

Tulaci Bhakti Faria Duarte

ORNITOLOGIA URBANA: APLICAÇÕES, DESAFIOS E PERSPECTIVAS

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Orientador: Prof. Dr. Marcos Rodrigues

Coorientador: Dr. João Carlos Pena

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TULACI BHAKTI FARIA DUARTE

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Para Frida e Naná,
uma lambida no
focinho
(*in memoriam*)

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'With a little help from my friends'. Sim, amigos, inclusive Lennon e McCartney estavam certos, em vários aspectos citados na música, sem mais por hora... Enfim, amigos que

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Eugênio, Nunes, Jason e Ubirajara. CBTU Estação Central: Eugênio, Davi e Silvio. CBTU Estação Santa Tereza: Everaldo, Gustavo e Alexandre. CBTU Pátio São Gabriel: Mariana. CBTU Estação Horto: Hugo, Bruno, Carlos, Bruna, José Luiz, Edimilson e Cleber. CBTU Estação José Cândido: Wilson, Nunes (segurança) e Luiz Carlos. Cemitério da Saudade: Vicente e Marcos. CEVAE-Taquaril: Popó e Giovani. Clube Associação dos Praças, Policiais e Bombeiros Militares de Minas Gerais (ASPRA/PMBM): Cabo Moura. Conselho Comunitário Unidos pelo Ribeiro de Abreu (COMUPRA): Virgílio e Itamar. ETE Arrudas (COPASA): Patrícia Castro e Ernane. Fundação João Pinheiro (FJP): Saulo, Gustavo, Liliane, Reinaldo, Ozéias e a cachorrinha Suzi. Fundação Benjamim Guimarães/Hospital da Baleia: Samuel e Jorge. Instituto Raul Soares (IRS): Marconi e Guilherme. Mercado Santa Tereza: Alyson Amendoeira. Minas Tênis Country Clube: Klécio Alves e Ilídio Brandão, além do Paulo Carvalho pela companhia nas amostragens. Museu de História Natural e Jardim Botânico da UFMG (MHNJB): Flávia Faria e Marcos. Fundação de Parques Nordeste: Robson (Parque Linear do Vale do Arrudas, Parque Linear José Cândido da Silveira, Parque da Matinha, Parque Ecológico e Cultural Professor Marcus Mazzoni). Parque Fernão Dias: Marcela, Reginaldo e Michele. Parque Orlando de Carvalho Silveira: Alcira e Lucas. Parque Professor Guilherme Lage: Reginaldo. Fernão Dias Parque Sol: Carlos (morador da região). Parque Escola Jardim Belmonte: Tiago. Parque Municipal Américo Renné Giannetti: Andréa e Tatiani. Parque Nossa Senhora da Piedade: Fábio, Toninho e Alexandre. Parque Primeiro de Maio: Getúlio. Parque Estadual Baleia/Instituto Estadual de Florestas: Henri. Gerência Regional de Manutenção Leste / Centro-Sul: Praça Hugo Werneck, Praça Duque de Caxias, Praça Rui Barbosa e Parque Rua Belém. Regional Nordeste (Fazendinha): Dênio.

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Tulaci Bhakti

“Tenho sangrado demais
Tenho chorado pra cachorro
Ano passado eu morri
Mas esse ano eu não morro”

Belchior
(*Sujeito de Sorte*, 1976)

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Resumo Geral

O desenvolvimento de pesquisas na área de biodiversidade em ambientes urbanos, seja com o foco em conservação ou manejo, tornou-se uma realidade dentro da Ecologia. Conseqüentemente, estudar as relações ecológicas entre diversos grupos de organismos, sejam da fauna ou da flora, com este ecossistema sob constante mudança tem sido cada vez mais apontado como uma saída para manutenção da biodiversidade. Com isso, estudos já aplicaram diversas abordagens dentro do contexto urbano, das quais é possível citar aqueles focados nas zonas periurbanas, nos gradientes de urbanização, na criação de corredores ecológicos, na relação dos espaços verdes urbanos com a biodiversidade e mais recentemente, na implicação destas pesquisas para a gestão urbana. Dentro os estudos desenvolvidos em cidades, as aves vêm sendo continuamente utilizadas como modelo por serem animais carismáticos, de fácil observação e que possuem diversas respostas às características das cidades. Assim, estudos que descrevem as relações entre aspectos taxonômicos e funcionais de comunidades de aves urbanas podem informar potenciais impactos da urbanização sobre a biodiversidade e auxiliar na formação de políticas públicas para a gestão sustentável de paisagens urbanas. Dessa forma, esta tese teve como objetivo explorar algumas facetas da ecologia e ornitologia urbanas na cidade de Belo Horizonte (Minas Gerais, Brasil) a partir de uma abordagem interdisciplinar, incluindo elementos da arquitetura e do urbanismo para a geração de políticas públicas municipais. No primeiro capítulo, foi desenvolvido um índice espacialmente explícito que descreve níveis de adequabilidade ambiental para a biodiversidade (*Urban Biodiversity Suitability index*, ou Índice UBS). Para a criação do UBS, foram sobrepostas diversas camadas geoespaciais que representam aspectos ambientais e urbanísticos da cidade de Belo Horizonte. Em seguida, foram selecionados 33 espaços verdes com diferentes tipos de uso e intensidades de manejo (parques, clubes, cemitérios, praças, linha férreas, dentre outros), nos quais foram distribuídos 60 pontos de escuta. Foram registradas 160 espécies de aves em todos esses espaços verdes, o que representa quase a metade das espécies já registradas em Belo Horizonte. A riqueza funcional e taxonômica de aves observadas em cada um dos 60 pontos de escuta foi utilizada para validar o UBS. Observamos que os níveis de adequabilidade descritos pela nossa abordagem interdisciplinar e espacialmente explícita foi capaz de descrever diferentes níveis de riqueza taxonômica e funcional de aves nas áreas estudadas. No segundo capítulo, o UBS foi aplicado para avaliar os padrões de distribuição de incêndios urbanos pela paisagem de Belo Horizonte. Observamos que a maior frequência de incêndios ocorre em locais com valores intermediários de adequabilidade para a biodiversidade. No terceiro capítulo, avaliamos como aspectos locais, da paisagem e a dimensão espacial dos espaços verdes estudados influenciam a abundância de espécies e a composição de traços funcionais da comunidade de aves de Belo Horizonte. Observamos que

características locais, principalmente relacionadas com o manejo da vegetação dos espaços verdes, possuem maior influência sobre a avifauna. No último capítulo da tese é apresentado um estudo de caso no qual a ornitologia foi colocada em prática para o engajamento comunitário para a preservação do último remanescente de vegetação nativa não protegido de Belo Horizonte. Demonstramos como a integração entre a academia, o poder público e a sociedade podem ajudar na aplicação do conhecimento científico para a gestão e planejamento de áreas verdes urbanas. Acredito que os resultados apresentados nesta tese fornecem informações importantes para a gestão sustentável de paisagens urbanas, podendo ser aplicados não somente em Belo Horizonte, mas também em outras cidades ao redor do planeta.

Palavras chave: ecologia urbana, ornitologia, urbanismo, urbanização, traços funcionais, políticas públicas, escalas da paisagem.

Abstract

Title: Urban Ornithology: Applications, challenges and perspectives

Research development in the field of biodiversity in urban environments, whether focusing on conservation or management, has become a reality within Ecology. Consequently, studying ecological relationships between various groups of organisms, whether fauna or flora, within this constantly changing ecosystem has increasingly been recognized as a solution for biodiversity maintenance. As a result, studies have applied various approaches within the urban context, including those focused on peri-urban areas, urbanization gradients, the creation of ecological corridors, the relationship of urban green spaces with biodiversity, and more recently, the implications of these studies for urban management. Among the studies conducted in cities, birds have been continuously used as models due to their charismatic nature, ease of observation, and diverse responses to urban characteristics. Thus, studies describing relationships between taxonomic and functional aspects of urban bird communities can inform potential impacts of urbanization on biodiversity and assist in forming public policies for sustainable urban landscape management. Accordingly, this thesis aimed to explore some facets of urban ecology and ornithology in the city of Belo Horizonte (Minas Gerais, Brazil) from an interdisciplinary approach, including elements of architecture and urbanism for the generation of municipal public policies. In the first chapter, a spatially explicit index was developed to describe levels of environmental suitability for biodiversity (Urban Biodiversity Suitability index, or UBS). To create the UBS, various geospatial layers representing environmental and urban aspects of Belo Horizonte were overlaid. Subsequently, 33 green spaces with different types of use and management intensities (parks, clubs, cemeteries, squares, railway lines, among others) were selected, where 60 listening points were distributed. A total of 160 bird species were recorded in all these green spaces, representing nearly half of the species previously recorded in Belo Horizonte. The functional and taxonomic richness of birds observed at each of the 60 listening points was used to validate the UBS. We observed that the suitability levels described by our interdisciplinary and spatially explicit approach could describe different taxonomic and functional richness levels of birds in the studied areas. In the second chapter, the UBS was applied to evaluate patterns of urban fire distribution across the Belo Horizonte landscape. We observed that the highest frequency of fires occurs in locations with intermediate biodiversity suitability values. In the third chapter, we evaluated how local aspects, landscape, and spatial dimensions of the studied green spaces influence species abundance and the functional trait composition of Belo Horizonte's bird community. We found that local characteristics, mainly related to green space vegetation management, have a greater influence on avifauna. In the thesis's final chapter, a case study is presented where ornithology was put into practice for community engagement in preserving Belo Horizonte's last unprotected native vegetation remnant. We demonstrated how integration between academia, government, and society can aid in applying scientific knowledge to the management

and planning of urban green areas. I believe the results presented in this thesis provide valuable information for sustainable urban landscape management, applicable not only in Belo Horizonte but also in other cities worldwide.

Keywords: urban ecology, ornithology, urbanism, urbanization, functional traits, public policies, landscape scales.

Prólogo: Que farei com esta tese?

Esta tese é intitulada “Ornitologia urbana: aplicações, desafios e perspectivas” e tem como objetivo discorrer sobre a pesquisa desenvolvida durante meu doutorado no campo de estudos da ecologia urbana. Sendo mais específico, a ênfase dada foi para a ornitologia urbana, pois as aves foram a motivação para este estudo e também fundamentais para os modelos propostos e avaliadas.

Ao longo deste documento, que foi dividido em quatro capítulos, apresento o desenvolvimento do projeto que acredito que possa ser uma importante contribuição para o tema da ecologia e da ornitologia em ambientes urbanos. Indo além de apenas contextos tropicais, acredito que as discussões trazidas ao longo dessa tese podem servir de molde para a ecologia urbana global. A seguir, apresento um pequeno resumo de cada capítulo, suas conexões e o motivo para a sequência na qual são apresentados.

O primeiro capítulo tem como objetivo apresentar um índice de adequabilidade para a biodiversidade (*Urban Biodiversity Suitability index*, ou UBS) baseado na ideia do *wilderness mapping*, abordagem que já foi aplicada em escalas continentais ou mesmo para países inteiros e que tem como objetivo indicar onde e quais áreas ainda podem ser consideradas selvagens (ou menos acessíveis e com menor impacto antrópico). Neste trabalho adaptamos essa abordagem para o ambiente urbano, produzindo um índice espacialmente explícito (ou seja, um mapa) que descreve níveis de adequabilidade ambiental para aves. Para a construção deste mapa, utilizamos várias camadas geoespaciais que descrevem diversas características do ambiente urbano, como acessibilidade humana, áreas protegidas, distribuição da iluminação urbana e outros. Tais camadas descrevem características que acreditamos influenciar a composição taxonômica e funcional de aves pelo ambiente urbano. Dessa forma, o mapa descreve regiões pela paisagem de Belo Horizonte que apresentam diferentes níveis de impactos antrópicos sobre a avifauna urbana, sendo assim identificar áreas com diferentes potenciais para a conservação da biodiversidade na cidade.

No segundo capítulo, apresento uma proposta de aplicação para o índice UBS. Para tanto, utilizamos um banco de dados cedido pelo Corpo do Bombeiros contendo a informação de todos os locais onde registrados incêndios em vegetação no intervalo de 2011 a 2020 (um total de 9877 registros distribuídos por toda a paisagem de Belo Horizonte). Essa aplicação foi definida de acordo com a ênfase em ecologia aplicada proposta pela tese, fornecendo informações para a gestão de paisagens urbanas e para auxiliar na produção de políticas públicas. Assim, nesse capítulo, identificamos como os diferentes níveis de adequabilidade para a biodiversidade descritos pelo UBS estão relacionados com a frequência de incêndios em Belo Horizonte.

No terceiro capítulo passo aplicamos uma abordagem multi-escala dentro da paisagem urbana de Belo Horizonte, com o foco em investigar como as características ambientais

locais (por exemplo, abertura do dossel, profundidade da serrapilheira e a presença de árvores mortas em pé) geram as micro percepções, ou seja, como as aves, por meio de atributos funcionais, “percebem” os espaços verdes. Esse foco na escala local foi interessante para contrapor a já sedimentada ideia de um gradiente de intensidade de urbanização, em que a variação dos impactos de uma cidade sobre a biodiversidade por ser explicada apenas por uma linha que sai das zonas periurbanas para o centro mais adensado e impermeabilizado. Apesar de o gradiente de intensidade de urbanização possuir um efeito bem descrito em cidades ao redor do planeta, ele desconsidera o impacto em escala local, relacionado à gestão das áreas verdes urbanas. Assim, nesse capítulo, mostramos que aspectos como o tipo de solo (se coberto por serrapilheira, asfalto ou por afloramentos rochosos) possui maior influência sobre a avifauna urbana do que o gradiente de intensidade de urbanização, descrito pela proporção de cobertura verde ao redor das áreas amostradas. Tal resultado pode ser diretamente aplicado na gestão mais sustentável das áreas verdes urbanas.

Para encerrar a tese, no quarto capítulo, apresentamos um estudo aplicado para um dos preceitos da ecologia urbana, o de promover a interação entre os diversos atores que fazem parte das cidades com a pesquisa acadêmica. Neste estudo de caso, utilizei o conhecimento sobre a avifauna do último remanescente de vegetação nativa não protegido de Belo Horizonte para dialogar com as comunidades que vivem ao seu redor, com movimentos que lutam pela conservação do espaço e com gestores da administração pública municipal. Esta tentativa de estreitar os laços entre esses três atores é essencial para que o conhecimento científico seja aplicado na conservação e na gestão de áreas verdes urbanas. Ao longo deste último capítulo, apresentamos os desafios enfrentados bem como possíveis desdobramentos do movimento criado em prol da conservação dessa importante área verde de Belo Horizonte, a Mata da Izidora.

Permeando a tese e separando os capítulos escrevi pequenas crônicas, aqui nomeadas como interlúdios, que tem como intuito ilustrar todo o processo de desenvolvimento desta pesquisa, ou também chamado de bastidores de um projeto. Esta proposta foi pensada para auxiliar ao leitor na compreensão de como o projeto foi idealizado e os vários tons que uma tese pode ter, para além dos já tradicionais artigos científicos.

Capítulo 1: Urban Biodiversity Suitability index: Decoding the relationships between cities and birds

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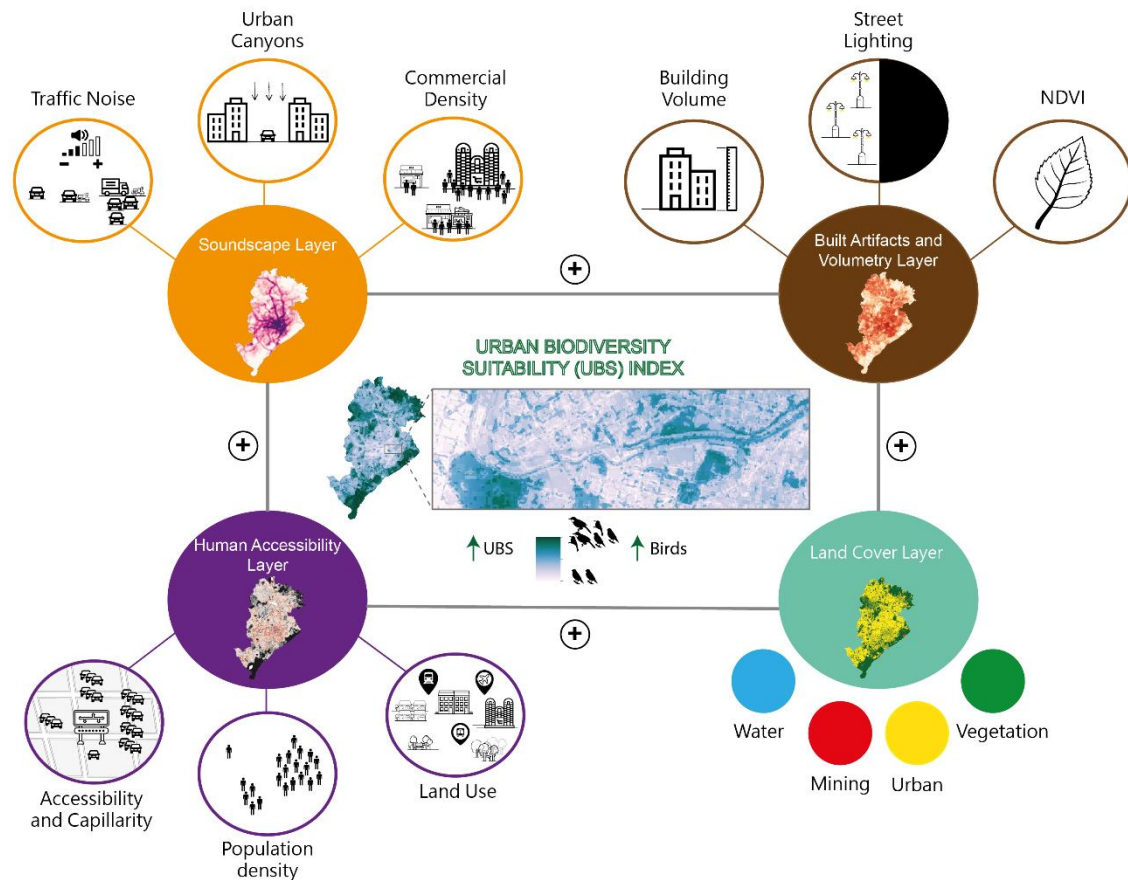
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Abstract

The expansion of cities has increased the necessity of multidisciplinary strategies to reduce the impacts of urbanization on ecosystems. Here we present the Urban Biodiversity Suitability (UBS) Index, a spatially explicit tool that describes levels of environmental suitability for biodiversity based on several urbanistic and socioeconomic data through a wilderness mapping approach. Using a tropical metropolis as a case study (Belo Horizonte, Brazil), we applied a multi-criteria Analysis to produce and join four geospatial layers that we believe describe the main aspects of cities that modulate urban biodiversity distribution: human accessibility, soundscape, built artifacts and volume, and land cover. To assess the accuracy of the UBS Index, we used bird species richness, functional richness (FRic), and Rao's Quadratic Entropy (RaoQ) based on data collected across several urban habitats (from streets to natural vegetation patches). We observed that as the suitability levels described by the UBS Index increases, higher bird species richness, FRic, and RaoQ values are also observed. Thus, quieter, less accessible urban regions, with few built artifacts, and with higher amounts of urban vegetation presented diverse bird communities. Those regions are distributed across the analyzed urban landscape, highlighting its spatial and environmental heterogeneity. The UBS Index is a simple tool that can be replicated in other cities across the globe to inform public policies for biodiversity conservation and environmental restoration in urban landscapes.

