant Lots	Streets	Low Dens. Build.	Med./High Dens. Build.	Water	Mined Areas	Slums	Consistency Index
Amazilia lactea	0.01046	0.03551	0.0246	0.06077	0.04575	0.05982	0.11343	0.11452	0.0894	0.12693	0.07069	0.13010	0.11805	0.021
Brotogeris chiriri	0.00757	0.06401	0.02004	0.06979	0.03782	0.08890	0.11918	0.10047	0.09158	0.12263	0.05564	0.1192	0.10317	>0.001
Empidonomus varius	0.01612	0.03721	0.03238	0.05498	0.05282	0.07858	0.12535	0.10575	0.09153	0.11657	0.06994	0.11304	0.10573	>0.001
Furnarius rufus	0.09688	0.01883	0.04039	0.02671	0.03621	0.02849	0.10975	0.09655	0.07934	0.12343	0.07021	0.15003	0.12317	-0.003
Mimus saturninus	0.07006	0.01904	0.03270	0.03023	0.03750	0.04346	0.11018	0.09755	0.08707	0.13591	0.08142	0.13606	0.11881	-0.002
Molothrus bonariensis	0.07282	0.01168	0.03889	0.02267	0.05208	0.03833	0.12119	0.10641	0.09701	0.13053	0.07791	0.12499	0.10549	-0.003
Myiozetetes similis	0.01227	0.05887	0.03770	0.04764	0.03847	0.06623	0.11568	0.10519	0.09115	0.12007	0.06827	0.12444	0.11405	-0.002
Pyaia cayana	0.00489	0.08087	0.01925	0.08382	0.02931	0.07983	0.10972	0.09450	0.07640	0.10552	0.08412	0.12339	0.10839	-0.001
Tangara cayana	0.01527	0.06354	0.02924	0.05823	0.03314	0.06689	0.12250	0.09377	0.08167	0.11644	0.07625	0.12766	0.11539	-0.001
Turdus leucomelas	0.01117	0.04861	0.02588	0.04007	0.02864	0.05163	0.11010	0.10162	0.08737	0.13072	0.09341	0.15135	0.11944	-0.002



S3.1 Figure: Selected sources and targets, composed by woody and herbaceous vegetation patches, distributed through the southern region of Belo Horizonte (Minas Gerais, Brazil).

S3.1 Text: Questionnaire:

We developed a questionnaire (originally in Portuguese), that was sent to experts to collect information about how the different land use types influence the movement of each of the selected bird species. Bellow we provide the form only for *Amazilia latea*.

Dear researcher,

You are being invited to participate in this consultation, because we understand that the knowledge that you have from your theoretical and practical experiences can contribute to the understanding of the behavior of the bird species that we are studying.

In our project, we are evaluating how the land use types of the urban landscape of Belo Horizonte influence the bird community able to occupy the city. One of our objectives is to evaluate the movement of these species through the urban matrix. However, information about how bird species utilize and are influenced by different urban land use types are scarce, especially when we consider cities located in tropical regions. Which land use types facilitate or hinder the movement of organisms between habitat patches?

In this form, you will find tables corresponding to each of the selected bird species. We would like to know your perception about the movement of these bird species through urban landscapes. You are being asked to assign values, on a scale from 1 (lower resistance, i.e. land use types equal or similar to species natural habitat) to 100 (higher resistance, i.e. barrier), which represent the permeability of each land use type for each species. From the contributions of researches that filled the form, we will calculate the average resistance value for each land use type, so that we can produce a measure of permeability. Thus we will be able to evaluate the connectivity of the landscape and propose "ecological corridors" between conservation units within the city.

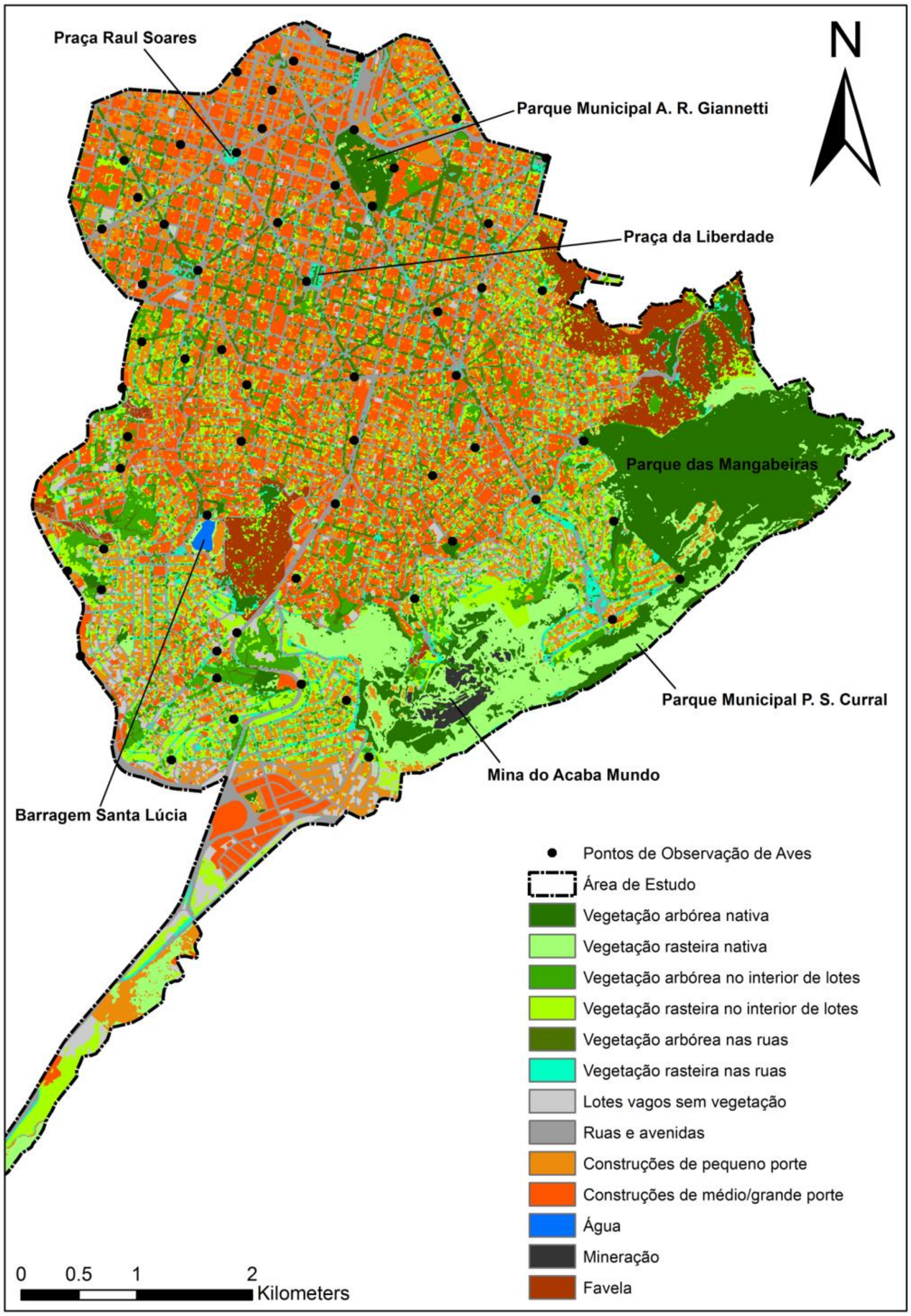
We ask you to respond only to species and to the land use types that you feel comfortable. In each table, there is an additional column ("Observations") that can be used, whenever you wish, for any justification or observation regarding the assigned value or the land use type in question. At the end of the questionnaire you will find the mapping of the study area, the southern regional of Belo Horizonte, and an Appendix in which explanations and illustrative images of each land use type are available.