Key-words: functional diversity; multi-criteria Analysis; urban ecology; urban landscape planning; urban ornithology; wilderness mapping

Graphical Abstract



Introduction

In a moment when the human population is mostly urban, which is related to a fast expansion of cities worldwide (Liu et al. 2020), urban ecosystems have become the focus of many studies assessing the impacts of urbanization on biodiversity and human quality of life (McPhearson et al. 2016; Guerry et al. 2021). In this context, concepts from the emerging urban ecology discipline have proved to be valuable for their multidisciplinary nature. By combining biological, sociopolitical, and economic perspectives to study patterns and trends of biodiversity and ecological processes in cities, it is possible to encourage public policies that reconcile human needs with more sustainable practices in urban planning and management (Bhakti et al. 2021a; Graviola et al. 2021; Gomes et al. 2023). Such an approach is fundamental considering that trends associated with the current climate and biodiversity crises we face correlate with urban areas, e.g., invasive species, habitat loss, and land use/land cover changes (McDonald et al. 2013, 2020).

A tool that allows the assessment of how human activities modulate environmental conditions and thus, the distribution of biodiversity across landscapes is the wilderness mapping (Carver and Fritz 2016). This spatially explicit tool consists on the merging of geospatial data (such as topography, land cover, and biodiversity records)

and human dynamics (such as accessibility, population density, and built structures) to determine regions that could be under less anthropogenic influences – or wilder (SNH 2014; Müller et al. 2015). The wilderness mapping has been applied on large spatial scales to assess levels of conservation of protected areas across countries (Ma and Long 2020) or the human perception of what could be considered as “wild” (Kliskey and Kearsley 1993).

Most recently, studies have been applying the wilderness mapping at the city scale, identifying patterns of urban environmental conditions to determine wilderness levels of urban parks and green spaces, the influences of the urbanization intensity on human quality of life, and to identify priority areas for biodiversity conservation in cities (Hand et al. 2016; Müller et al. 2018; Martin and Hill 2021). By associating characteristics of the urban areas (e.g., land use types) with the composition of species (e.g., native plants and birds) across urban landscapes, it is possible to assess the potential of different urban habitats (such as wooded streets, squares, parks, and cemeteries) to conserve biodiversity and ecological processes in cities (MacGregor-Fors et al. 2022). This identification of environmental suitability levels for biodiversity across urban landscapes can also assist in the definition of regions eligible for rewild initiatives by adopting sustainable and biodiversity friendly management practices, such planting native plant species and maintaining the understory for conserving structurally complex vegetation patches in cities (Matsuba et al. 2016; Kowarik 2018; Hwang et al. 2019). Rewild is a concept that aims to restore ecological functions in green areas through active management, by for example, incorporating the role of key species, such as seed-dispersing birds (Root-Bernstein et al. 2018; Thierry and Rogers 2020). Since wilderness mapping is an interface between ecological and human perspectives, it can be incorporated into urban planning and management (Kowarik 2018), guiding the definition of urbanistic parameters that can increase the permeability and accessibility of urban landscapes for biodiversity (Bhakti et al. 2021a).

Usually, the accuracy assessment of wilderness maps is based on the human perspective of what is wild (Ma and Long 2020). However, it is important to assess the ability of geospatial data-based approaches to infer environmental suitability levels using *in situ* biological information. Most importantly, the model organisms should be able to indicate the variation of conditions across all habitat types within urban landscapes (from woodless streets to well-preserved forest patches), promoting a better understanding of the existing ecological relationships (Canedoli et al. 2018). In this context, birds are bioindicators (Morelli et al. 2021) and can be considered the most adequate group of organisms to be applied in the accuracy assessment of wilderness maps, since it is well known that communities’ functional, phylogenetical, and taxonomic compositions are modulated by biotic and abiotic singularities of cities (Conole and Kirkpatrick 2011; Curzel et al. 2021). For instance, elevated noise levels are associated with taxonomically and functionally depauperated bird communities in urban parks, small public urban green spaces, and even across the streetscape (Perillo et al. 2017;

Silva et al. 2021; Pena et al. 2023). Plant species composition and vegetation structure (e.g., tree height, canopy cover, and standing dead trees) are important attributes that modulate bird species composition in urban vegetation patches (Zhou and Chu 2012; Campos-Silva and Piratelli 2021; Sánchez-Sotomayor et al. 2023). Urbanistic parameters defined across urban zones, such as the maximum height of buildings and the minimum permeable area that needs to be maintained in individual lots, may influence the movement of bird species across urban landscapes (Bhakti et al. 2021a). Considering this vast theoretical framework about the relationships between urban avifauna and urbanization (Aronson et al. 2017; Bernat-Ponce et al. 2020; Sánchez-Sotomayor et al. 2023), birds can be used not only to validate the environmental suitability estimated based on a knowledge driven approach using geospatial data (Müller et al. 2018), but also as additional information to estimate levels of ecological integrity (MacGregor-Fors et al. 2022).

In this study, we present the Urban Biodiversity Suitability (UBS) Index. Although based on the same fundamentals as traditional wilderness mapping approaches (SNH 2014; Müller et al. 2018), we propose the replacement of the terms “wilderness levels” by “biodiversity suitability levels”, since in the city scale the use of “wild” may not be the most appropriate due to the intense human influences on environmental conditions (McDonald et al. 2009; McDonald et al. 2020). Despite other environmental suitability indices based on abiotic and biotic aspects of cities have already been proposed to describe levels of ecological integrity (e.g., land surface temperature, built cover, and the richness of native plant and bird species, MacGregor-Fors et al. 2022), the UBS Index is based on a diverse set of geospatial data that describes urban landscape features that influence patterns of biodiversity distribution in cities (Alberti 2005; Luck 2007; Amaya-Espinel et al. 2019). We developed the UBS index based on four landscape attributes: human accessibility, soundscape, built artifacts and volumetry, and land cover. To assess its accuracy, we related the levels of suitability indicated by the UBS Index and bird data (species richness, functional richness (FRic), and Rao’s Quadratic Entropy (RaoQ)) collected across different habitats of the city, from streets to native vegetation patches. We expected that more biodiverse suitable urban areas described by the UBS index would be related to more diverse bird communities, described by higher functional and taxonomic diversities.

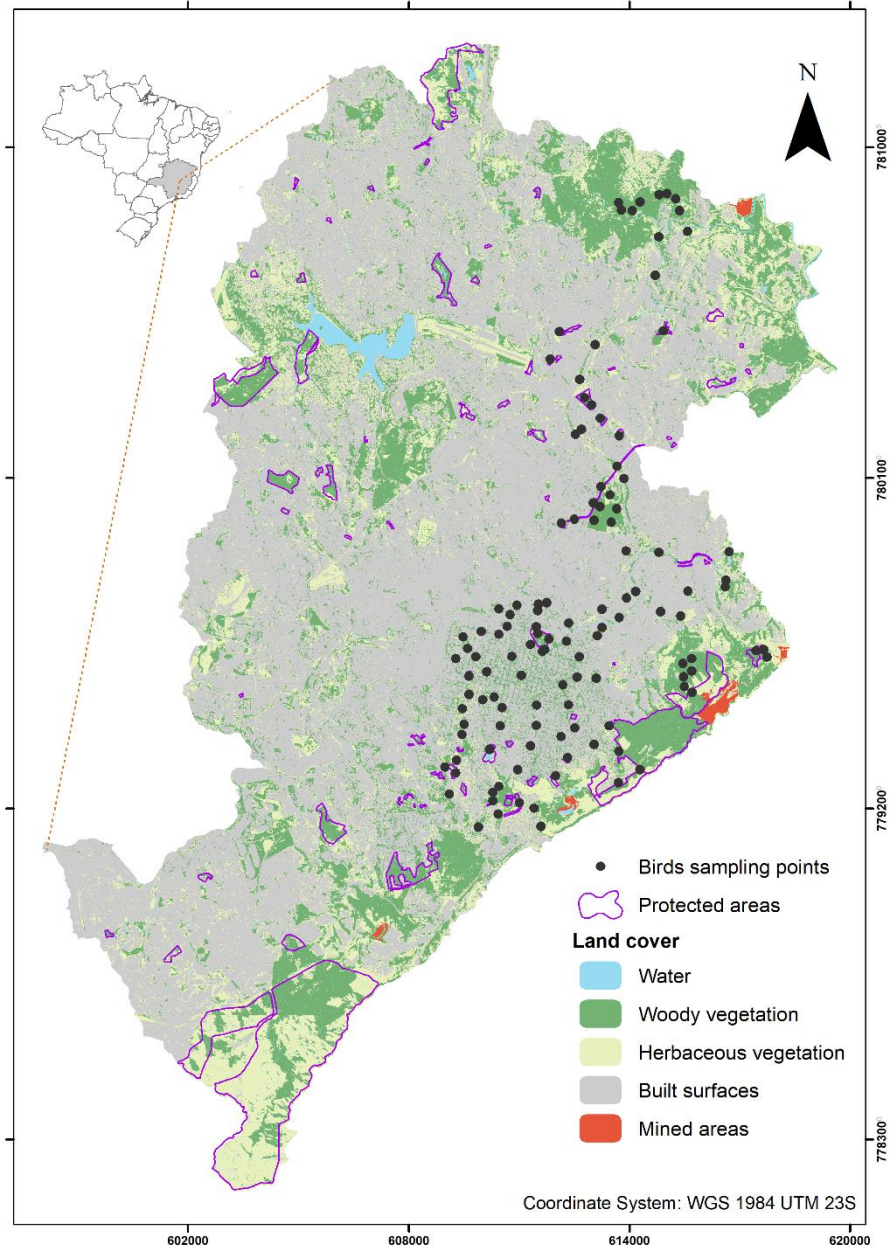
Methods

Study area

The tropical city of Belo Horizonte (43° 56′ 34″ S, 19° 55′ 37″ W), located in southeastern Brazil, was selected as a case study to build the UBS Index and test its ability to describe levels of functional and taxonomic diversities of urban bird communities (Fig. 1). The city has an area of 331,354 km² with an estimated human population of 2,530,701 people (IBGE 2021), and is located in the transition zone between two biodiversity hotspots, Cerrado and Atlantic Forest (Myers et al. 2000). Belo

Horizonte can be considered an interesting model for the application of an urban biodiversity suitability map because it is a completely urbanized municipality, without a rural zone, forming a heterogeneous mosaic of vegetated and non-vegetated areas. Across its territory there are more than 90 conservation units (from municipal and state parks to private protected areas) (Fig. 1), besides several peri-urban native vegetation patches without a properly defined land use (Belo Horizonte 2019).

Figure 1. Land cover map of the urban landscape of Belo Horizonte (Minas Gerais, Brazil), the municipality used as a model for the application of the Urban Biodiversity Suitability (UBS) Index. Purple polygons highlight the protected areas spread across the landscape. The black dots highlight the 120 survey sites where the bird data used to test the accuracy of the UBS Index was collected.



Geospatial data for the Urban Biodiversity Suitability (UBS) Index map

To build the UBS Index map based on a knowledge driven approach, we merged four main layers that describe several landscape attributes that may modulate the environmental suitability for birds across urban landscapes using the ArcMap v.10.x software (Fig. 2): (1) human accessibility (described by streetscape attributes, human

population density, and land use types), (2) soundscape (described by traffic noise, urban canyons, and commercial density), (3) built artifacts and volumetry (described by building volume, street lighting, and NDVI), and (4) land cover (describing water, mining, and woody and herbaceous vegetation). We used bird data collected across several urban contexts to assess the ability of our knowledge driven approach to estimate environmental suitability for urban birds. All these layers were selected to produce the most complete representation of environmental conditions across the urban landscape

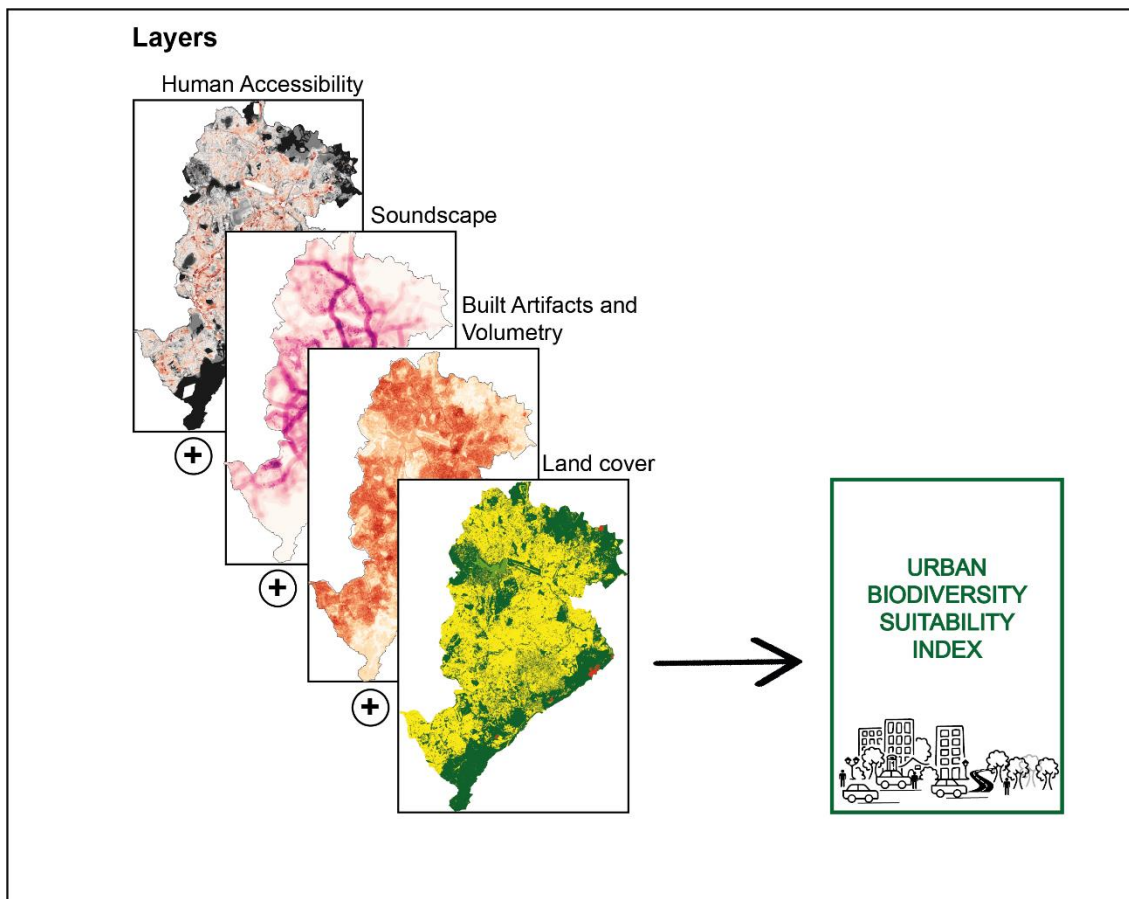


Figure 2. Representation of the Multi-Criteria Analysis approach adopted to merge the four main layers – human accessibility, soundscape, built artifacts and volumetry, and land cover – for the formulation of the Urban Biodiversity Suitability (UBS) Index.

as possible, and were already used in previous studies (SNH 2014; Müller et al. 2018). We produced layers (1), (2), and (3) by merging other geospatial data (hereafter intermediate layers) through a Multi-Criteria Analysis (MCA). In the MCA approach, the reality is decomposed into main variables (i.e., layers) that are transformed into matrices (i.e., sets of pixels), in which the attributes are transformed into numerical values according to, in our case study, how they facilitate or hinder the ability of birds to exploit the different regions of the landscape. We standardized all geospatial data into raster files with 5 m of spatial resolution, under UTM projection DATUM WGS 84, 23S Zone and pixel values ranging from 1 to 10, being 10 higher urban birds' vulnerability (or lower

suitability). Then, to produce each layer, we applied a map algebra process by summing the intermediate layers and calculating the average value of each pixel of the resulting matrix, maintaining the variation of each layer into values between 1 and 10. The MCA approaches adopted to build layers (1), (2), and (3), as well as the methods adopted to produce the land cover map (layer 4) are described in the following sections. The development process and the origin of each layer will be detailed in the following sections.

Layer 1: Human accessibility

The first intermediate layer used to produce the spatially explicit representation of Human accessibility of Belo Horizonte's landscape describes streetscape accessibility and capillarity, originally as a line feature map (obtained from the Company of Informatics and Information of the Municipality of Belo Horizonte - PRODABEL). It is based on the density and the carrying capacity (i.e., traffic volume) of different types of streets (e.g., roads, highways, alleys). We applied the kernel density estimator weighted by the streets' typology (or attribute) to produce a raster surface describing the density of streets and the traffic volume across the landscape of Belo Horizonte (Supplementary I Fig. S-1). Values closer or equal to 10 represent regions with high density of roads and highways with the largest carrying capacity (Supplementary I Fig. S-1). Those regions would present highly stressful conditions for biodiversity (Pena et al. 2017b).

The second intermediate human accessibility layer was the human population density, originally obtained as polygons describing census sectors and their respective population density estimated during the last Brazilian population census in 2010 (IBGE 2012). Values closer or equal to 10 represent highly densely occupied regions across Belo Horizonte (Supplementary I Fig. S-2). Human population density can have important influences on bird species richness (Luck 2007) and on the proportion of vegetation – especially native vegetation – that comprise urban landscapes (Liu and Slik 2022).

The third intermediate human accessibility layer describes the land use type attributed to each individual lot across Belo Horizonte landscape originally as a vector map (<http://bhmap.pbh.gov.br/>). Each individual lot (or polygon) was classified as commercial, residential (low, medium and high density), industrial, mixed uses, green spaces, among others (Supplementary I Fig. S-3 and Supplementary II Table S-1). We reclassified polygons to values between 1 and 10 (Supplementary II Table S-1), being 10 attributed to land use types that we believe can lead to higher disturbances to the urban biodiversity, such as areas that produce high levels of noise and air pollution and/or are related to a high flow of people across the landscape (airports, industrial zones) (Alberti 2005; Hodgson et al. 2007; Reis et al. 2012; Pena et al. 2023). Finally, we summed and calculated the average between those three intermediate layers to obtain the description of the degree of human accessibility across Belo Horizonte landscape (Supplementary I Fig. S-4).

Layer 2: Soundscape

First, we obtained a line feature map representing the city streetscape in which the lines' attributes describe the traffic volume (i.e., number of vehicles per track of road) of each street (PRODABEL - 2018). We applied the kernel density estimator weighted by the traffic volume to produce a raster surface that describes both the density of streets and the noise pollution that would be produced due the number of vehicles in circulation, being 10 attributed to those with a high degree of noise (Supplementary I Fig. S-5). Noise exposure is considered a limiting factor for urban bird communities, modifying physiology communication, reproductive success, and leading to a reduction on communities' functional and taxonomic diversities (Ortega 2012; Pena et al. 2017b; Curzel et al. 2021; Redondo et al. 2021; Bernat-Ponce et al. 2021).

We also included a description of the urban morphology, the urban canyons, as the second intermediate soundscape layer. Using a vector map composed of polygons containing as attributes the estimated buildings' height obtained through LiDAR flights in 2007 (Pinto 2015), we measured the frontal distances between the facades of the buildings. We then identified the urban regions where buildings with heights equal to or greater than five floors are positioned facing each other (i.e.: urban canyons), which indicates high potential for sound reverberation (Nakamura and Oke 1988). Values were normalized between 1 and 10, being the highest values related to regions with higher potential for the formation of urban canyons (Supplementary I Fig. S-6).

The third soundscape intermediate layer was a description of the distribution of commerce and services across the landscape. From the land use map describing the attributes of individual lots, we extracted only polygons classified as commercial, services, industrial or similar uses. We then applied the kernel density estimator weighted by the number of activities conducted within each individual lot. In the resulted intermediate layer values closer to 10 indicate regions with high concentration of commerce and service activities (Supplementary I Fig. S-7). Those regions would be related to higher noise pollution due to the concentration of people and especially, vehicles in circulation. Finally, we summed and calculated the average between those three intermediate layers, obtaining a raster surface describing the soundscape of Belo Horizonte (Supplementary I Fig. S-8).

Layer 3: Built artifacts and volumetry

The first intermediate layer is the building volumetric density, for which we applied the kernel density estimator on the vector map describing the estimated buildings' height weighted by the height value. We normalized the produced raster surface to values between 1 and 10, being 10 representing regions with higher concentrations of tall buildings (Supplementary I Fig. S-9). Buildings may represent barriers for birds to access and move through urban landscapes due to the risks of window collisions (van Doren et al. 2021). Furthermore, the increase in building density

was already observed to be negatively related to the richness of bird groups, such as insectivorous species (Amaya-Espinel et al. 2019).

The second intermediate built artifacts layer was based on a point feature map describing the Belo Horizonte public lighting poles obtained from PRODABEL (from: <https://prefeitura.pbh.gov.br/prodabel>). We made a 45-degree cone in relation to the height of the poles (15 m) representing the radius under influence of light around each point. As a result, we obtained a raster surface describing urban regions with different lighting levels. Values closer or equal to 10 indicate the brighter regions across Belo Horizonte landscape (Supplementary I Fig. S-10). Cities considered as having high environmental quality for birds are related to those with lower light pollution (Morelli et al. 2021).

The third intermediate built artifacts layer was a Normalized Difference Vegetation Index (NDVI) surface which we produced from a Sentinel 2A satellite image obtained in August 2020 (from: <https://scihub.copernicus.eu/>). The data and image were selected due to the absence of clouds. Originally the NDVI surface is composed of values ranging from -1 and 1, being values closer or equal to -1 representing areas with absence of vegetation (e.g., bare soil, water, impermeable surfaces). Values closer or equal to 1 are related to vegetation patches with high photosynthetic activity (e.g., dense woody vegetation cover). We normalized the NDVI layer to values between 1 and 10, being 10 the urban regions with absence of vegetation, i.e., pixels originally with values closer or equal to -1 (Supplementary I Fig. S-11). The NDVI was recently applied to estimate bird species richness across urban landscapes, being values closer to 1 indicating the most diverse communities (Leveau et al. 2020). We summed and calculated the average between those three intermediate layers to obtain the description of the density and volumetry of built artifacts, as well as the quality of the urban vegetation, across Belo Horizonte landscape (Supplementary I Fig. S-12).

Layer 4: Land cover map

The final layer used to produce the UBS Index was the land cover map developed for Belo Horizonte landscape (Supplementary I Fig. S-13). We obtained Planet Scope satellite imagery from September 2020 with 3 meters resolution (Planet Team, 2017). Through a supervised classification using the Maximum Likelihood Algorithm of ArcGIS 10.X software, we identified three classes: woody vegetation, herbaceous vegetation and built surfaces (Kappa = 0.86). We added the hydrography and the mined areas by merging the classified raster map with layers originally obtained in vector format (<http://bhmap.pbh.gov.br/>). Then, we reclassified the raster surface into four classes between 1 and 10, being 1 woody + herbaceous cover, 3 for water, 6 for built surfaces, and 10 for mined areas. We merged the woody and herbaceous covers since the built artifacts layer already describes the vegetation volume. Finally, we resampled the resolution of the raster surface to 5 meters (Supplementary I Fig. S-13). Land cover data

can be used to estimate the presence and the ability of bird species to move across urban landscapes (Fillooy et al. 2019; Bhakti et al. 2021a; Graviola et al. 2021).

Building the UBS Index map

To produce the UBS Index map, we also applied the MCA approach by summing and calculating the average between the four layers (human accessibility, soundscape, built artifacts and volumetry, and land cover) (Fig. 2). We then obtained a raster surface that varies between 1 and 10, being 10 regions of the urban landscape more vulnerable (or least suitable) to the bird community. We are aware that some selected intermediate spatial layers could be correlated with each other. However, this is not an issue since we are assessing the relationship between the resulting UBS map and bird diversity metrics, not the influences of each intermediate layer separately. Furthermore, correlated layers would highlight urban regions that could have a higher influence (positive or negative) on the bird community. For example, a joint effect of the amount (land cover, layer 4) and quality (built artifacts and volumetry, layer 3) of the urban vegetation on bird species richness.

To facilitate the interpretation of the resulting UBS index map, we reclassified the raster surface to its inverse values. Thus, instead of vulnerability, the final map describes suitability levels being values closer to 1 indicating low suitability (or high vulnerability) and values closer to 10 indicating urban regions with high suitability for the bird community (or with low vulnerability). This final map is the spatial explicit representation of the UBS Index (Figs. 2 and 4).

UBS Index validation and statistical analysis

We obtained bird data from 120 survey sites distributed across the Belo Horizonte landscape. The data from 60 sites was obtained from Pena et al. (2017b), who conducted bird surveys across the streetscape of the southern region of Belo Horizonte between September 2014 and February 2015. The other 60 sites were surveyed between October 2020 and March 2021 adopting similar methods as in Pena et al. (2017b), but bird data was collected in a variety of green spaces distributed across the urban landscape of Belo Horizonte (natural vegetation patches, cemeteries, leisure spaces, linear parks, among others) (Fig. 1). In both surveys, point counts were performed during birds' breeding season in southeastern Brazil. The 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). Each site was visited three times and each visit lasted 20 minutes. The duration of each visit was defined by Pena et al. (2017b) in a pilot study, through which they observed that after 10 minutes visits (standard approach applied in bird studies) new species were still being included, especially in regions where green cover is high. We recorded all bird individuals observed perching, nesting, foraging or singing in a 50 m radius around the observer. By using both bird survey data, we are able to describe the taxonomic and functional diversities of communities inhabiting

urban habitats that comprise a gradient of urbanization intensity, from peri-urban conservation units to brownfields, streets, and train tracks. Thus, we used a database that describes the bird community across a variety of urban contexts, which would be adequate to assess the accuracy of the UBS Index map.

We calculated for each bird survey site the species richness (SR) and two Functional Diversity indices, Functional Richness (FRic) and Rao's Quadratic Entropy (RaoQ). We obtained information on bird functional traits – body mass (g), clutch size (number of eggs per clutch), diet, nesting and foraging substrates – from published literature (del Hoyo et al. 2010; Wilman et al. 2014). We used the FD package (Laliberté et al. 2014) in the R programming environment (R Core Team 2021) to calculate the functional diversity indices. FRic is a representation of the amount of niche space occupied by the species at each site (Schleuter et al. 2010). RaoQ incorporates species relative abundances to estimate the pairwise functional differences between species (Botta-Dukát 2005), and can be considered as a measure of functional evenness, since the higher the value of RaoQ, the greater the dissimilarity between functional groups. We extracted the UBS Index values from each of the 120 bird survey sites.

In order to validate the ability of the UBS Index map to describe levels of bird diversity across the urban landscape, we modeled the relationships between the UBS index at each survey site, as a predictor, and the diversity indexes as response variables using generalized linear models. For SR and RaoQ we used the gaussian distribution and for the FRic index, we used the Gamma distribution with a log link function. The assumptions were checked through simulation-based residual diagnostics (Hartig 2022). We used the Cox and Snell pseudo-R squared as a measure of goodness of fit. These models were performed using the DescTools package (Signorell 2023) in the R programming environment (R Core Team 2021).

To facilitate the interpretation of the results and the relationships between the UBS Index and the bird diversity indexes, we also built three combinatorial analysis matrices. To do this, we applied Jenk's Natural Breaks to reclassify the UBS Index values into five suitability classes ranging between 1 and 5, being 5 high suitability for the bird community. We also used Jenk's Natural Breaks to reclassify the SR, FRic, and RaoQ values into five classes between 100 and 500 (being 500 the highest values observed for each diversity index). The three combinatorial analysis matrices represent all possible spatial combinations between the five UBS Index classes in one axis and the five levels of each bird diversity indexes (SR, FRic, and RaoQ) in the other axis, separately (Fig. 3). Using this approach, it is possible to identify and interpret the meaning of all existing arrangements (Xavier-da-Silva 2001; Moura 2003). For example, when the maximum UBS Index value (i.e., 5) coincides with the maximum diversity index value (i.e., 500), the final arrangement (i.e., 505) indicates high bird diversity inhabiting an area with high biodiversity suitability (Fig. 3). This visual approach can be useful to inform decisions and

can assist in the interpretation of the modeling approach we adopted to validate the UBS Index map.

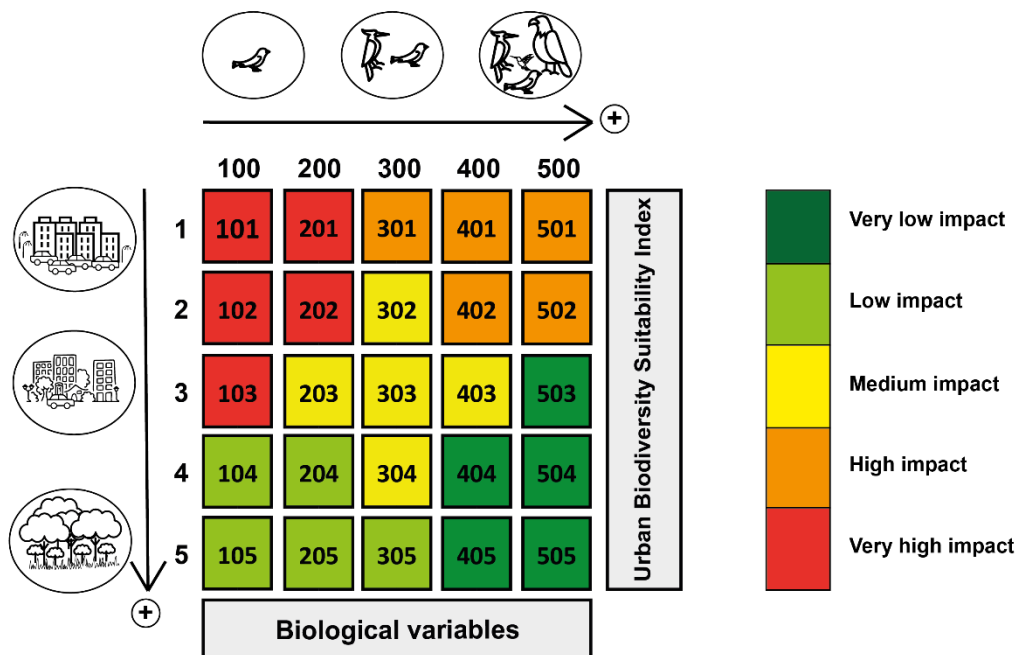


Figure 3. Representation of the combinatorial analysis matrix used to assess the relationships between the suitability levels described by the Urban Biodiversity Suitability (UBS) Index and the taxonomic and functional diversity levels observed across 120 bird survey sites in Belo Horizonte (Minas Gerais, Brazil).

Results

The final UBS Index map describes urban biodiversity suitability levels across the Belo Horizonte landscape (Fig. 4). Suitability values ranged from 1 (low suitability, such as woodless streets and highways) to 8.58 (high suitability, such as peri-urban protected and non-protected areas) (Fig. 4).

Across Belo Horizonte streetscape, Pena et al. (2017b) registered a total of 73 bird species, distributed in 26 families and 12 orders. During the 2020-2021 survey period, we registered a total of 148 species, distributed in 49 families and 19 orders. This difference is related to the higher bird species richness usually observed in green spaces in comparison with streets, especially in natural vegetation patches. Thus, in total 153 bird species were recorded inhabiting a variety of urban habitats across the Belo Horizonte landscape.

The number of species recorded in each survey site considering both databases varied between 1 and 45. The indices scores ranged between 0.002 to 0.065 for FRic and 0 to 0.194 for RaoQ. The ability of the UBS Index to describe the bird diversity distribution across the urban landscape was confirmed by the general linear regression models for SR (Pseudo- $R^2 = 0.42$, $P < 0.001$), FRic (Pseudo- $R^2 = 0.38$, $P < 0.001$), and RaoQ

(Pseudo- $R^2 = 0.10$, $P < 0.001$) (Fig. 5 and Fig. 6). All the raw data used to assess the accuracy of the UBS Index is available at Supplementary II Table S-2.

When assessing the combinatorial analysis matrices, it is also possible to visualize that most sites with high bird diversity levels (SR, FRic, and RaoQ) also presented high UBS Index values (Fig. 5). The same is true for sites with low bird diversity, which were mostly related with low UBS Index values (Fig. 5).

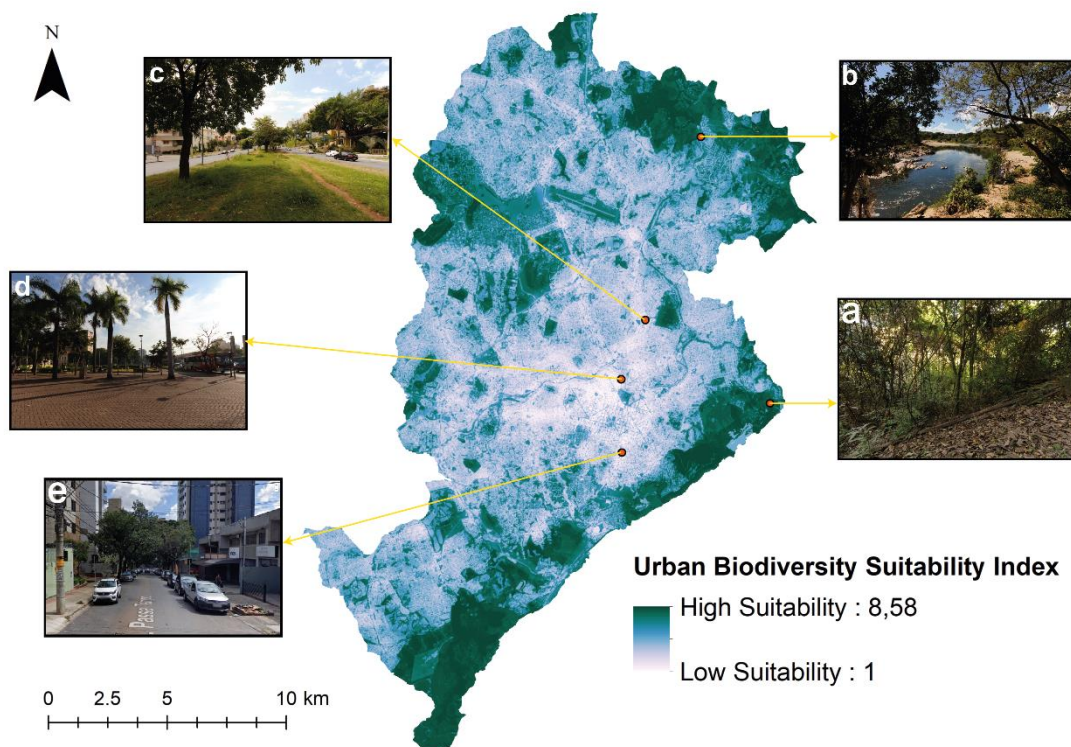


Figure 4. The Urban Biodiversity Suitability (UBS) Index formulated for the landscape of Belo Horizonte (Minas Gerais, Brazil). Images “a” to “e” are examples of areas that presented different suitability levels according to the UBS Index, being a = 8.58, b = 6.55, c = 5.16, d = 4.2, and e = 3.85.

Discussion

The UBS Index was able to efficiently describe levels of environmental suitability for birds across the urban landscape of Belo Horizonte. Our multidisciplinary knowledge driven approach allowed us to produce a holistic view of the relationships between several urban environmental characteristics and how they modulate the levels of suitability for biodiversity. Cities comprise high dynamic and heterogeneous ecosystems, shaped by environmental, sociopolitical, and economic influences, which we believe we could represent by the geospatial data we included during the development of the UBS Index. By assessing the accuracy of our suitability map using a bird database, we

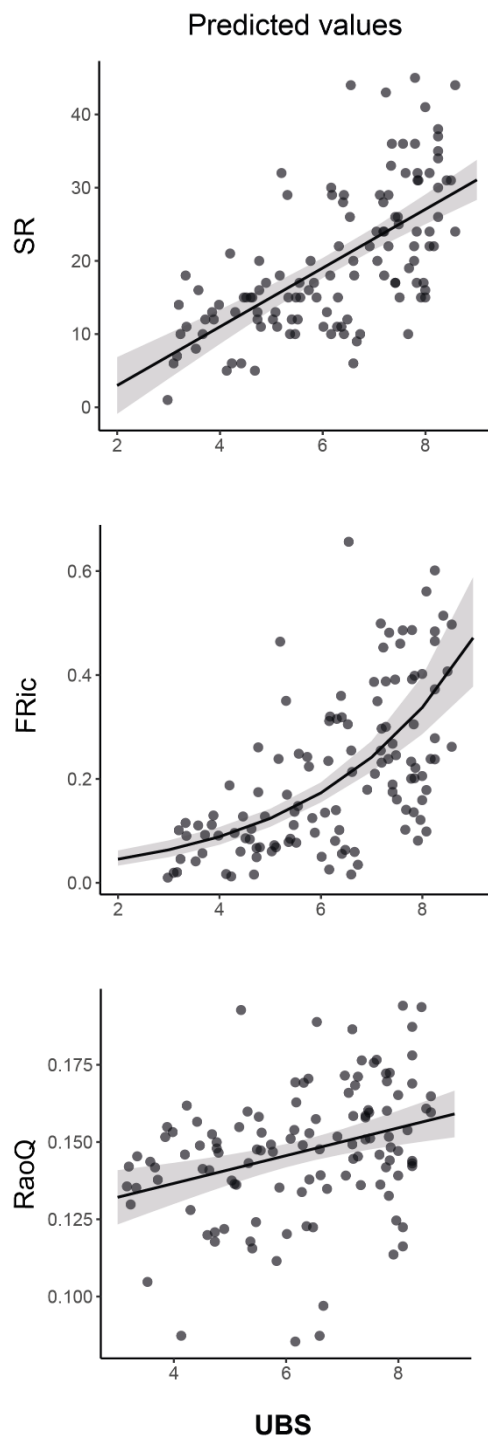


Figure 5. Result general linear regression models of the biological data in relation to the values of the Urban Biodiversity Suitability (UBS) index. Taxonomic richness (SR) Pseudo- $R^2 = 0.42$, $P < 0.001$; Functional richness (FRic) Pseudo- $R^2 = 0.38$, $P < 0.001$; and Rao's quadratic entropy (RaoQ) Pseudo- $R^2 = 0.10$, $P < 0.001$.

described the potential of regions across the urban landscape to support different biodiversity levels. Whereas high suitability regions inhabited by high bird diversity in Belo Horizonte can be considered as important for conservation, some urban areas, especially vegetation patches that present medium-to-low biodiversity suitability levels, may be eligible for restoration or rewild initiatives.