Best regards,
MSc. João Carlos de Castro Pena
Prof. Dr. Marcos Rodrigues
Prof. Dr. Milton C. Ribeiro
Prof. Dr. Robert J. Young

1. Land use types' resistance values for *Amazilia lactea*

Land Use Types	Resistance (1 to 100)	Observations
Native woody vegetation (eg.: Atlantic Forest patches)	Click here to enter text.	
Native herbaceous vegetation (ex.: natural grasslands)	Click here to enter text.	
Woody vegetation within lots (ex.: gardens, vacant lots, warehouses, buildings)		
Herbaceous vegetation within lots (ex.: gardens, vacant lots, warehouses, buildings)		
Woody vegetation in streets (e.g.: street trees)		
Herbaceous vegetation in streets (e.g.: road junctions, squares)		
Vacant lots without vegetation (e.g.: parking lots)		
Streets and avenues		
Low density buildings (e.g.: houses, mansions)		
Medium/high density buildings (e.g.: buildings, transportation stations, schools, malls)		
Water		
Mined areas		
Slums		

S3.2. Figure: Land use/land cover map of the southern region of Belo Horizonte, Minas Gerais, Brazil



Appendix

1. Native woody vegetation

Represented by Atlantic Forest remnants and urban parks, such as the Americo Renné Giannetti Municipal Park.

S3.3 Figure: Americo Renné Gianetti Municipal Park, Belo Horizonte, Minas Gerais, Brazil (source: Internet).

S3.4 Figure: Atlantic Forest remnants located within the Mangabeiras Municipal Park, Belo Horizonte, Minas Gerais, Brazil (source: Internet).

2. Native herbaceous vegetation

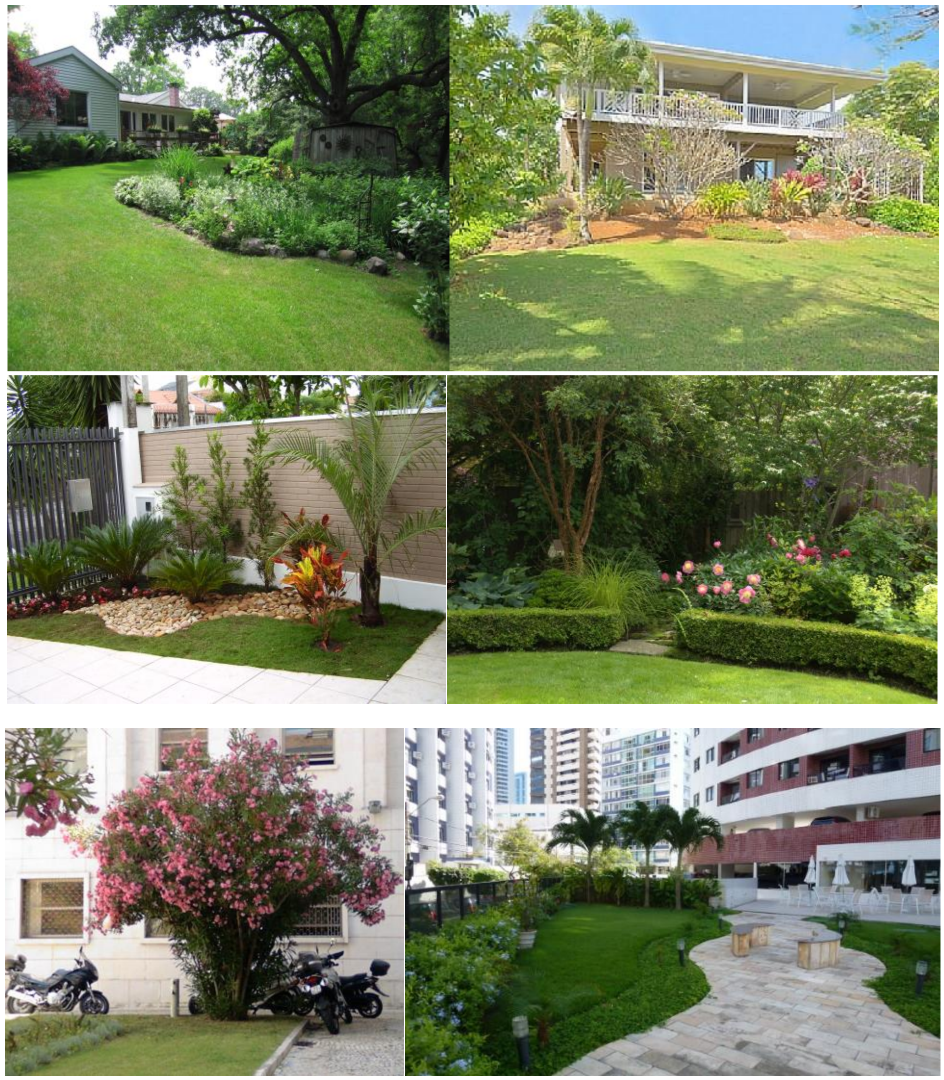
Represented by *campos rupestres* (rocky fields) and *campos de altitude* (high altitude fields) patches.

S3.5 Figure: Paredão da Serra do Curral Municipal Park, Belo Horizonte, Minas Gerais, Brazil (source: Internet).

S3.6 Figure: Section of the Serra do Curral Heritage Site, Belo Horizonte, Brazil (source: Internet).

3. Vegetation within lots

Represented by woody and herbaceous vegetation within private and public gardens, vacant lots, backyards, schools, churches and other commercial and residential land use types.



S3.7 Figure: Different types of woody and herbaceous vegetation within lots (source: Internet).

4. Woody vegetation in streets

Street trees and woody vegetation in squares.

S3.8 Figure: Liberdade Square in Belo Horizonte, Minas Gerais, Brazil (Fonte: Internet).

S3.9 Figure: Street trees in Barbacena Avenue (left) and Afonso Pena Avenue (right), Belo Horizonte, Minas Gerais, Brazil (source: Internet).

5. Herbaceous vegetation in streets

Cultivated lawns in squares, road-side grass and road junctions.

S3.10 Figure: Cultivated lawns in Raul Soares (left) and Papa (right) squares in Belo Horizonte, Minas Gerais, Brazil source: Internet).

S3.11 Figure: Road junctions between Raja Gabáglia Avenue and the road BR356 in Belo Horizonte, Minas Gerais, Brazil (Fonte: Internet).

6. Vacant lots without vegetation

Vacant lots composed by bare soil or concrete, empty or utilized as, for example, parking lots.

S3.11 Figure: Examples of vacant lots (source: Internet).

7. Streets and avenues

In this context, we are considering street sections without arboreal cover.

S3.13 Figure: Andradas Avenue (left) and Caetés Street (right) in Belo Horizonte, Minas Gerais, Brazil (source: Internet).

8. Low density buildings

Houses, mansions and small buildings up to three floors. Commercial and residential buildings.

S3.14 Figure: Bairro Mangabeiras (à esquerda) e construção de pequeno porte localizada na Rua Pernambuco (à direita) em Belo Horizonte, Minas Gerais, Brazil (Fonte: Internet).

9. Medium/high density buildings

Residential and commercial buildings with more than three floors, such as malls, schools, and churches.

S3.15 Figure: Examples of medium/high density buildings in Belo Horizonte, Minas Gerais, Brazil (source: Internet).

10. Water

S3.16 Figure: Santa Lúcia dam in Belo Horizonte, Minas Gerais, Brazil (source: Internet).

11. Mined areas

S3.17 Figure: Acaba Mundo mine in Belo Horizonte, Minas Gerais, Brazil (source: Google).

12. Slums

Within our study area a few of Belo Horizonte's slums are located, such as Aglomerado da Serra and Morro do Papagaio slums.

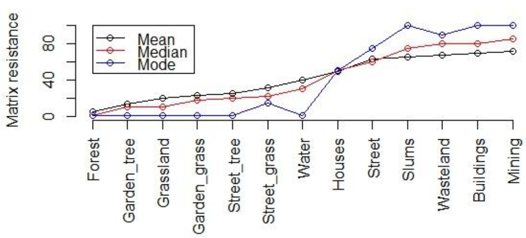
S3.18 Figure: Aglomerado da Serra slum in Belo Horizonte, Minas Gerais, Brazil (source: Internet).