Based on our previous knowledge and the urban ecology literature, we selected layers (i.e., landscape and environmental variables) that influence the ecosystem dynamics that occur within cities. This process allowed us to have an overview of the relationships between the human and the ecological dimensions across the landscape. The human accessibility, soundscape, and built artifacts and volumetry layers describe important influences that may reduce the environmental suitability for biodiversity (in this case, birds) such as the land use types, streets and population densities, noise exposure, buildings' height, and the street lighting (Heggie-Gracie et al. 2020). The NDVI, together with the land cover layer, describe the amount, volume, and the

quality of the vegetation across the landscape, which modulate the diversity and composition of urban bird communities (Leveau et al. 2018). Although several studies have already shown that the amount and configuration of vegetation patches can describe the diversity of organisms across urban landscapes (Hayes et al. 2020; La Sorte et al. 2020), it is important to recognize the potential of unconventional habitats (such as cemeteries, wooded streets, small green spaces, and yards) to support biodiversity in cities (Morelli et al. 2018b, a; Soanes et al. 2019). By including those four dimensions (human accessibility, soundscape, built artifacts and volumetry, and land cover), formed by combinations of several geospatial data, the UBS Index highlighted the high heterogeneity of the urban ecosystem and areas with high biodiversity suitability can be found across the landscape. Even in the most central part of urban landscapes, it is possible to find regions with low traffic noise and volume, smaller buildings, lower street and human densities, and other aspects that led to higher UBS Index values.

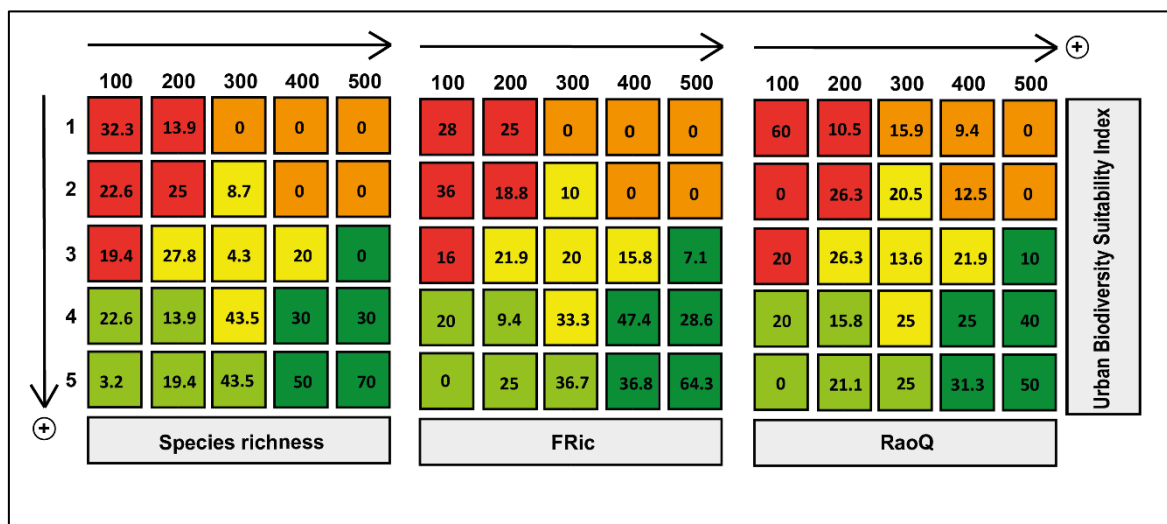


Figure 6. Results of the combinatorial analysis matrices to assess the relationships between levels of bird species richness, functional richness and Rao's Quadratic Entropy, and the levels of the Urban Biodiversity Suitability (UBS) Index. Values inside squares represent the proportion of each bird diversity level (100 – 500, being 500 sites with high functional or taxonomic diversity) that were classified according to each UBS Index level (1 – 5, being 5 sites with high suitability).

We observed a significant relationship between bird taxonomic and functional diversities and the UBS Index levels, as we expected. It has already been shown that the amount and quality of the urban vegetation has positive influences on the diversity of bird communities inhabiting urban and peri-urban vegetation patches (Suri et al. 2017; Sánchez-Sotomayor et al. 2023). Thus, the largest areas with the highest UBS Index levels were concentrated in the peri-urban region, where the largest native vegetation patches are located. In addition to the amount of vegetation, the land use types can influence the level of conservation, and the quality and structural complexity of the urban vegetation (Sol et al. 2020). Residential areas, comprising houses with yards, with reduced traffic volume and noise and nearby natural habitat patches, may be inhabited

by a high diversity of species (Belaire et al. 2014; Canedoli et al. 2018; Bhakti et al. 2021b; Pena et al. 2023). In fact, the vegetation in some of these areas presented medium-to-high biodiversity suitability across the Belo Horizonte landscape. Therefore, the UBS Index was able to identify different suitability levels of the urban vegetation, considering a series of disturbances already described in the literature that may affect habitat quality, such as noise and light pollutions (Alberti 2005; Morelli et al. 2021). It is important to mention, however, that the highest suitability level identified by the UBS Index (8.58) indicates that all of Belo Horizonte landscape presents a level of human disturbance, even the core of the protected areas. Therefore, this large metropolis probably does not harbor a completely wild or pristine habitat patch, which is probably the reality of every metropolis across the globe.

Besides the identification of the best and most suitable areas for biodiversity, the UBS Index can also assist in the identification of areas that could be restored or have the management type or conservation level modified. Regions with intermediate suitability levels may be eligible for the application of rewild or restoration projects, while the lowest UBS Index levels (closer to 1) highlight areas that are already occupied by the human population for a variety of purposes (e.g., housing, industries, commerce). Nevertheless, urban areas dominated by low suitability levels may receive special attention for the creation of new and multifunctional vegetation patches. This process should consider human well-being, allowing a higher contact with nature and increasing awareness about the importance of conserving biodiversity even within urban landscapes (Locke et al. 2019). The support of the human population can assist the application of rewild initiatives for increasing biodiversity, reducing management intensity, and changing plant species composition in green spaces (Zefferman et al. 2018; Kowarik 2018). The UBS Index can be tested by researchers in cities in different countries or regions to assess the efficiency of our mapping approach in identifying different suitability biodiversity levels in urban landscapes. The accuracy of the UBS Index could also be tested for other animal groups, allowing us to assess if the same geospatial layers can describe suitability levels for other organisms or adjustments need to be made.

Although the wilderness mapping technique has its main applicability on large spatial scales (SNH 2014), it has been demonstrated to be adequate to estimate habitat suitability levels for biodiversity at the city scale. Another application of the UBS Index is in the assessment of landscape connectivity, by identifying greenways connecting areas with high environmental suitability across the landscape. They can be multifunctional and lower cost alternatives to the traditional ecological corridors, connecting not only the biodiversity but also people through cycling paths or wooded streets (Ignatieva et al. 2011; Keith et al. 2018). In Belo Horizonte, the train tracks and several wooded avenues were highlighted as intermediate suitability levels for biodiversity. Wooded streets provide refuges and resources for several bird species (Pena et al. 2017b; Wood and Esaian 2020) and train tracks can act as habitat areas due to the lower traffic volume than the streetscape (Erickson 2004; Bhakti and Rodrigues 2020). The creation of

greenways can also follow the margins of the rivers, helping the preservation of riparian forests (Parris et al. 2018).

The UBS Index can be used by urban planners and managers that aim to include biodiversity in their agenda. It is possible to identify regions of the city that lack areas with high environmental suitability for biodiversity, determining priority areas for the adoption of sustainable management and planning strategies, such as the creation of parks and green areas. Regions with high suitability can provide numerous ecosystem services for the human population (e.g., thermal comfort, increased soil permeability, absorption of pollutants) due to the large amount of vegetation, less vehicles circulation and concentration of less impacting land uses (e.g., low density residential buildings). Finally, it is possible to include the UBS Index in participatory decisions, considering the views and needs of all sectors of society (civil society, academia, economic sectors, politicians) about how to plan and manage the landscape during the formulation or revision processes of cities' master plans (Pena et al. 2017a). To inform decisions, both the final map and the combinatorial analysis matrices can be used to illustrate the potentialities and limitations regarding urban biodiversity conservation across the landscape.

Belo Horizonte has the advantage of the availability of several high-quality geospatial data that allow the production of high-quality maps. Thus, the UBS Index map approach can be easily replicated for cities where a collection of geospatial data is available. It is important to highlight that our MCA approach is not a simple process of overlapping layers, but it was based on an interdisciplinary knowledge driven approach that allowed for the interpretation of how different geospatial layers, and their interactions, would influence biodiversity. Either way, the UBS Index approach can be replicated for other cities by including similar or different layers that describe environmental, socioeconomic or biological aspects of landscapes and also be adapted to assess the suitability levels for other animal groups. For example, in the case of arboreal mammals, the light cable network could improve landscape connectivity for more generalist species (Duarte et al. 2012). For pollinators, more information on green space management or the distribution of flowering plant species, could assist in the identification of suitability levels for different organisms (e.g., bees, butterflies), allowing inferences about the realization of ecological processes across urban landscapes. Our approach also allows for analysis regarding the influences of socioeconomic aspects on the distribution of urban biodiversity by crossing the suitability map with information on, for example, family income. Thus, considering the high potential of the UBS Index as a management tool, we hope that our approach, not only stimulates city planners and managers to invest in the acquisition of geospatial data, but also on their application to assess how the complex environmental conditions of urban ecosystems modulate local biodiversity.

Conclusions

We demonstrated that it is possible to apply a knowledge driven approach to produce a spatial explicit urban biodiversity suitability index based on several geospatial data. The UBS Index efficiently described the functional and taxonomic diversities of the bird community inhabiting a variety of habitats across the urban landscape. Furthermore, the UBS Index highlighted the high environmental heterogeneity across urban landscapes; throughout the whole city it is possible to find regions highly suitable for biodiversity. However, we did not observe a pristine natural habitat patch in Belo Horizonte, reinforcing our decision of not using wilderness levels when describing environmental conditions within urban landscapes. The approach described in our study can be considered a management tool, helping decision makers to identify priority areas for conservation and restoration, as well as urban regions that lack areas with high environmental quality for biodiversity and for the human population.

Supplementary files

Supplementary I – Figures S-1 to S-13

Supplementary II – Tables S-1 and S-2

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Supplementary Material

Supplementary I – Figures S-1 to S-13

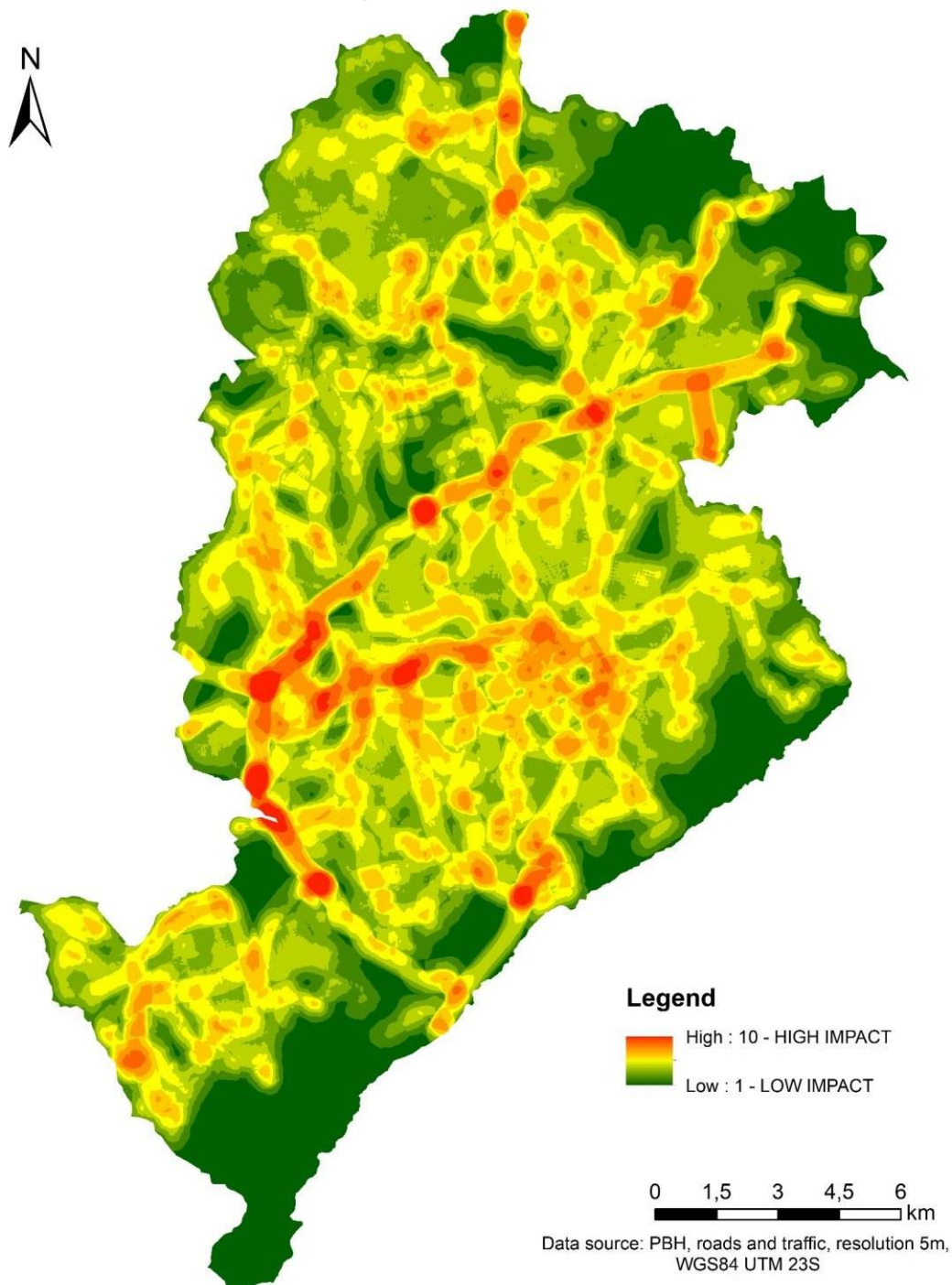
**Accessibility and Capillarity
Belo Horizonte-MG, Brazil**

Figure S-1. Access and Remote Areas Layer: Intermediary raster 1 - Accessibility and Capillarity

Population Density Belo Horizonte-MG, Brazil

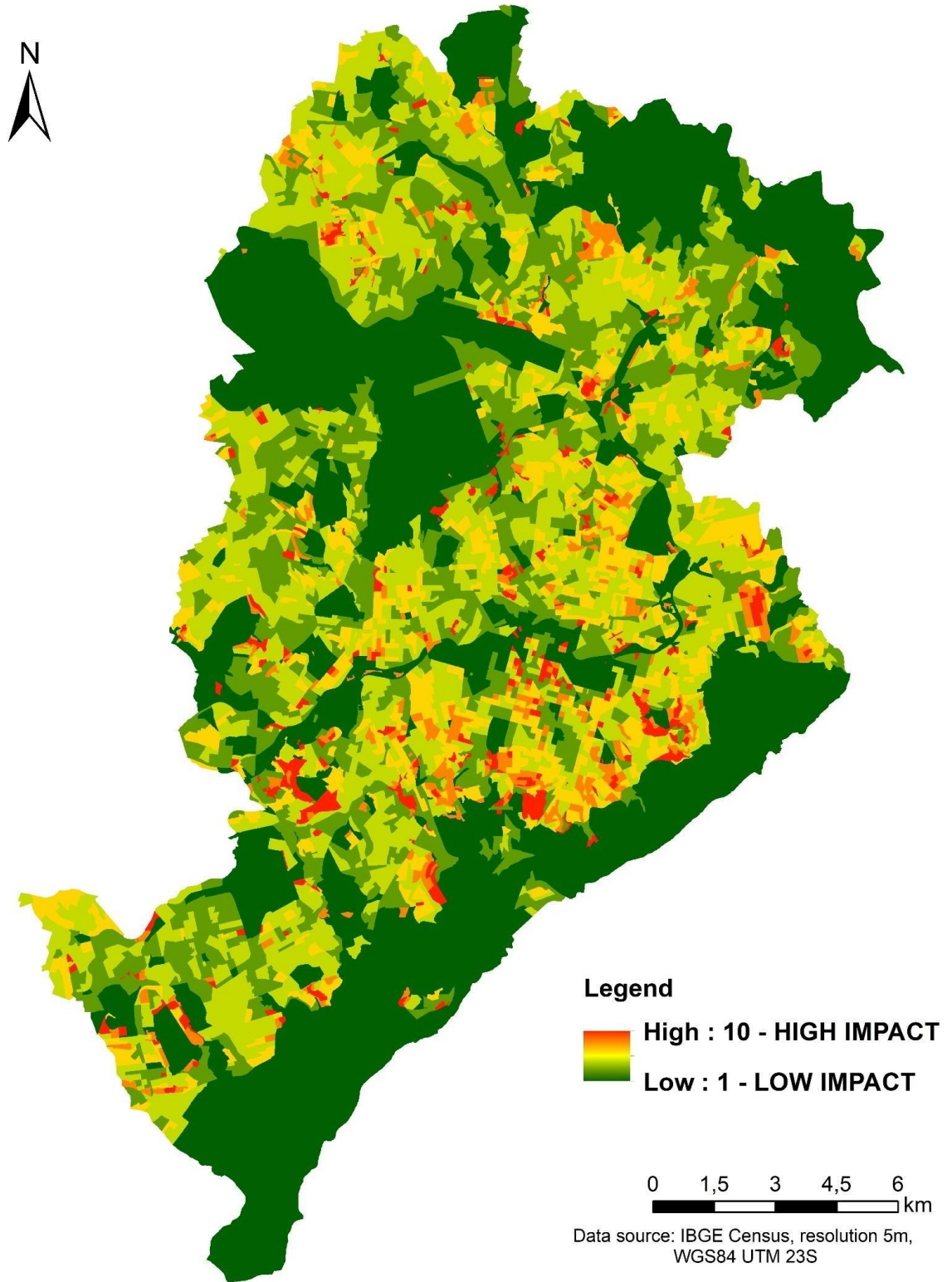


Figure S-2. Access and Remote Areas Layer: Intermediary raster 2 – Population density