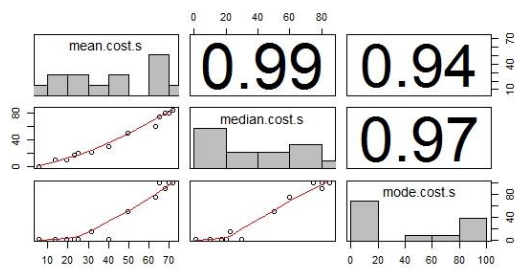
S3.19 Figure: Morro do Papagaio slum in Belo Horizonte, Minas Gerais, Brazil (source: Internet).

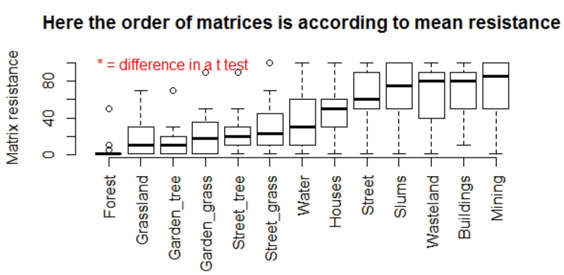
S3.2 Text: Expert knowledge gathering process

We assessed the correlation between the average, median and mode of resistance values attribute by all experts for each species. We also made a T test to assess if the variance of resistance values attributed for each land use type for each species is statistically different between all researches. For land use types of which the variance was statistically different, we performed a second round of interviews.