Land Use

Belo Horizonte-MG, Brazil

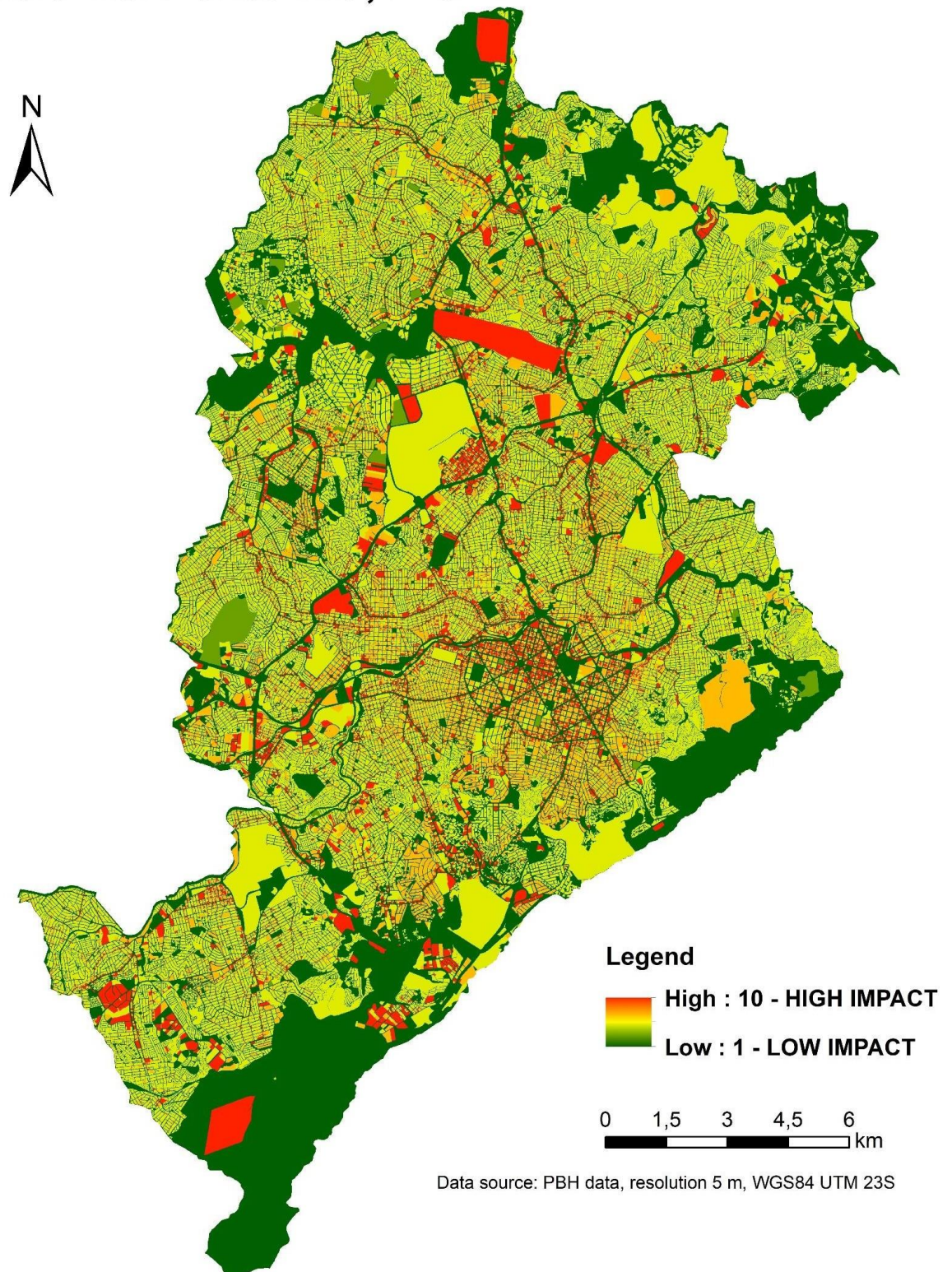


Figure S-3. Access and Remote Areas Layer: Intermediary raster 3 – Land Use

Access and Remote Areas Belo Horizonte-MG, Brazil

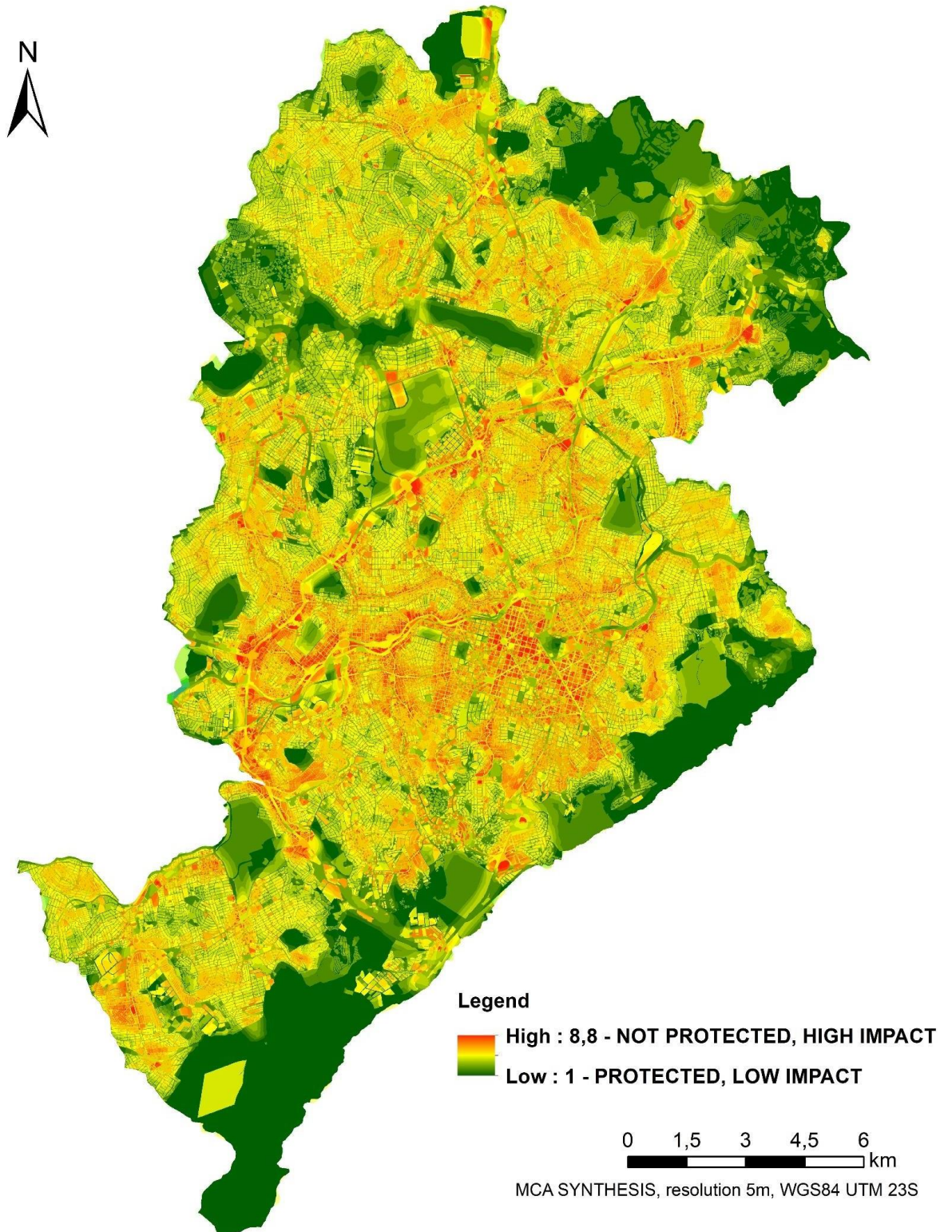


Figure S-4. Access and Remote Areas Layer Final Map

Traffic Loading Belo Horizonte-MG, Brazil

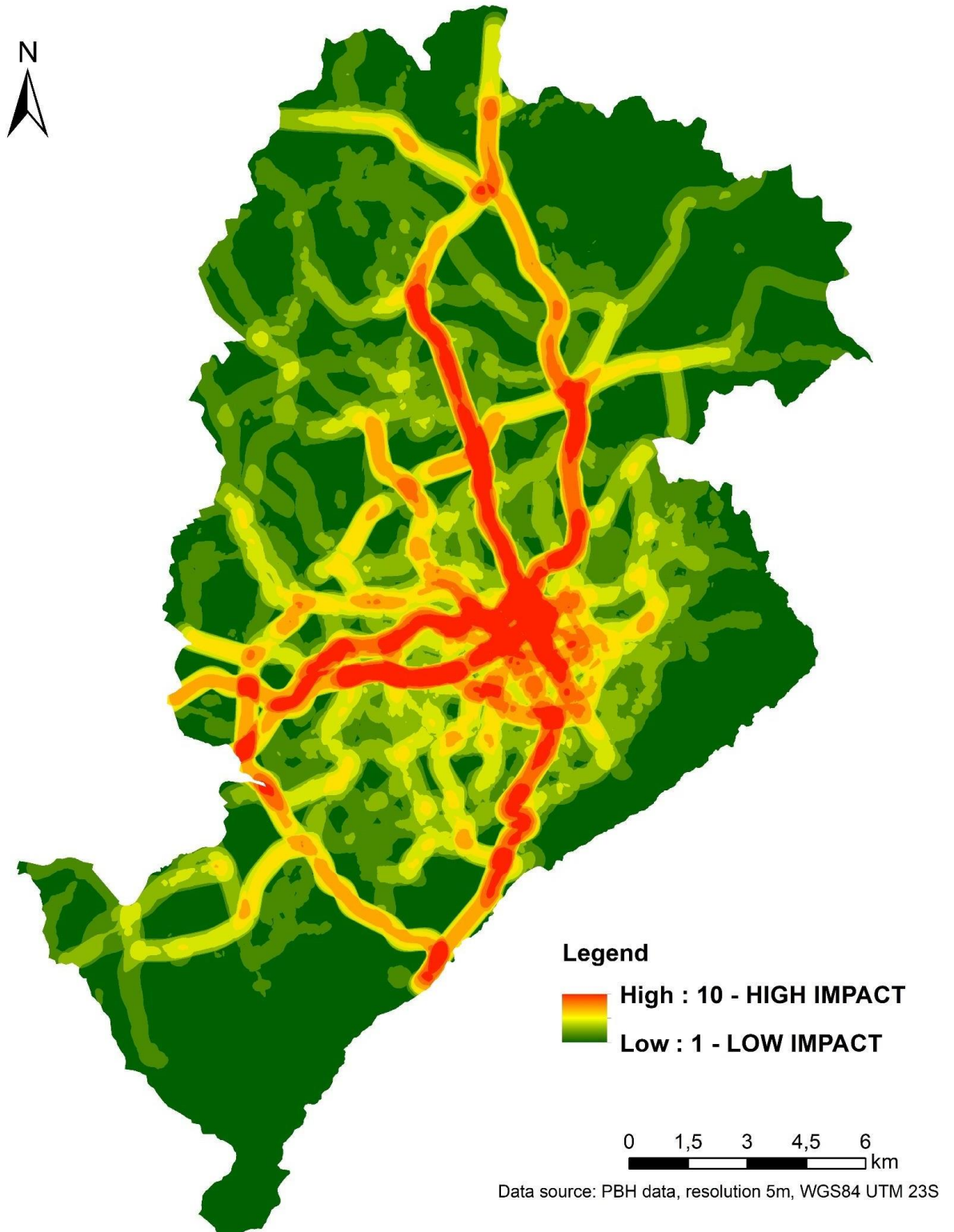


Figure S-5. Sound Landscape Layer: Intermediary raster 1 – Traffic Loading

Urban Canyons Belo Horizonte-MG, Brazil

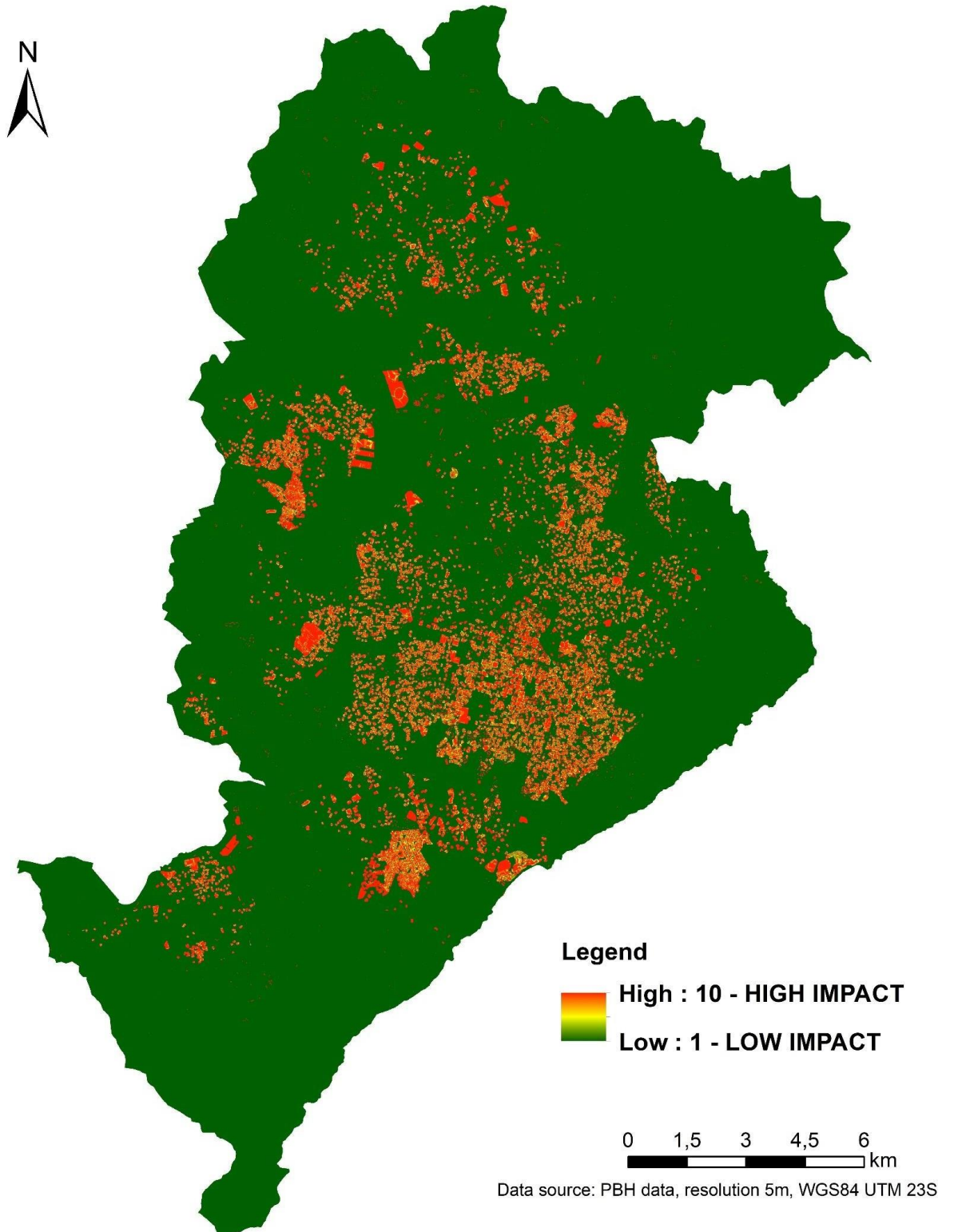


Figure S-6. Sound Landscape Layer: Intermediary raster 2 – Urban Canyons

Commerce and Services Belo Horizonte-MG, Brazil

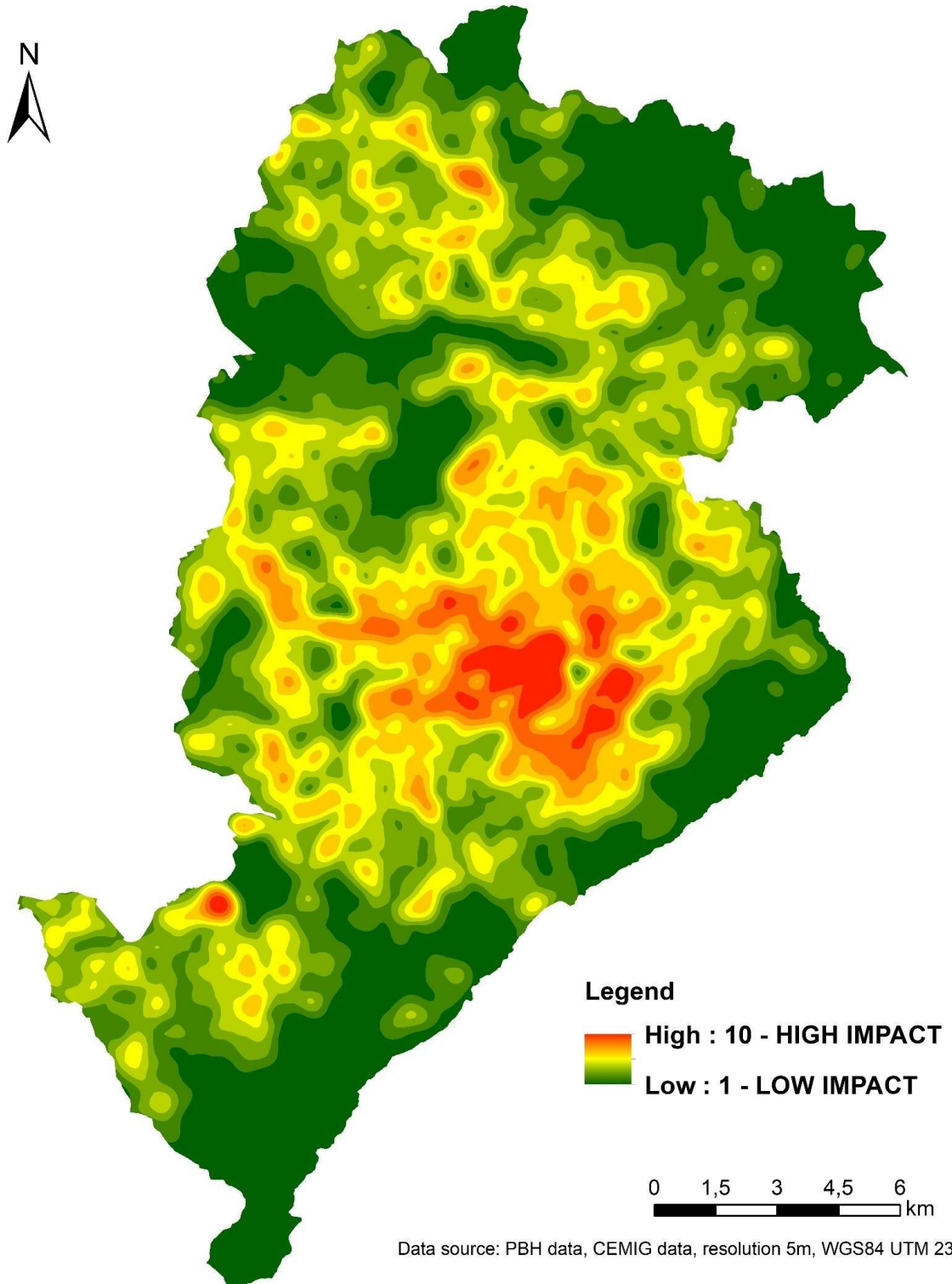