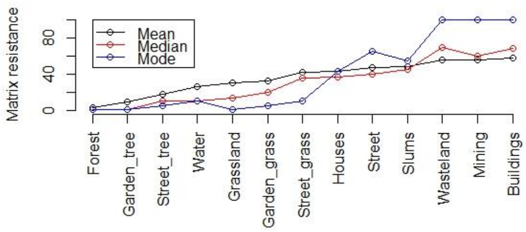
Amazilia lactea

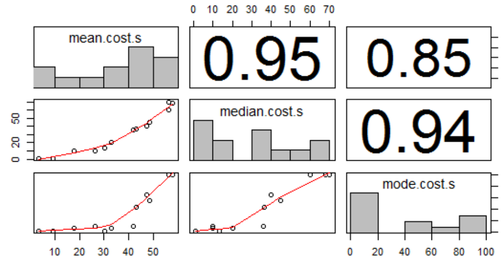


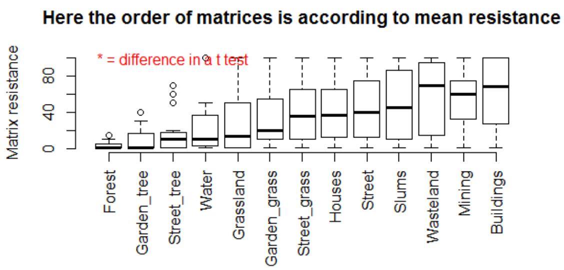




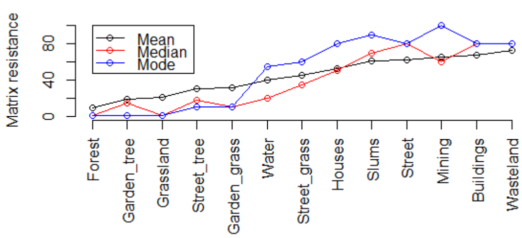
Brotogeris chiriri

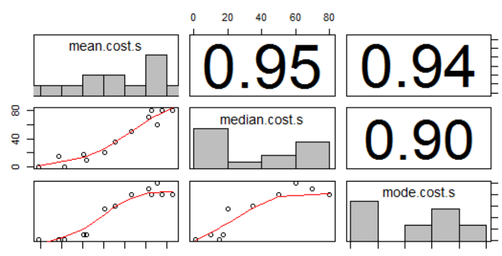


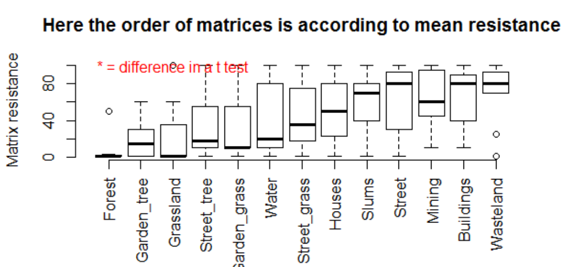




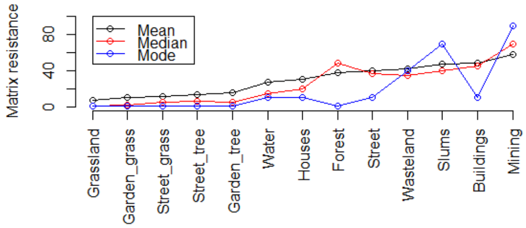
Empidonomus varius

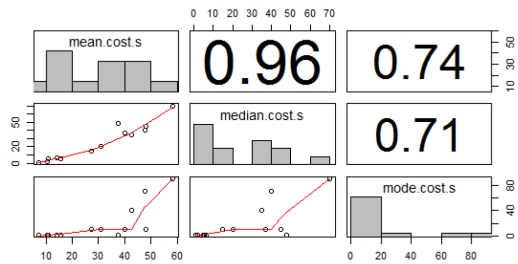


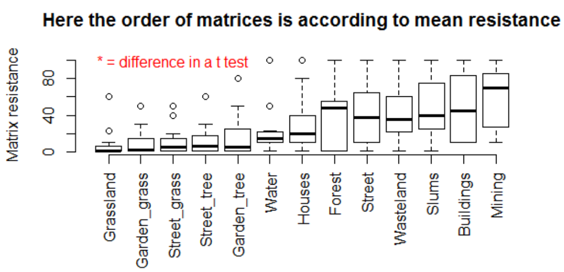




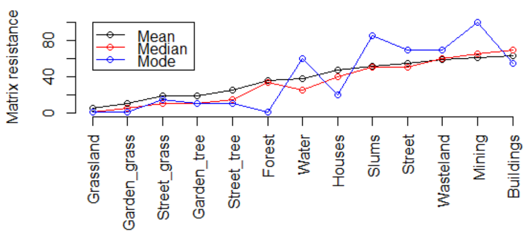
Furnarius rufus

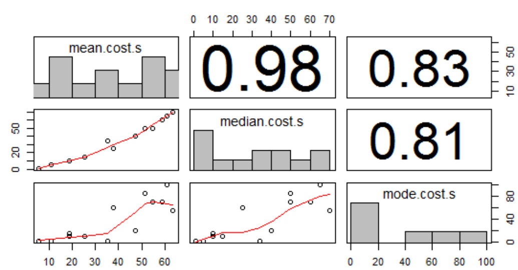


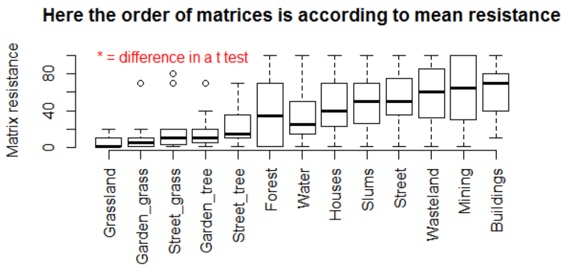




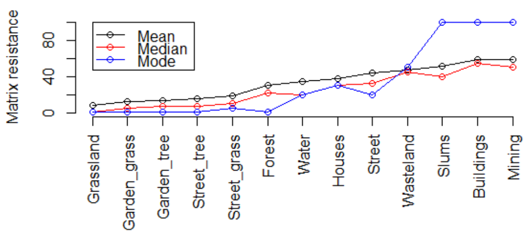
Molothrus bonariensis

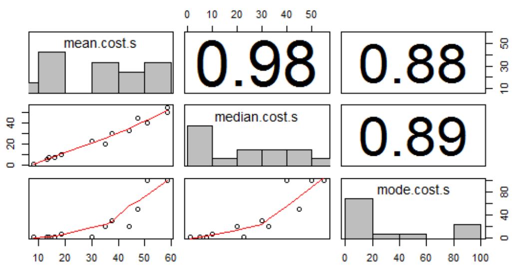


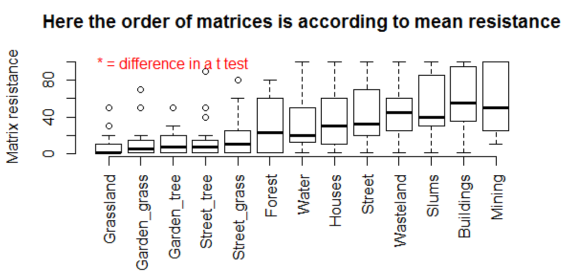




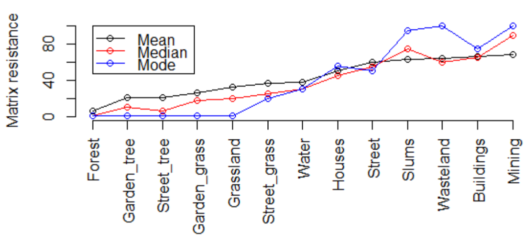
Mimus saturninus

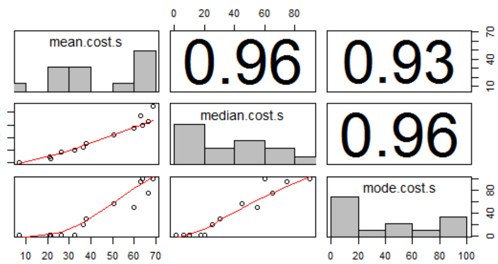


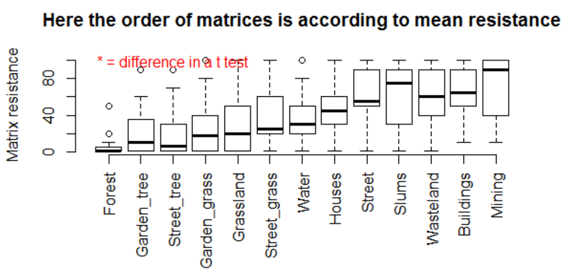




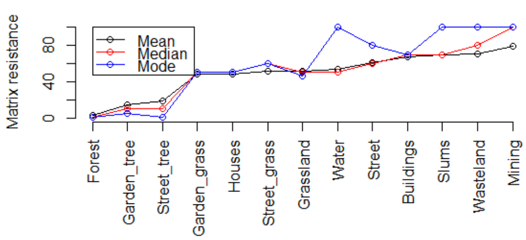
Myiozetetes similis

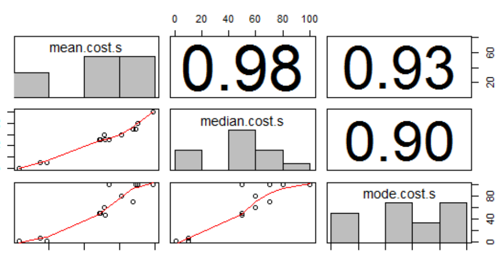


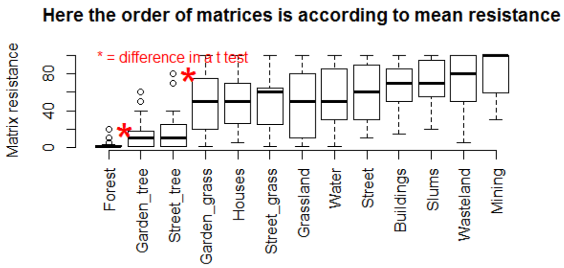




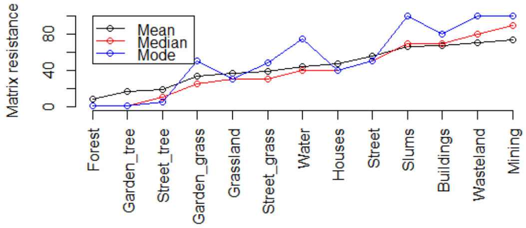
Piaya cayana

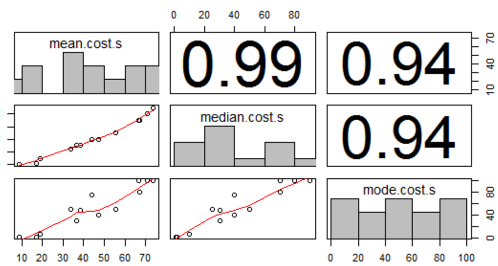


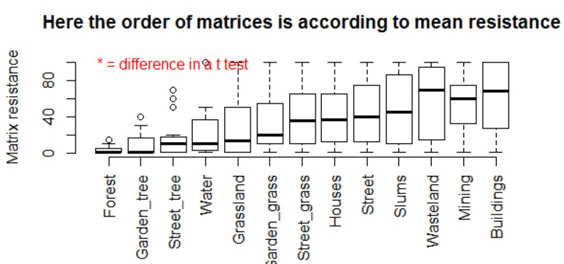




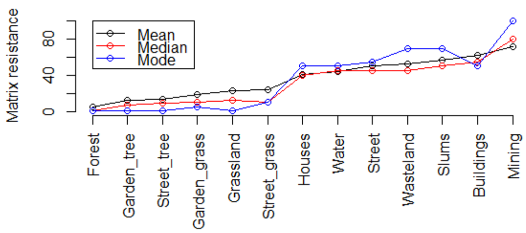
Tangara cayana

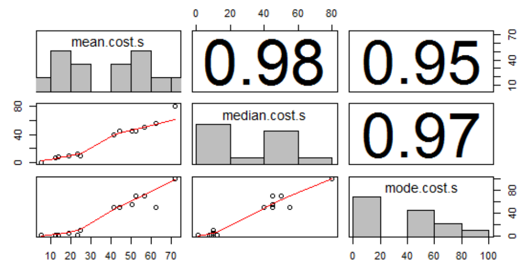


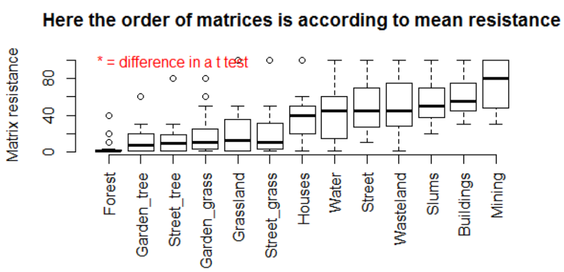




Turdus leucomelas







It is possible to observe that experts were more congruent in defining resistance values for natural and semi-natural land use types than human made structures. Although the high apparent variance in expert answers in defining resistance values for human made structures, we decided to do a second round of interview only for those land use types that presented statistically different variance. This decision was also based on the high consistency index obtained during the analytical hierarchy process and due to the reduced number of researches that answered our questionnaire.

Chapter 4

Beyond the mining pit: the academic role in social deliberation for participatory environmental planning

Manuscript under review in the journal *Perspectives in Ecology and Conservation*

Fluvicola nengeta

Beyond the mining pit: the academic role in social deliberation for participatory environmental planning

João Carlos de Castro Pena, Julia Camara de Assis, Rafaela Aparecida da Silva, Laura Kyoto Honda, Maria Inez Pagani, Milton Cezar Ribeiro

Abstract

Although mining activities are required to supply human needs, the academic participation on the allocation and planning of mining activities is reduced. We presented our experience in the participatory review of Rio Claro's (São Paulo, Brazil) master plan. In 2015, Rio Claro City Hall triggered a multi-agent discussion about new perspectives on local environmental planning to improve human life quality. Representatives of economic sectors were invited for public consultations, and civil society was neglected. The academic participation was represented by amendment proposals that intended to represent common interests of society (e.g.: reducing the impacts of clay extraction on the population). We discuss the need of greater appreciation of university outreach initiatives for their high impact on public issues. Academia may ensure an equitable balance of interests between different sectors of society, aiding in the pursuit of quality of life improvement and natural resources preservation for future generations.
Key-words: Environmental planning; Master Plan; mining impacts; participatory process; Rio Claro

Introduction

Current global economic development is largely based on mineral extraction leading to intense environmental degradation, particularly in developing countries where the economic base is primarily commodity exports. Worldwide, increasing consumption of goods and services is heightening the demand for minerals. For example, the Brazilian Government expects increases of 217% in iron production and 466% in copper production by 2030 (Brasil, 2010). This scenario will further increase the mining sector's political and economic influence, creating the need for strategies that ensure sustainable development and regulate mineral extraction and production (e.g.: Caron et al., 2016) and avoid a retrogression in mining regulation (Meira et al., 2016).

To ensure that social and environmental issues are fairly addressed while planning the spatial distribution of mining activities, the formulation process should include active participation not only from economic sectors but also from academia and society. Mineral extraction should occur in regions that have been defined through social deliberation to maintain the integrity of social-ecological systems (Vela-Almeida et al., 2015). Academia's technical expertise makes it a key actor in the identification of the most ecologically sensitive areas and regions at different scales. Different aspects must be considered when balancing the benefits and costs of mineral extraction beyond the mining pit, such as the location of freshwater resources, conservation units, geological formations and human settlements. However, academic participation in the management and planning of the localization of mining activities is extremely limited.

We systematically assessed studies related to this topic, conducted in different parts of the world at scales ranging from global to national to local (for more details see S4.1 Text). We found only 25 studies, conducted in 13 countries around the globe. We observed that most studies (18) were published after 2010, and only seven included some aspect of participatory planning. Most studies aimed to extrapolate local perceptions to the broader application of planning, based on case studies that ranged from resource location to state-level analyses (S4.1 Text). Mining activity planning is closely linked not only to resource distribution (as we identified in six studies) but also to local administrative boundaries (seven studies) and immediately affected areas (delineated, for instance, by basins or water catchments in four studies). Despite the practical information these studies provide, academia generally acts as an external agent of investigation, not as a vector of improvement in planning or the active transfer of knowledge into practice. Meanwhile, decision and policy makers are often expected to passively assimilate this knowledge

In this study, we will describe academia's participation in the formulation of a new master plan for Rio Claro, which includes public policies and directives for reducing the high impacts of sand and clay extraction in the municipality. Due to the impacts of the main economic activities (mineral extraction, sugarcane cultivation and cattle ranching) in Rio Claro (São Paulo, Brazil), the city has the second highest level of suspended particulate matter in São Paulo State (CETESB, 2016), and 54% of its 1,447 springs and streams are disturbed or degraded (PMRC, 2014). Municipal master plans can be strategic for local planning and for specifying best practices in mineral resource management. Master plans in Brazil are defined by a specific bill and regulated by a Federal law (Brasil, 2001). They must state priorities and directives for urban growth and development, and they must be transparent, democratic and participatory, open to public criticism and evaluation (Brasil, 2001). We demonstrate that academic participation in the master plan's development may be critical to ensure an equitable balance of interests between different sectors of society (Figure 4.1).

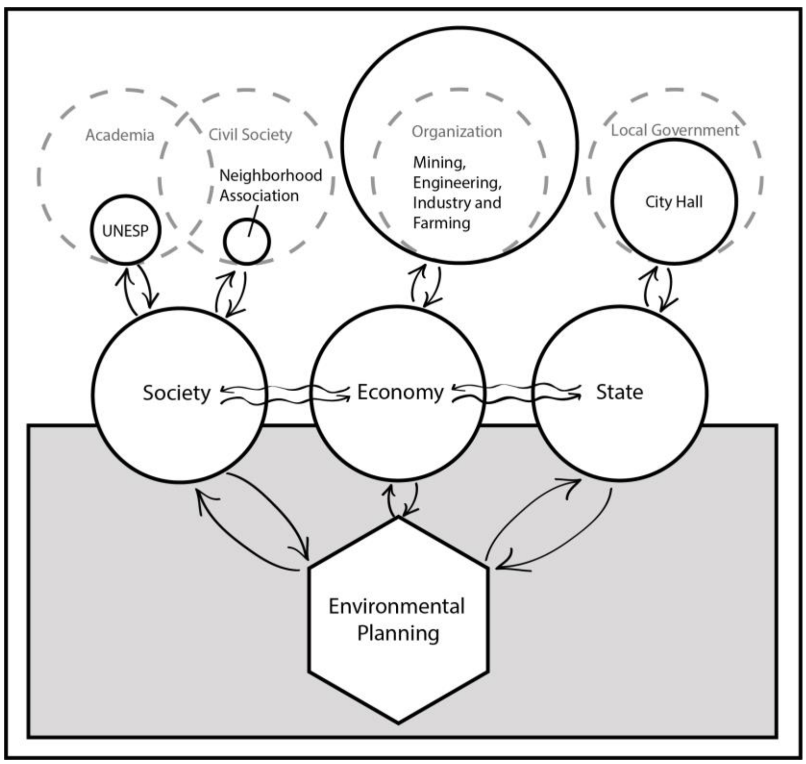


Figure 4.3: The influences of the different social agents on environmental planning. Black solid lines represent the unbalanced scenario of most Brazilian cities, such as Rio Claro, in which the economic sector's influence prevails. Gray dashed lines represent the scenario with balanced influences of the different social agents.

Formulation of the new master plan

Rio Claro is a medium-sized municipality covering 498.7 km², located in São Paulo State, southeastern Brazil (Figure 4.2). The last population census reported approximately 200,000 inhabitants, with 97.6% living in the urban areas (IBGE, 2016). Located in the ecotone between Atlantic Forest and Cerrado biomes, Rio Claro has a 66% deficit in natural vegetation according to the Brazilian Forest Code (Soares-filho et al., 2014). The population is aware of the environmental degradation of the landscape, and acknowledge the necessity of investments in restoration projects (Silva et al., 2016). Thus, the new Rio Claro Master Plan (RCMP) aimed for the first time to organize the municipality's rural areas and urban perimeter. Besides planning and organizing urban space, the proposal also regulates different economic activities in the city's periphery. According to the Brazilian Statute of Cities, a master plan needs to be reviewed at least every 10 years (Brasil, 2001). Without a valid and effective master plan, City Hall has no guidelines by which to promote or oppose new economic initiatives. In 2015, Rio Claro's City Hall assigned a commission within the Municipal Secretariat for Urban Planning, Development and Environment (SEPLADEMA) to lead the participatory reformulation of the master plan, assisted by specialist consultation. The commission prepared a first draft based on technical documents, such *as Rio Claro's Environmental Assessment* (PMRC, 2014) and the *Mineral Production Map of the State of São Paulo* (IPT, 2013), and several public consultations with representatives of different economic sectors: farming, mining, civil engineering and industry.

Academic representatives were invited to the public consultations—mainly professors from the São Paulo State University's Júlio de Mesquita Filho campus in Rio Claro, hereafter UNESP—but civil society was highly neglected (Figure 4.1). Therefore, PhD candidates and undergraduate students from UNESP, who attended several public consultations, formed a working group and formulated fourteen amendment proposals for the new RCMP. These proposals intended to represent the common interests of society, considering general aspects for sustainable development of the city, environmental conservation, improvement of human quality of life and the spatial organization of mining and other rural economic activities (S4.2 Text). The group members discussed issues related mainly to the urban and rural environments within their expertise to propose solutions and new amendments that would benefit society and not a particular economic sector. During this process, the group had weekly meetings and online forums via social media, which were instrumental in informing other academics and civil society in general about the new RCMP formulation and academic participation. Unfortunately, there was no time to mobilize civil society and discuss their aspirations. The proposed amendments were presented and held to a vote in a public audience before SEPLADEMA's commission, economic sectors and civil society representatives. Mobilization and participation of undergraduate students of UNESP played an important role in the approval of thirteen of the fourteen amendments. Notably, the mining sector did not present amendments on that occasion.