Figure S-7. Sound Landscape Layer: Intermediary raster 3 – Commerce and Services

Sound Landscape Belo Horizonte-MG, Brazil

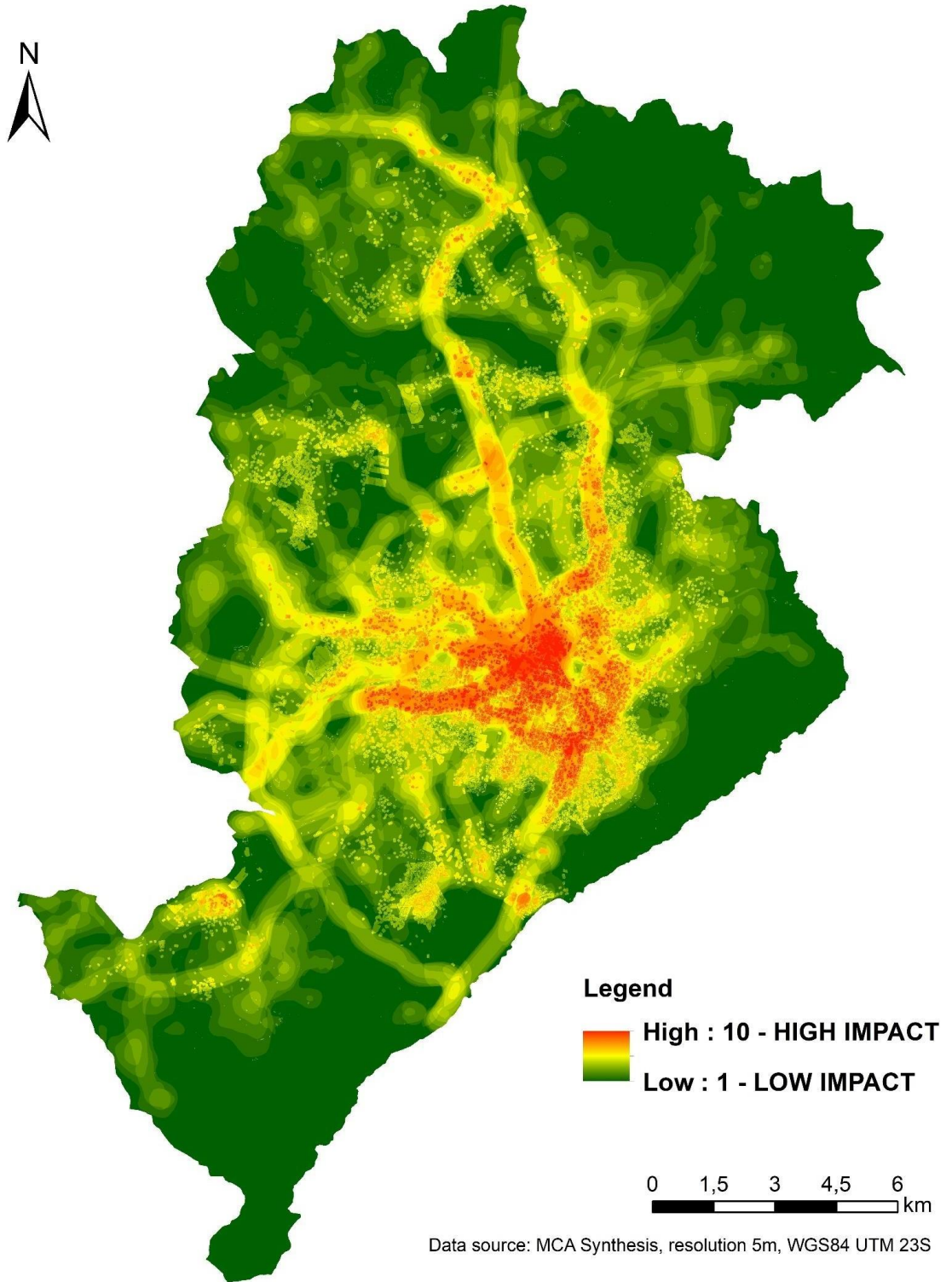


Figure S-8. Sound Landscape Layer Final Map

Volumetric Density - height of buildings Belo Horizonte-MG, Brazil

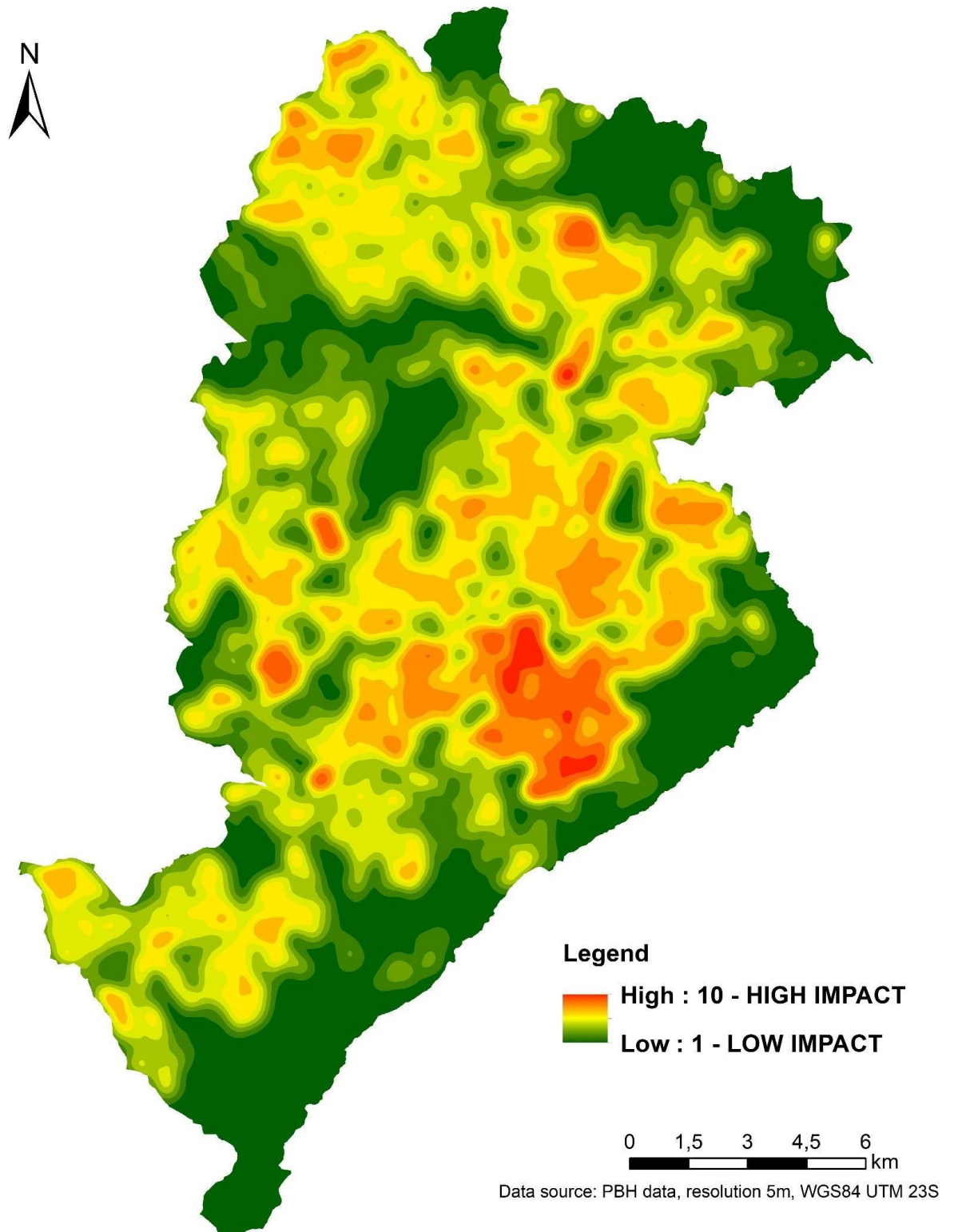


Figure S-9. Build Artifacts Layer: Intermediary raster 1 – Volumetric Density,height of buildings

Lighting Belo Horizonte-MG, Brazil

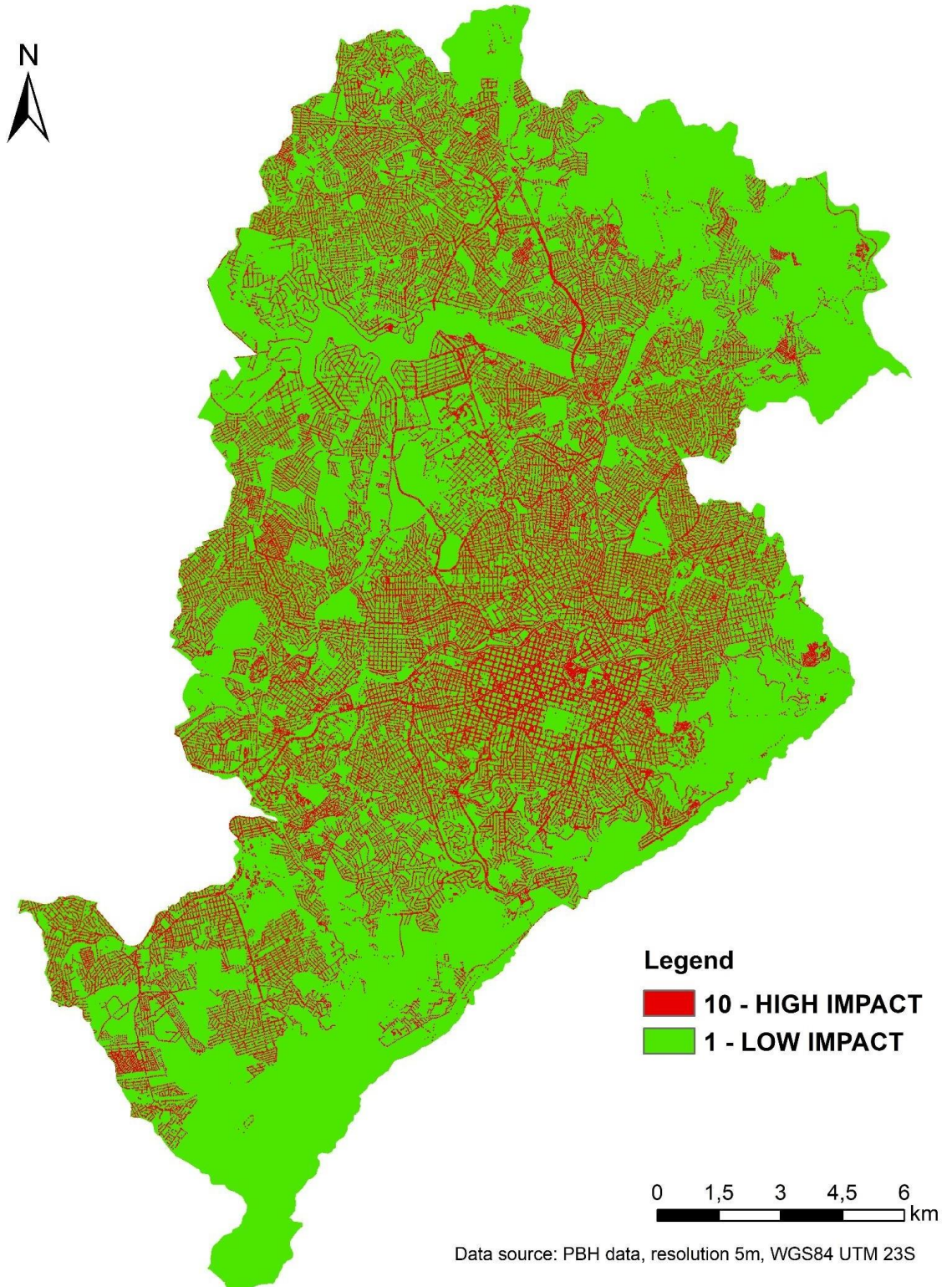


Figure S-10. Build Artifacts Layer: Intermediary raster 2 – Lighting

NDVI Normalized Difference Vegetation Index Belo Horizonte-MG, Brazil

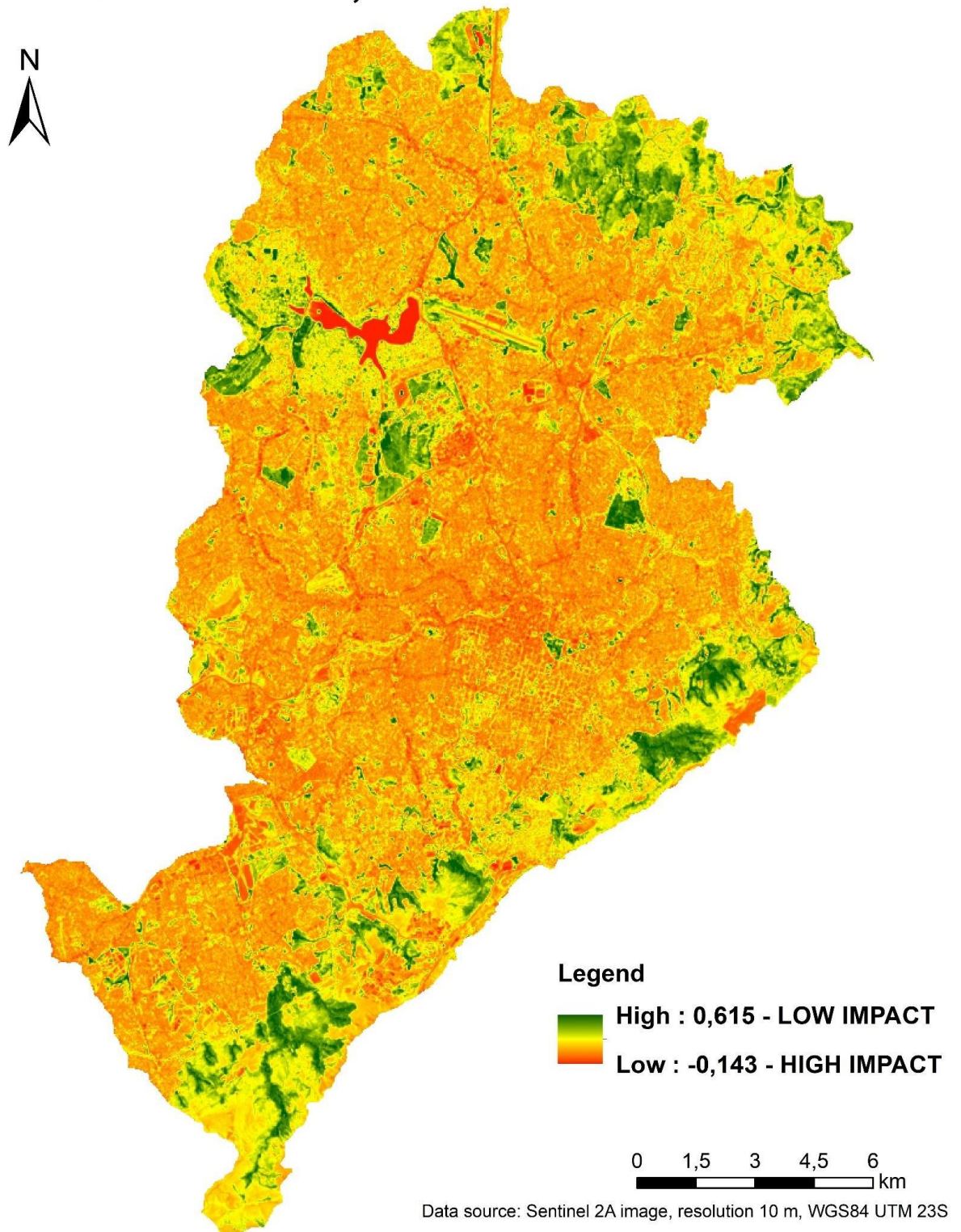


Figure S-11. Build Artifacts Layer: Intermediary raster 3 – Normalized Difference Vegetation Index (NDVI)