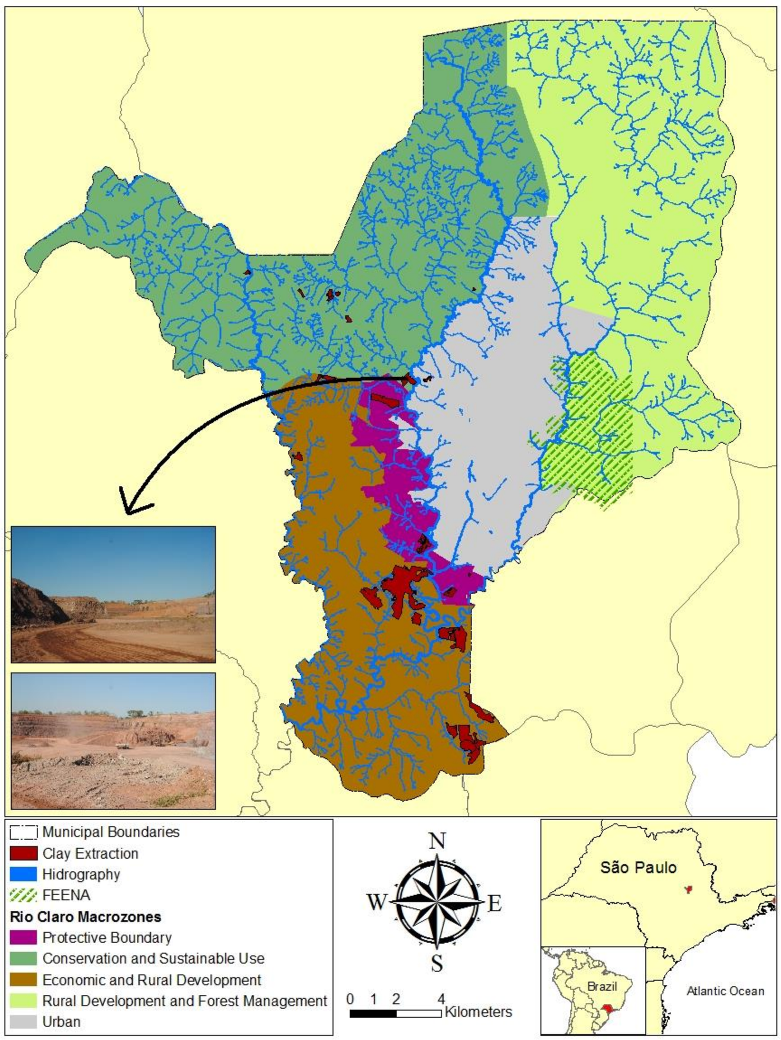


Figure 4.4: Macrozones defined in the first draft of the new Rio Claro Master Plan, highlighting municipal hydrography and clay extraction pits. The pictures show a small-scale clay extraction near the urban fringe. FEENA: State Forest Edmundo Navarro de Andrade.

SEPLADEMA's commission incorporated UNESP's and other approved amendments into the final draft of the new RCMP. This document was sent to the City Council for assessment. One of the most important points of this final draft was the definition of five macrozones with different economic purposes or environmental restrictions within the municipal boundary: a) Economic and Rural Development, b) Rural Development and Forest Management, c) Conservation and Sustainable Use, d) Urban and e) Protective Boundary (Figure 2). Within each macrozone, specific economic activities were permitted according to their environmental and social sensitivities and characteristics (S4.1 Table). For example, the Protective Boundary Macrozone aimed to reduce the direct impacts of clay and sand extraction on Rio Claro's population. Currently, there are several clay pits just a few meters from the urban fringe (Figure 2).

The master plan approval process

The City Council presented the document at two public hearings. The participation of civil society and academic representatives was again crucial to defend the final draft of the new RCMP. Their participation materialized through cooperation between the Rio Claro Lawyers' Organization, which provided legal reinforcement to the environmental and social demands, and UNESP, which provided technical support. The first hearing occurred with intense academic and social participation. Most representatives supported maintaining the final draft of the new RCMP as it was. The Protective Boundary Macrozone received special attention for its potential to minimize the direct impact of mining on urban population wellbeing.

The mining sector attended the second public hearing, represented by a regional association of coating ceramics (ACC). They presented data highlighting the economic importance of mineral extraction and ceramics production expansion in Brazil, particularly in São Paulo State. ACC also presented the current spatial limitation of mining activities due to resource location in Rio Claro, noting that the area defined as the Protective Boundary Macrozone is of great importance for the municipality due to its abundance of clay reserves. Impeding mining expansion in those areas may affect Rio Claro's economy negatively. However, a prosecutor from São Paulo Public Ministry (SPPM) declared that no ACC amendment proposal would be accepted before the association performed a proper technical study.

In bill approval processes, the alderman can usually submit their amendment proposals—which can be influenced by public hearings and economic interests—up to 24 hours before voting. At the second public hearing, the academic representatives expressed their concern that such a short time would limit population awareness of any modifications in the document. Therefore, the City Council defined a deadline for the aldermen's amendment proposals and held a public plenary session (S4.3 Text) prior to the vote; this was considered a victory for civil society and academic representatives.

Prior to the public plenary session, the UNESP working group assessed the amendments proposed by the aldermen, available on the City Hall website. The amendments intended to allow small mining enterprises within the Conservation and Sustainable Use Macrozone and the Protective Boundary Macrozone. In São Paulo State, a mine is considered small when the effective area of mineral extraction is ≤ 30 ha for clay and < 50 ha for sand (São Paulo, 2014). Although considered small, the cumulative effect of all mining pits and the area directly affected by this type of activity is extensive (Figure 4.2). The permission of small mining enterprises within the Conservation and Sustainable Use Macrozone and Protective Boundary Macrozone would nullify more than a year of open discussions and the participatory formulation of the master plan. However, during the public plenary session, the City Council stated that the amendments proposed by the mining sector were not included in the new master plan. Moreover, the amendments proposed by UNESP's working group were not modified. The ACC representatives then made a request to postpone the master plan vote. That request was denied by the City Council.

The master plan vote was initially scheduled for May 2016 (S4.3 Text). However, half of the aldermen—mostly from opposition political parties—requested access to the document, and deliberation was postponed for 120 days. Municipal elections were held in October 2016, with the newly elected mayor and most of the elected aldermen representing the main coalition in opposition to Rio Claro's political mandate for 2013–2016. Furthermore, although the vote on the new RCMP should have taken place before the municipal elections, it was not included in the 2016 agenda (S4.3 Text). In March 2017, the elected aldermen requested access to the document and deliberation was again postponed for 120 days. The defined Macrozones and the limitation of mining activities are one of the main reasons for this request and new public hearings were held on May 2017 exclusively for clarifications. Thus, our objective now is to reinforce the importance of limiting economic activities, with special attention to mining, in environmentally and socially sensitive regions. It is essential to develop a more detailed definition of the Macrozones, considering physical aspects of Rio Claro's landscape, and the identification of the most suitable areas for mineral extraction. Thus, it will be possible to conciliate economic development and environmental protection, restricting this economic activity to certain regions that, if exploited, will not have profound impacts on the environment and on human well-being,

Thus, the approval of the new RCMP is uncertain. Equally uncertain is whether any points in the document will be altered. The new government may decide to archive the current proposal and elaborate a new one. Whether the objectives of the new government will favor economic activities instead of environmental and social issues is still unknown. Once again, the fate of Rio Claro relies on society's and academia's involvement in this issue. Having a master plan that prioritizes human wellbeing and environmental conservation is a first step in ensuring local sustainability and avoiding juridical maneuvering.

Lessons learned and potential implications

In a municipality such as Rio Claro – and in most Brazilian cities - where the participation of civil society in public issues is minimal, the involvement of academic representatives was a great achievement. Academia can catalyze the inclusion of citizens in participatory processes. Planning land-use modification requires long term perspectives and goals for society's wellbeing. The new RCMP aimed to enhance water resources conservation, incentivize environmental conservation and restoration (e.g. via Payment for Ecosystem Services), and reduce mining extraction near the urban fringe. Mining can severely impact several ecosystem services (Bian and Lu, 2013). Even with the mandatory plans for restoration of degraded areas (acronym in Brazil: PRAD) after mining activities, the area can only recover to a certain degree. It is important to highlight that in many cases, PRADs may not be put into practice. Fines and environmental compensation agreements are rarely enforced in Brazil due to the considerable political power of the mining sector and of larger companies in particular (Garcia et al., 2016; Spiegel et al., 2012). Recent social-environmental disasters have demonstrated the weakness of Brazilian environmental impact assessments and mineral extraction licensing (El Bizri et al., 2016).

It seemed a genuine intention of City Hall to balance the high environmental impact and economic value of mining activities with local demand for quality of life. However, backstage negotiation indicated that political influences were delaying the process of approving the new RCMP. The role of academics, the Rio Claro lawyers' organization and the SPPM prosecutor were critical in the defense of environmental and civil society interests. In our literature review, the only Brazilian study addressed the importance of interdisciplinary participation (academia, practitioners, policy makers and stakeholders) in surveillance projects for mining activities (Spiegel et al., 2012). Participatory processes are crucial due to the political power of large-scale industrial extraction companies in Brazil (Spiegel et al., 2012).