Built Artifacts And Volumetry Belo Horizonte-MG, Brazil

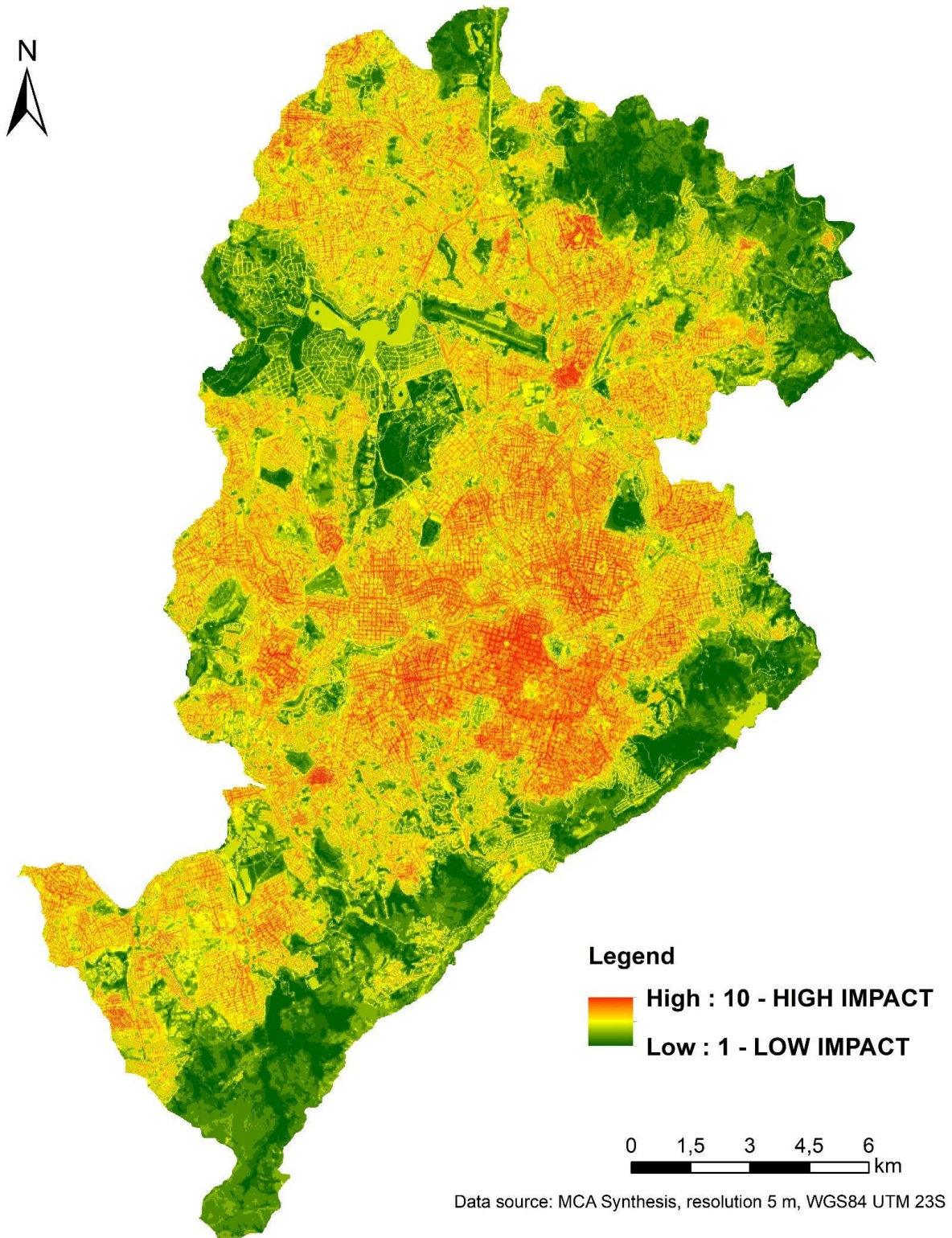


Figure S-12. Build Artifacts Layer Final Map

Land Cover Belo Horizonte-MG, Brazil

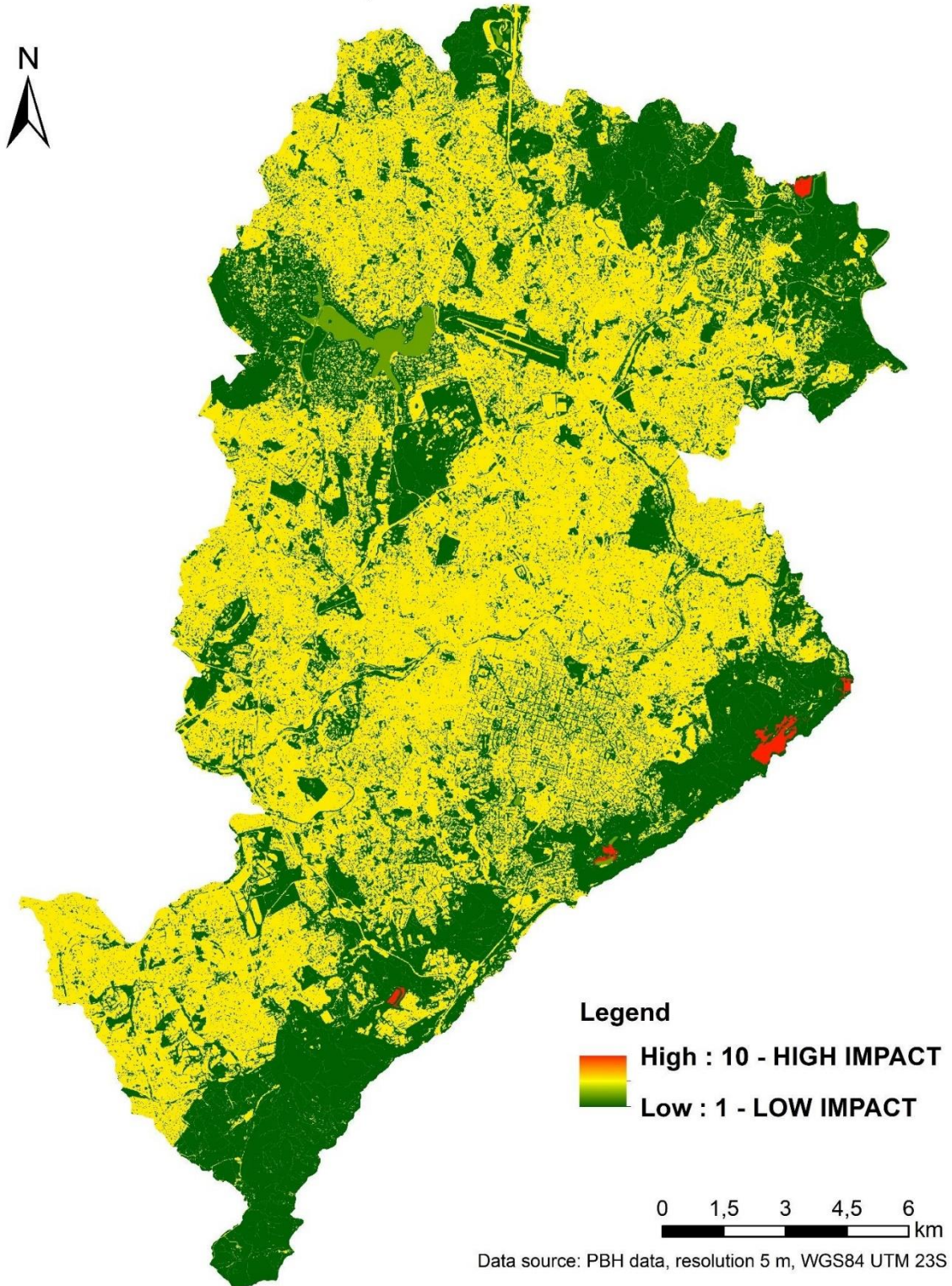


Figure S-13. Land Cover Layer Final Map

Supplementary II – Tables S-1 and S-2

Table S-1. Land use type attributed to each individual lot across Belo Horizonte landscape. For each lot, a corresponding value was assigned according to the possible disturbance to biodiversity.

Land use type	Value
airport	10
landfill	3
commercial areas with low density	7
residential area with low density	5
sports and social clubs	3
commercial areas with medium and high density	7-10*
residential area with medium and high density	7
public transport stations	7
hospitals	7
sports gym and stadium	10
warehouse	10
industry	10
educational institutions	5
temples and churches	5
vacant lots	5
parks (green spaces)	1
parking	5
informal settlements	5
squares	1
cemeteries	1

* 10 for buildings with a greater flow of people and structure such as shopping malls

Table S-2. Raw data from biological variables and Urban Biodiversity Suitability index values. Points are the 120 bird survey sites from which we used the data in the validation process. SR = Species Richness, FRic = Functional Richness, RaoQ = Rao's quadratic entropy, and UBS = Urban Biodiversity Suitability index.

Point	SR	FRic	RaoQ	UBS
1	32	0.550803051	0.194130987	8.0792503
2	29	0.377679222	0.171167524	7.2797508
3	32	0.476013954	0.176629899	7.612751
4	24	0.376738841	0.171515157	7.0462513
5	43	0.442879927	0.168366198	7.2300005
6	37	0.591248812	0.187286735	8.2457504
7	36	0.471447162	0.176426141	7.3462505
8	18	0.228521172	0.154848205	5.1645002
9	17	0.16479495	0.150865494	7.4127512
10	22	0.190508641	0.14181735	7.7792511
11	22	0.305528282	0.169185644	6.3137512
12	19	0.130604567	0.136226908	7.6792507
13	31	0.211285236	0.14827357	7.8625002
14	17	0.111153126	0.12461108	7.9625006
15	18	0.221288303	0.158437813	7.1965008
16	31	0.191339289	0.144071129	7.8457508
17	45	0.476505055	0.169646041	7.7960005
18	31	0.397039044	0.160826485	8.4955006
19	38	0.474046377	0.178049245	8.2457504
20	29	0.339545827	0.165928888	7.1132507
21	20	0.24463696	0.147652259	6.5970001
22	36	0.381786741	0.160122007	7.7960005
23	17	0.137793715	0.147285875	5.5472507
24	22	0.169211886	0.151772146	6.9127512
25	29	0.340258953	0.159869852	5.3130007
26	32	0.388491523	0.172401734	7.8457508
27	26	0.295153168	0.157436163	6.5300007
28	17	0.125788825	0.132600358	7.8295012
29	24	0.168619727	0.122429005	8.0792503
30	22	0.088846363	0.11623409	8.0792503
31	30	0.301484362	0.16933039	6.1640005
32	29	0.310067218	0.162846505	6.1807508
33	28	0.489108876	0.186495832	7.1797504
34	26	0.257813508	0.157945969	7.4127502
35	24	0.244505574	0.149263743	7.1797504
36	31	0.504193284	0.193681458	8.4122505
37	28	0.349887258	0.17051224	6.3965006
38	24	0.286777902	0.14456351	7.1965008
39	18	0.224595113	0.153912354	6.1460009

40	32	0.454189471	0.192729767	5.1972513
41	44	0.646416181	0.188868871	6.5472507
42	34	0.455218428	0.168931971	8.2457504
43	15	0.071229001	0.113592542	7.9127502
44	30	0.268279997	0.143114857	8.2457504
45	44	0.487201933	0.15960978	8.5787506
46	29	0.30863395	0.152859894	6.4130011
47	10	0.092232105	0.145902066	7.6630011
48	22	0.228409611	0.153836073	8.1625004
49	26	0.227797958	0.142208958	8.2457504
50	35	0.362457342	0.143889688	8.2457504
51	33	0.228445388	0.136064087	7.3300009
52	24	0.251847907	0.164824444	8.5787506
53	41	0.392089989	0.165205026	7.9960003
54	15	0.195605472	0.147124965	7.9960003
55	24	0.295108499	0.151718509	7.8295012
56	15	0.129943221	0.148986248	6.2965002
57	21	0.177546385	0.14595387	4.1972504
58	26	0.381234101	0.160334662	7.4630003
59	20	0.223318175	0.172190729	7.7792511
60	36	0.450301937	0.175667687	7.5630007
61	10	0.035799934	0.129797133	3.2312505
62	14	0.09121782	0.142054411	3.1982505
63	10	0.046920262	0.141772387	3.6647508
64	1	0	0	2.9815009
65	15	0.073940297	0.119899252	4.5980005
66	15	0.117716667	0.148867979	4.4642506
67	6	0.009417534	0.045883215	3.0982502
68	7	0.010427195	0.135649755	3.1647508
69	6	0.050156135	0.156563816	4.4140005
70	11	0.058425182	0.146547288	4.796751
71	13	0.062403225	0.136443202	5.0807505
72	5	0.006917936	0.08730467	4.1315012
73	11	0.080470312	0.145385806	3.3480008
74	12	0.057047214	0.120801331	4.7310009
75	15	0.238469605	0.15304203	5.5637512
76	16	0.164463526	0.147936287	4.7645006
77	8	0.031411112	0.104730196	3.5312507
78	11	0.058373661	0.136185609	5.1137505
79	18	0.105333491	0.13517506	3.3312509
80	17	0.117795274	0.121863176	4.8967514
81	12	0.050614665	0.137555451	5.0310011
82	12	0.053418486	0.122413029	6.4802504
83	13	0.125079739	0.151069233	6.0807505
84	20	0.250712455	0.149954836	4.763751

85	12	0.067192636	0.15816689	5.513751
86	18	0.203404564	0.139259628	6.6137505
87	5	0.005954097	0.152533347	4.6805
88	10	0.02480411	0.134849013	6.7295008
89	20	0.213690524	0.1468488	5.7640009
90	17	0.179181462	0.158465419	7.4127512
91	13	0.039332341	0.117747323	4.7310009
92	25	0.235672992	0.159562961	7.4797506
93	12	0.119613352	0.154871709	3.8807504
94	16	0.100381211	0.143625977	3.5810006
95	12	0.082370915	0.137793919	3.7145007
96	15	0.075807609	0.141297284	4.5140009
97	10	0.101258972	0.124090235	5.463501
98	12	0.074836101	0.115565564	5.397501
99	15	0.086505146	0.135260099	5.8807507
100	14	0.080944532	0.153222651	3.9810007
101	13	0.101673307	0.151629445	3.8475006
102	15	0.126823941	0.147612125	5.4800005
103	17	0.114649709	0.111499583	5.8305006
104	10	0.015644626	0.085425171	6.1635008
105	10	0.068603738	0.11782311	5.3632507
106	11	0.09160423	0.122756027	6.3635006
107	15	0.150507853	0.151200337	7.496501
108	16	0.149154804	0.13913881	7.9960003
109	11	0.07074844	0.133809182	6.2802505
110	9	0.049494575	0.096997445	6.6635008
111	15	0.159709093	0.143180785	5.3310003
112	6	0.006112906	0.08728908	6.5970011
113	16	0.232363718	0.149189196	5.7302513
114	15	0.093907332	0.140899929	4.6307507
115	11	0.040200624	0.12023627	6.013751
116	10	0.045850003	0.13788116	6.4137506
117	20	0.199919166	0.139144201	7.0635004
118	13	0.085935937	0.128005456	4.2972507
119	22	0.2901401	0.145341521	7.2797508
120	6	0.002342233	0.161791728	4.2312508

Interlúdio parte I: Nasce um projeto

Um dia estava lendo uma reportagem sobre um mapeamento das áreas mais silenciosas do planeta, que iniciou com um pesquisador curioso e culminou em uma espécie de certificação em que os países podem se candidatar. A ideia era tão incrível que até rota de avião tinham conseguido alterar para preservar o silêncio. Achei aquilo incrível e bem, de um curioso para outro, fui ver mais sobre e descobri que já estava numa segunda fase em que parques urbanos também poderiam concorrer, inclusive com alguns no Brasil em avaliação. O que isso de fato tem ligação com uma tese, um leitor mais impaciente pode-se perguntar, sendo bem direto para você: nada! Entretanto o processo para construir um projeto vai muito além de ficar caçando ideias por aí ou simplesmente replicar coisas, claro que de início não soa assim, e requer tempo e leitura (sim, a eterna leitura) e muita observação do meio. No meu caso o meio era o urbano, mais especificamente Belo Horizonte, a cidade que me orgulhava de conhecer bem (agora mais do que nunca a conheço e não só coisas boas) e onde queria que o projeto do doutorado ocorresse. Com essa ideia dos locais silenciosos em mente comecei a ler outro trabalho que tinha uma ideia tão maluca quanto que era de achar os locais mais selvagens dentro de cidades. Selvagem aqui no sentido de estarem mais isolados e manterem maior biodiversidade como um todo. O tempo passou e estava num momento da vida que ainda não tinha muita certeza se faria doutorado, o lado financeiro me obrigava a trabalhar e ao mesmo tempo sombrios pairavam sobre o país, era 2018 meus amigos, e então apenas fazia anotações em uma caderneta que aprendi com o “mestre” que devia carregar para todos os lados e enfim, coisa de ornitólogo. E até que numa manhã de primavera ouço a vocalização de uma *Taraba major*, ou choró-boi, bem do lado da linha do metrô. Não tinha erro, o canto é inconfundível e eu já havia estudado insetívoros de sub-bosque no mestrado e tinha uma ideia que era um grupo que valia investigar. O choró-boi ainda seria ouvido perto demais ou estação do metrô e o que me inspirou para o primeiro esboço de um projeto, ainda por meio de rabiscos em um quadro verde (com giz!) na escola que dava aulas. O que queria saber na época era o quanto aquela vegetação ao longo do metrô poderia de fato abrigar as aves e quem. Além disso, será que poderia emular de alguma forma a ideia dos locais silenciosos e também selvagens pela cidade? Posso dizer que nada foi fácil! A busca por dados e principalmente conseguir que tudo aquilo que estava na minha cabeça fosse para o papel e que ainda fosse possível convencer alguém a embarcar nessa comigo foi só o começo. Depois de convencer o Marcos e o João a entrar nisso, tentei o Google e até a empresa 99 (sim, a dos aplicativos) pois ambos de orgulhavam em diversas matérias sobre como sua captação de dados poderiam ser úteis para o planejamento urbano, a segunda então até criou um índice. Um completo *fail* pois ninguém quis me ceder nada! E oh eu criei meu próprio índice que está disponível agora e vocês perderam! Isso só foi possível com ajuda, principalmente com a entrada da Ana, que como arquiteta pode contribuir muito com o trabalho e mostrou como é importante projetos

interdisciplinares. Dessa parceria fica a dica, sei que é uma fábula, cientistas em formação não tentem aprender todas as ferramentas sozinhos, não gastem o precioso tempo que possuem querendo ser o melhor em todos os milhares de programas de análises e criação do que for. Peçam ajuda e façam parcerias, ciência não se faz só e nem de um dia para outro como pregam em cursos de campo pelo mundo afora. As parcerias que fiz (Ana, Diego e outros) que tornaram essa tese possível e me ensinaram muito mais do que passar horas em vídeo aulas ou no Youtube tentando aprender tudo sobre tudo. Afinal como eu cheguei a ouvir de um amigo que eu já contribuo com as ideias malucas e o que preciso é de gente que tope ajudar a transformar aquilo em algo palpável. Lição: se permita ser maluco na pesquisa, e assim como a menininha vestida de abelha no clipe *'No Rain'* do *Blind Mellon*, ache seu nicho!

Capítulo 2: Applying the Urban Biodiversity Suitability (UBS) index to assess patterns of urban fire outbreaks

Tulaci Bhakti, João Carlos Pena, e Marcos Rodrigues

Introduction

Fire outbreaks and their impact on biodiversity are normally associated with wild areas (Durán-Medraño et al., 2017; Silveira et al., 2016). These best known as wildfires occur almost annually and their frequencies are prospectively increasing due to climate-changing effects (Durán-Medraño et al., 2017; Pausas and Keeley, 2021). These events cause a reduction in habitats for biodiversity besides damaging to the human population, mostly those who live near or in rural areas (Chas-Amil et al., 2013; Salvati and Ferrara, 2014).