The current academic productivity assessment system, which overemphasizes publication in scientific journals that are accessed by a few academic peers (Evans, 2008) but rarely accessed by civil society and especially stakeholders, greatly devalues academic outreach. However, academia is ideally suited for direct involvement in decisions related to social and environmental issues. The knowledge produced and acquired within universities must be directly applied in the formulation of laws and policies that make economic activities socially responsible and environment-friendly. Likewise, institutions responsible for research funding should recognize and value university's' outreach initiatives for their direct impact in society. With this type of recognition, researchers would be willing to bridge the abyss between science and policy. University outreach initiatives that boost knowledge and innovation beyond campus have an enormous potential to contribute in participatory planning and decision-making.

Rio Claro has the privilege of having an excellent university, with professionals engaged in improving the population quality of life and the sustainable development of the municipality. However, most municipalities are not that privileged. The Academia's active participation is essential to expand its influences on decision making within a broader range of local governments. Such upscale requires not only the academia's participation, but also the engagement of and collaboration with local governments, NGOs and civil society representatives that want to participate and take action. All these actors should be constantly engaged in participatory decision making.

Mining within Rio Claro will continue because its importance is recognized. The proposed amendments intend only to regulate these activities and restrict them in environmentally and socially sensitive areas. Considering the current scenario of very limited academic participation and an interest in the active transfer of knowledge into regulatory practices for mining activities, we expect that the experience described in this study will stimulate students and professors from various universities to apply their technical knowledge to decisions that involve social interests. The formulation of amendment proposals for the new RCMP started as a working group related to an undergraduate course at UNESP. However, it evolved into an extremely positive experience, especially for undergraduate students, engaging the academic community in the pursuit of improvement in quality of life, environmental conservation and preservation of natural resources for future generations.

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Supporting Information

S4.1 Text: Literature review

We conducted a systematic literature review to locate studies published between 1948 and 2016. We used the keywords “environmental planning”, “master plan’, “environmental policy”, “environmental governance”, “environmental management”, “urban planning” and “landscape planning”, all together with “mining” on Web of Science database. We considered only publications that addressed mining activities in different stages (planning, extraction and impact assessment) and at different scales beyond the mineral extraction. We did not consider publications that only considered aspects related to the mining pit itself. We also identified the studies that, somehow, included social participation.

Authors	**Year**	**Country**	**Region**	**Participatory planning**	**Coverage**	**Topic**
Abuodha	2002	Kenya	Africa	No	District	Planning
Bhadra et al.	2007	India	Asia	No	State	Planning
Botequilha-Leitão & Muge	2001	Global	Global	No	Theoretical, landscape level	Planning
Burton et al.	2012	Australia	Oceania	Yes	Water catchment	Impact
Charou et al.	2010	Greece	Europe	No	Basin	Rehabilitation
Dulias	2010	Poland	Europe	No	Region	Impact
Gwimbi & Nhamo	2016	Zimbabwe	Africa	Yes	Resource location	Impact
Himley	2013	Peru	South America	Yes	District	Planning
Himley	2014	Peru	South America	Yes	Regional	Planning

Larsen & Mamosso	2014	Niger	Africa	No	Local to national	Planning & rehabilitation
Lei et al.	2016	China	Asia	No	Landscape	Rehabilitation
Liao et al.	2013	China	Asia	No	Resource location	Impact & planning
Loayza & Rigolini	2016	Peru	South America	No	National (several districts)	Conflict
Marschalko et al.	2012	Czech Republic	Europe	No	Resource location	Planning
Marschalko et al.	2015	Czech Republic	Europe	No	Resource location	Planning
Mata et al.	2016	Chile	South America	Yes	Local	Planning
Sklenicka et al.	2004	Czech Republic	Europe	No	Multiple-scale	Governance
Sobczyk et al.	2014	Poland	Europe	No	Local	Impact
Spiegel et al.	2012	Brazil	South America	No	Basin	Planning & conflict
Subspace Associates	1990a;b	USA	North America	No	Local	Planning
Taylor & Kruger	1986	Zimbabwe	Africa	No	Local	Planning
Tiwari et al.	2016	India	Asia	No	Resource location	Rehabilitation
Zhang et al.	2011	China	Asia	No	Landscape	Impact & rehabilitation
Zhang et al.	2013	China	Asia	Yes	Resource location	Planning

Zwane et al.	2006	Zimbabwe	Africa	Yes	Water catchment	Impact

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S4.2 Text: Amendments proposed by the UNESP working group

Additive proposal to Article 9, new Paragraph – Objectives of Environmental Policy

Paragraph 1st – To create the Linear Park *Rio Corumbataí*, alongside the river within the urban perimeter and upstream, and the Park *Mãe Preta* aiming at maintenance of water provision to the city, avoiding river siltation and ensuring connectivity within forest remnants.

Paragraph 2nd – To regularize the protection within the 300 meters buffer around State Forest *Edmundo Navarro de Andrade*.

Additive proposal to Article 17, new item, Section IV – Guidelines and Objectives of Environmental Sanitation Policy

V- To use methods and techniques of water and sewage treatment that produce less impact on the environment such as biological treatment of sewage, evapotranspiration basins and artificial wetland systems.

Additive proposal to Article 20, item IV – Ecological Agriculture

To incentive ecological agriculture following the principles of agroecology.

Additive proposal to Article 21, item V – Technical Assistance and Rural Extension

To ensure and provide technical assistance and rural extension to rural producers with properties up to four fiscal modules.

Additive proposal to Article 29 – Macro Zone of Environmental Preservation

Paragraph 1st – It is prohibited in this zone the implementation of large, medium or small size mining activities, as described by boarding decision of CETESB 25/2014.

Paragraph 2nd - Paragraph 1st is not applicable to currently licensed mining activities.

Additive proposal to Article 30 – Macro Zone of Rural Development and Forest Management

Paragraph 1st - It is prohibited, in this zone, the implementation of large or medium size mining activities, as described by boarding decision of CETESB 25/2014. Those considered of small size must be approved by the organ in charge, with the requirement of evaluation of cumulative effects.

Paragraph 2nd - Paragraph 1º does not apply to current licensed mining activities.

Additive proposal to Article 32 – Protective Boundary Macro Zone

Paragraph 1st – It is prohibited in this zone the implementation of large, medium or small size mining activities, as described by boarding decision of CETESB 25/2014.

Paragraph 2nd - Paragraph 1º is not applicable to currently licensed mining activities.

Additive proposal to Article 37 – ZEPRHI Description

The ZEPRHI includes at least fifty meters radius from permanent and temporary springs and thirty meters buffer from streams, according to Federal Law 12.651/2012, article 4, item I.

Additive proposal to Article 45, item X – Objectives of Environmental Policy

Paragraph 1st - In the Macro Zone for Environmental Protection and Sustainable Use and the Protective Boundary Macro Zone it is prohibited implementation of large, medium or small size mining activities, as described by boarding decision of CETESB 25/2014.

Paragraph 2nd - In the Macro Zone of Rural Development and Forest Management it is prohibited implementation of large or medium size mining activities, as described by boarding decision of CETESB 25/2014. Those considered of small size must be approved by the organ in charge, with the requirement of evaluation of cumulative effects.

Paragraph 3rd - Paragraphs 1st and 2nd do not apply to current licensed mining activities.

Modification proposal of Article 9, item IX – Objectives of Environmental Policy

Monitoring of environmental licenses made by the competent organs of mining and earthwork activities for the establishment of mitigation actions to negative impacts and development of strategies to ensure appropriate and reasonable recovery of degraded areas, after the termination of activities.

Modification proposal of Article 29, item II – Macro Zone of Environmental Preservation

Monitor and monitor land use within the Area of Environmental Protection (APA) *Piracicaba-Juqueri-Mirim* (Area 1).

Modification proposal of Article 84, item III

Uncovered parking areas must use draining floor on at least 1/3 of the area to be waterproofed and tree plantation must account with at least one individual tree, native and preferably from diverse species for each 35m².

S4.3 text: Chronology of events in the development of the new Rio Claro Master Plan (RCMP) from July 2015 to July 2017.

2015	
July	02 – First Public Consultation by SEPLADEMA (General explanation and consultation Agenda) Specific consultation with economic sectors, two meetings each. (mining, civil engineering, farming, and industry)
August	SEPLADEMA writes the first draft of the new RCMP
September	SEPLADEMA writes the first draft of the new RCMP 30 – SEPLADEMA presents the first draft of the new RCMP
October	02- Last day for submission of amendments by society 07 and 08 – Public audience for deliberation on proposed amendments
November	06 – SEPLADEMA forwards the final draft of the new RCMP to the City Council Aldermen’s meetings to discuss new amendment proposals
December	Aldermen’s meetings to discuss new amendment proposals
2016	
April	Rio Claro Lawyers’ Organization reinforces aspects of the final draft of the new RCMP with technical support of Unesp 28 – First Public Hearing organized by City Council
May	03 – Second Public Hearing organized by City Council 06 – Aldermen publish proposed amendments 09 and 10 – Aldermen’s meeting to discuss and deliberate on amendments (no public access, uncertainty concerning meeting agenda) 11 – Plenary Session with open to the public

	(Mining representative proposes new amendments) 16 – The new RCMP would be voted. However, half of the alderman – mostly from opposition political parties – requested access to the document and deliberation was postponed for 120 days, extendable if necessary.
October	Municipal elections. Deliberation was postponed again for 90 days.
2017	
March	20 - Deliberation was postponed again for 120 days
May	09 and 11 – Public Hearings regarding mining activities in Rio Claro
July	The new RCMP vote is scheduled for the second half of July

S4.1 Table: Macro zones defined in the first draft of the Rio Claro Master Plan, their specific characteristics and the allowed economic activities. Source: Final draft of the new Rio Claro Master Plan, 2015.

Macro zone	Specific characteristics	Economic activities proposals
Conservation and Sustainable Use	Region with the highest number of sources in the municipality, it is important for the municipal water supply. The relief is relatively hilly, with a predominance of pastures and family farming.	Prohibited mining activity. Characterized by activities aimed at sustainable use of natural resources and rural development. Examples: Research and environmental education; agribusiness, agro-forestry, agriculture; ecotourism; ongoing sand mining water when serving of environmental damage mitigation already installed; Water uptake for human consumption.
Rural Development and Forest Management	Region characterized by the presence of family farmers and food production of the municipality	Allows the same uses macro zone Conservation and Sustainable Use, but aimed at economic development with activities that reconcile environmental and agricultural functions of the rural area. This macro zone the small mining is permitted.
Economic and Rural Development	Characterized by flat lands, dominated by sugarcane and mining activities,	Besides the activities already mentioned, only macro zone that will be allowed to small, medium and large mining
Urban	Region where is the urban area of the municipality	Typical uses of the urban area
Protective Boundary	Region created to mitigate the impacts arising from mining activity	The same uses of macro zone Conservation and Sustainable Use

Concluding remarks

A couple of *Forpus xanthopterygius*

“We need nature as much in the city as in the countryside”

Ian McHarg, 1969, *Design with nature*

During the last 50 years, studies conducted in cities under different planning and management policies, under distinct environmental conditions and with different amounts and composition of fauna and flora, have shown how nature can enhance urban environmental resilience and sustainability and human quality of life. Although most information about urban landscapes was acquired in cities located in North America and Western Europe, this is especially true within urban landscapes located in developing countries. With large social and economic inequalities, the green infrastructure has an important role in providing a variety of provisioning goods – such as food and medicine– and in increasing the urban men contact with nature (Shackleton et al., 2017). However, the green infrastructure still is considered a cosmetic element in Brazilian cities, especially in planning and managing low income neighborhoods and slums. The urban afforestation process and the preservation of habitat patches are seen as obstacles and difficulties for urban development, not as important infrastructural elements for the proper function of the urban environment.

The green infrastructure of the southern region of Belo Horizonte follow an uneven pattern of distribution through the urban landscape. Within slums it is observed an extremely low amount of woody and herbaceous vegetation, which is lower than the amount of vegetation within wastelands and vacant lots. Further, as in most Latin America cities, the afforestation process is based on a small pool of commonly planted, often exotic tree species (Moro and Castro, 2015; Pauchard and Barbosa, 2013). At the same time, almost half of this urban landscape is occupied by herbaceous and woody vegetation, and the large amount of gardens is an indicative of high landscape heterogeneity. Therefore, with a proper planning and management, the green infrastructure of Belo Horizonte can improve landscape functionality and increase human well-being.

Birds can be used as models to identify management and planning decisions for the green infrastructure. Currently, the southern region of Belo Horizonte is only able to retain 20% of its rich bird community within the urban matrix. However, the maintenance of large street trees, and the increase in street tree species richness and in the amount of native street tree species, are management practices able to increase bird species richness, abundance and functional aspects, even in the most urbanized areas of the urban landscape. Exposure to noise is the most limiting factor for bird species. Throughout the southern region of Belo Horizonte were registered an average Equivalent Continuous Sound Level of more than 55db – which is the limit established by the World Health Organization for outdoor living areas (WHO, 1999) – in 95% (57) of the point counts. Considering that trees characteristics can reduce the negative effect of the exposure to noise on birds, we can consider that trees can also help the human population in overcome the serious negative effects that high noise exposure can have on human health (WHO, 1999). For example, the abundance and richness of woody plant species in gardens of schools and churches can help students to concentrate and increase the sense of peace and tranquility, respectively (Shackleton et al., 2017).

Using birds, we were also able to identify the most permeable portions of the urban landscape, and the most important green infrastructure elements for the maintenance of landscape functional connectivity. Gardens and street trees can connect urban habitat patches and parks, and this was also observed in different urban landscapes worldwide (Fernandez-Juricic, 2000; Vergnes et al., 2013). Although we were efficient in eliciting the knowledge gathered from Brazilian experts to formulate resistance surfaces for bird species, it is necessary a better understanding of how urban landscapes influence animal movements. Meanwhile, we demonstrated that expert knowledge can be a reliable source of information when data is unavailable and important decisions need to be made. The best potential routes identified for bird species between habitat patches can be used as green corridors for human and non-human organisms. Therefore, expert knowledge and least cost path modeling can help in planning and managing a multifunctional green infrastructure, which will be able to increase urban permeability and ecosystem functionality.

However, a proper urban environmental planning cannot consider only biophysical aspects of urban landscapes (Eakin et al., 2017). Socio-political aspects need to be taken under consideration when defining public policies and directives for urban growth and development, such as goals and opinions of all sectors of society. Above all, environmental protection, sustainability and human well-being should be considered priorities. However, during our experience in Rio Claro, it was evident the high political influence of a specific economic sector. Although being supported by the majority of academic and civil society representatives, the voting and approval process of the participatory master plan for Rio Claro was delayed by half of the aldermen. Further, the political scenario defined after the 2016 elections reduced even more our expectations for the approval of the proposed bill. However, our research group will keep working for the improvement of Rio Claro environmental indicators and human well-being. Considering the reduced academic participation in environmental planning and management worldwide, we argue that students, professors and researchers from universities and research centers need to be more actively involved in decision making. Academia can catalyze social participation in public issues and warn stakeholders about the potential social-environmental consequences of mistaken planning and management decisions.

Therefore, Neotropical urban landscapes are, indeed, poorly planned and managed. The urban environmental filter has a strong effect on the urban bird community, reducing species richness, abundance and functional aspects. However, it is possible to increase urban environmental quality, not only by the better planning and management of the green infrastructure. It is also necessary to change the current uncontrolled and unsustainable urban development, that is stimulated by strong economic sectors that have high political influences. Urban and landscape planning need to prioritize human well-being, environmental sustainability and biodiversity conservation. It is necessary to preserve the integrity of ecological processes that are essential for a health urban environment. Thus, by the identification of urbanization impacts on human and non-human organisms and the socio-political aspects that shape urban growth and development, we will be able to build friendlier and resilient cities, that are socially responsible and environmentally sustainable.

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