Nevertheless, fire outbreaks can also affect people and biodiversity in cities both directly (when occurring within or in the vicinity of urban landscapes) or indirectly (when occurring in the surrounding landscape) (Cobbinah et al., 2023; Kotze et al., 2022). In this regard, many studies are about the consequences of fire outbreaks' effect on the urban environment, like fog, but with a focus mostly on human health (MacLeod et al., 2019). However, the effects of urban fire outbreaks on urban biodiversity, are little explored. It was already demonstrated that fire impacts the habitat quality for birds in habitat quality for birds and the natural regeneration process mediated by them (Lindenmayer et al., 2008; Stojanovic et al., 2016). Furthermore, it was already addressed the impacts of fire-related air pollution on urban wildlife behavior (Sanderfoot et al., 2021).

However, to efficiently prevent and control the occurrence of fire outbreaks in cities – especially vegetation fires – it is important to investigate if they are modulated by the environmental and spatial characteristics of urban landscapes. Within cities, fire outbreaks may be related to human conflicts, especially in regions of interest for real estate development (Chas-Amil et al., 2013; Salvati and Ranalli, 2015). In addition, there is a direct association with the growth of cities overlapping areas with vegetation, with the occurrence of fires, affecting the structure of the vegetation (Hubert et al., 2023; Schug et al., 2023), which can directly affect urban biodiversity (Chang and Lee, 2016; Stojanovic et al., 2016).

Considering that urban fire outbreaks may have strong impacts on biodiversity and that the occurrence of fires is affected by characteristics of the urban landscape, in this study we assessed how spatial characteristics that describe suitability levels for birds in a large metropolis may influence the occurrence of urban fire outbreaks. To do that, we tested this relationship using the Urban Biodiversity Suitability index (UBS) developed by Bhakti et al. (2023). The UBS Index is based on a knowledge driven approach on four landscape attributes: human accessibility, soundscape, built artifacts and volumetry, and land cover. In this way, the USB index intends to indicate, within the urban context, areas that would be more suitable for biodiversity. In a previous assessment of its accuracy,

regions indicated as with high suitability values by the UBS Index where those with high amount of vegetation especially woody cover, reduced noise exposure, and lower accessibility and number of built artifacts (Bhakti et al., 2023). Thus, our goal in this study was to assess if the UBS Index can also describe urban vegetated areas with more risk of urban fire outbreaks according with the local geospatial characteristics of Belo Horizonte (Minas Gerais, Brazil). As fire outbreaks in cities are related to regions in urban expansion, mainly peri-urban areas (Schug et al., 2023), we expected fire outbreaks to occur mainly at regions with intermediate to high suitability levels.

Methods

To assess the relationships between the suitability levels of the UBS Index and the occurrence of urban fire outbreaks we used the distribution of 9,877 records (Fig. 1A) obtained as a point feature map from the Minas Gerais State Fire Department within the municipality of Belo Horizonte. We used Belo Horizonte as our case study because it is the same city for which the UBS Index was developed.

All these records represent occurrence of fire outbreaks on urban vegetation of vacant lots, public and private green spaces, brownfields, and protected areas, between 2011 and 2020. We built a histogram to assess the distribution of the frequencies of fire outbreaks records according with the five classes representing the levels of the UBS Index, 1 being the lowest and 5 the highest suitability levels (Fig. 1B).

Results

According with our expectations, most of the fire outbreak records occurred at intermediate levels (7,489 records), followed by high levels of suitability (1580 records) and the area with the lowest suitability value were those with the lowest frequency of records (806). Therefore, the regions with the lowest UBS Index values, i.e. with a higher degree of urbanization, presented the lowest frequency of fire outbreak records. (Fig. 2).

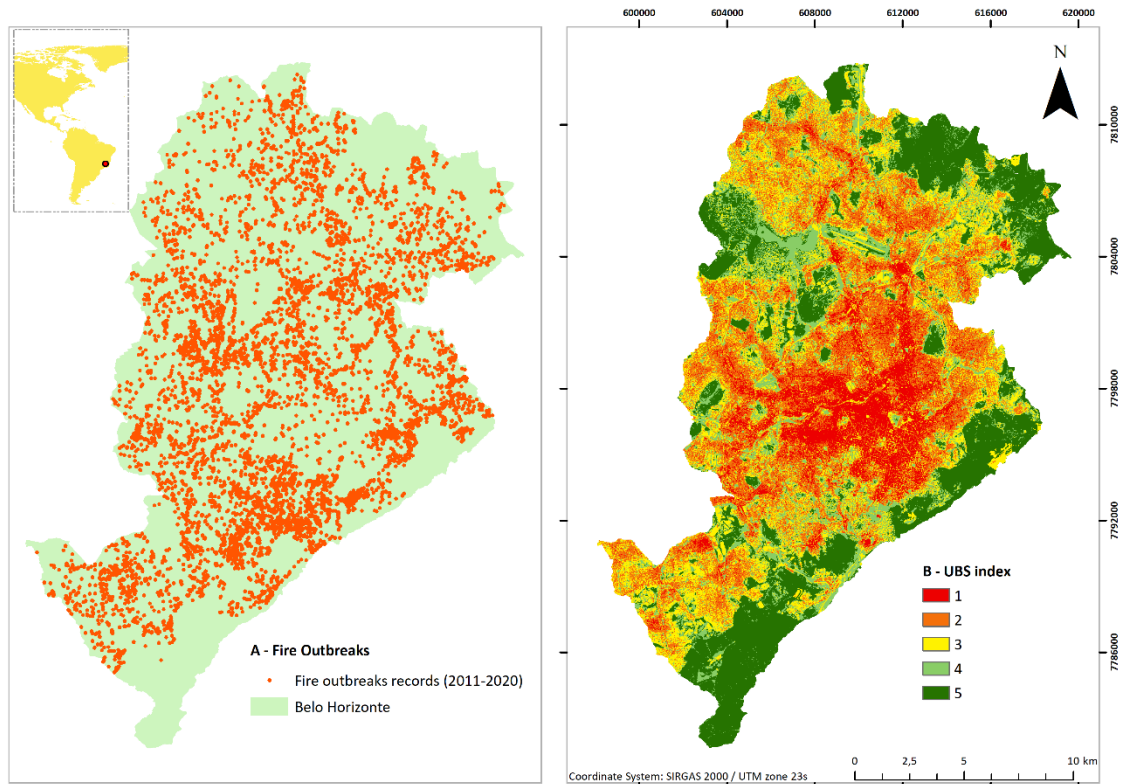


Figure 1. (A) Location of records of fire outbreaks in urban vegetation in the Belo Horizonte municipality (Minas Gerais, Brazil) during the period from 2011 to 2020. (B) Urban Biodiversity Suitability index (UBS): 1 being the lowest and 5 the highest suitability levels.

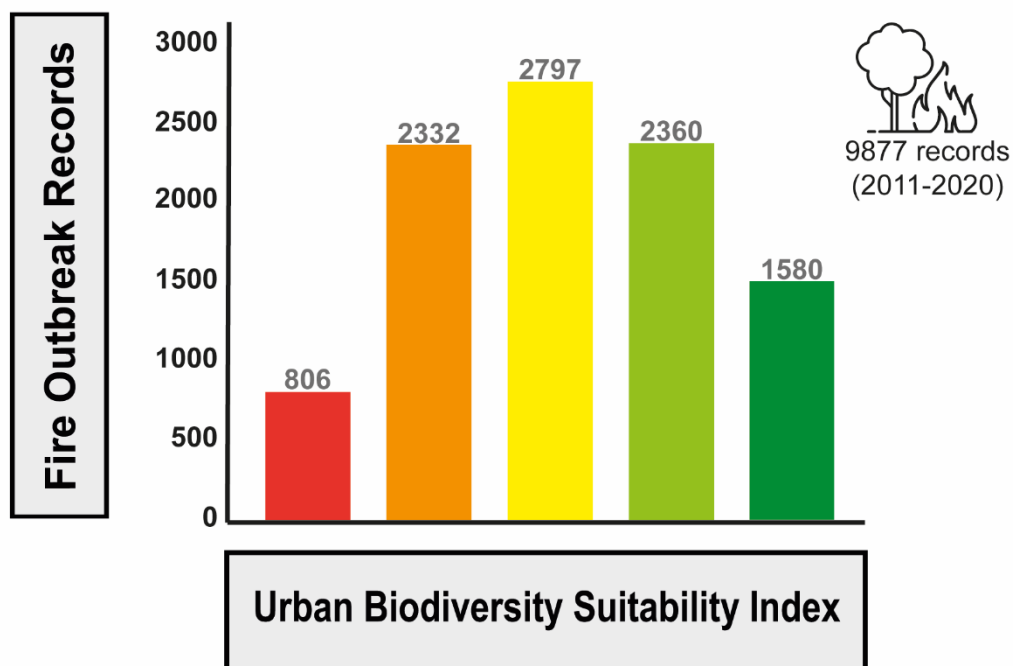


Figure 2. Histogram with the result of the relationship between the frequency of fire outbreaks and the Urban Biodiversity Suitability Index (UBS)

Discussion

The UBS Index can describe patterns of fire outbreaks across an urban landscape: the highest frequency of records occurred in intermediate suitability levels. They mainly represent peri-urban vegetated areas, where law enforcement is probably limited, and indicated a medium access to the human population. Furthermore, vegetated areas with the lowest biodiversity suitability levels presented the lowest frequency of fire outbreaks. This could be related to small vacant lots and brownfields located in the most urbanized areas of the landscape, where law enforcement is probably higher and the use for other activities (such as cattle ranching and agriculture) is limited. On the other hand, the most biodiverse suitable areas presented double the frequency, indicating the presence of human disturbances within native and preserved vegetation patches.

Despite the important role of fire outbreaks on modulating habitat quality and availability for biodiversity (Haugaasen et al., 2003), they can facilitate the spread of exotic species across natural areas (Rossi et al., 2014), as well as lead to changes in the vegetation structure (Silveira et al., 2016), which can directly affect biodiversity, including habitat for some bird species (Stojanovic et al., 2016). Thus, our findings highlight a worrisome pattern that urban areas that harbor intermediate to high levels for urban biodiversity also concentrates most of the fire outbreak records across this urban landscape.

Relating the occurrence of these fire outbreaks to urbanization is a starting point for assessing their impacts on biodiversity (Hubert et al., 2023). With the expansion of built surfaces in cities, there is also greater access to more isolated green areas (such as peri-urban areas), which implies in an increase in the probability of occurrence of fires. This relationship can be associated with the use of fire as a management practice to prepare new areas for urban expansion, especially grassland and open habitat vegetation patches (Barger et al., 2003). Those areas are more easily occupied due to the lower above ground biomass than forest patches (Bhakti et al., 2020). Additionally, fire is used not only to facilitate urban expansion but also as a form to prepare the soil for agriculture, although considered as an environmental crime in Brazil (Brasil, 1998). Such practice can cause the spread of flames to various green spaces, including protected areas (Rezende, 2023), causing health problems due to smoke, affecting biodiversity, and increasing public spending on firefighting (CBMMG, 2023). Therefore, regions with intermediate levels of the UBS Index and with high frequency of fire outbreaks may receive especial attention for surveillance and environmental education programs, increasing the awareness of the human population about impacts of the use of fires not only on biodiversity, but also on human health and well-being (e.g., air pollution, respiratory issues, property damage). The continuous changes caused by fire outbreaks and the lack of campaigns or management actions by managers can result in ecological impacts and a reduction in the ecosystem services that urban vegetation provides for the human population (Cobbinah et al., 2023).

Finally, we would like to conclude this study with the following recommendations:

- We reinforce the need for further studies that relates urban fire outbreaks and the occurrence of biodiversity in cities, since urban landscapes are important refuges for native flora and fauna (Rega-Brodsky et al., 2022).
- Second, the approach we adopted in this study can be considered as a form of integrated management of urban green spaces. By relating the occurrence of fire outbreaks with vegetated areas with specific spatial characteristics, it is possible to investigate people motivations for the use of fire, as well as assist in the formulation of public policies aiming at reducing the occurrence of fire outbreaks and their impacts on urban biodiversity and human health.

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Interlúdio parte II: Da falha ao acerto crítico no RPG da ciência

Minha ideia com esses interlúdios era dar um pouco dos bastidores, por assim, dizer dessa tese. E em cada separar um tema que eu possa ilustrar os passos ou perrengues que passei para concluir. Ou simplesmente posso dizer que era uma forma de pôr para fora tudo que guardei em mais de quatro anos na minha cabeça e que essa foi a minha forma de escape. Talvez um pouco dos dois, e claro, de quem de fato vai ler tudo isso. Rindo ou chorando, lá vamos nós. Um ponto que senti o peso ao desenvolver um projeto só (não é, meu precioso?) foi como de fato escolher as áreas, e depois de escolher, onde coletar, e todo aquele viés disso e daquilo que a gente aprende nas disciplinas de métodos? É como a vizinha do ego do professor de estatística batendo na sua cabeça com as palavras 'aleatório' e o maldito 'n amostral' sem parar. Pois bem, joguei toda a minha megalomania no mapa e isso não poderia ter sido mais do que literal, pois marquei TODAS as áreas verdes (verdonas, verdinhas e ainda as quase nada verdes) numa enorme faixa da cidade. E aqui entre nós, não tinha percebido que sem querer tinha seguido os dois grandes rios de BH e ainda os uni com o metrô. Genial, não é? Nada, pura sorte! Ok, vi em algum momento que não seria possível dar conta de tanto, até desenhei um mapa imenso e preguei na parede (pandemia né gente) e ficava ali encarando o dia todo. Daí veio a parte mais difícil: conseguir falar com quem quer que fosse responsável pelas áreas que escolhi. Várias foi via prefeitura que o mais o complicado era que tinha que mandar email para vários setores individualmente depois de conseguir a licença. Mas as demais, ai foi osso! Cheguei até "andar" pelo *street view* para buscar qualquer referência para ter um contato e quando isso não foi tão eficaz tive que sair de casa e andar (e como andei, não é COPASA??) e também esperei muito por algumas das respostas, como tipo 1 ano da CBTU. No final fechei em 33 locais, com algumas negativas e esnobadas, obrigado CEMIG e UEMG. Feito isso ainda vinha a ideia de onde na área eu teria de coletar os dados e como coletar tudo que eu queria, mais leituras? Sim, muitas, mas no geral tive que aceitar que parte da vida é ser autoritário com algumas coisas, não havia uma fórmula mágica e que caberia exatamente no que eu queria. Para isso marquei pontos nas áreas como se não houvesse o amanhã e achei uma forma de decidir quantos seriam por local de amostragem. Aqui um pequeno adendo, deu muito errado isso de quantos pontos, em resumo, áreas na cidade nem sempre tem um acesso tão fácil e seguro... daí tive que me contentar com apenas 60 (que visitados 3x viraram 180) num meio de uma pandemia e carregando pra todo lado um monte de equipamentos, literal, pois tenho apenas minhas pernas como meio de locomoção. Voltando onde parei: a grande marcação de pontos no GSP, que nunca devolvi ao meu irmão. Ai como iria escolher os pontos? Bom, estava entediado em casa, e sair escrevendo em uma folha de papel os números dos pontos e fiz uma disputa entre eles com dados! Sim, realizei quase uma versão das Olimpíadas na minha mesa para escolher os pontos campeões de cada área. Algumas vezes com "obaaa!" e outras vezes com "ah droga". E foi assim que nasceram esses 60 pontos. Antes de finalizar tem mais

um momento nessa etapa de metodologia de campo, por assim dizer, que quero compartilhar, afinal fez parte do processo. Sentir o processo como ouço na terapia. Então, li que para medir a vegetação, mais especificamente a complexidade de sub-bosque eu poderia usar um enorme pano branco, uma câmera e um tripé, além de uma lente estilo 50mm e um suporte para o pano, e isso não poderia ser a melhor forma de iniciar uma piada... “um pesquisador entrar num bar com uma câmera, um tripé e um pano grande imenso...” Passo 1: disponha isso tudo em frente a vegetação e fotografe com x metros de distância e tal. Agora eu pergunto a você leitor, como se faz isso no meio da mata fechada? E com vento em áreas abertas no meio de uma avenida cheia de carros passando? Te respondo: não tem! Simplesmente foi um completo desastre, depois de horas de tentativas e vendo aquele pano enrolar em tudo, nas matas mais fechadas, e quase voar no meio da avenida, como se fosse um barco a vela! No final do dia eu sentei e chorei e mandei um áudio puto dizendo que não faria aquilo de jeito nenhum. Eu terei feito uma pilha com tudo e botado fogo, se não fosse crime ambiental e eu teria que devolver as coisas também. Nada como a vida no campo! Tantas coisas acontecem e no final sempre temos que decidir por algo, e muitas destas vezes vamos contar apenas com a gente, mas é como dizem “se você souber justificar bem” pode até funcionar.

Capítulo 3: Micro-perceptions of urban landscapes: management practices modulate bird communities inhabiting green spaces

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Abstract

The interplay between local and landscape characteristics of cities and urban biodiversity has garnered attention in numerous studies globally. Understanding urban biodiversity patterns necessitates a grasp of city dynamics—a landscape constantly evolving due to a plethora of elements. In this research, we explored the influence of local attributes (vegetation and land cover data), landscape features (vegetation and river presence), and spatial dimensions (Distance-Based Moran's Eigenvector Maps) on the bird community within a tropical metropolis. Bird surveys were conducted across 60-point counts spanning various green spaces. We evaluated how the prevalence of the ten most dominant species and their functional traits composition correlated with urban attributes. Utilizing partial redundancy analysis (pRDA), we discerned two distinct clusters of green spaces: one comprising protected areas and the other encompassing remaining green spaces. This differentiation primarily stemmed from local-scale attributes like soil type (whether exposed, grassy, or rocky). Protected areas exhibited denser vegetation and deeper litter, with certain functional traits—such as birds foraging in the understory and insectivorous and frugivorous species—being more prevalent. Conversely, smaller green spaces and cemeteries predominantly hosted generalist species like ground-foraging granivores and gregarious birds (Columbiformes). At the landscape level, the extent of green cover and proximity to water influenced the presence of forest bird species within protected regions. Spatially, proximal green spaces clustered together, underscoring regional patterns associated with analogous local attributes. Our findings emphasize that urban biodiversity predominantly hinges on local green space characteristics, such as management type and intensity. Consequently, we introduce the "micro-perceptions framework" for analyzing urban biodiversity patterns, underscoring the imperative of recognizing the pronounced heterogeneity of local-scale green spaces.

Keywords: functional attributes; urban ornithology; urban ecology; green space management; urbanization.

Introduction

The complexity of urban landscapes is intricately tied to the growth and development patterns of cities, often mirroring ecosystems undergoing continuous transformation (Ramalho & Hobbs, 2012). Concurrently, urban green spaces manifest in diverse forms and purposes, encompassing wooded streets, gardens, small parks, recreational areas, cemeteries, schools, and railway corridors, among others. These spaces extend to more traditional protected areas (Rupprecht et al., 2015; Soanes et al., 2019). Additionally, informal green spaces, not officially recognized but influenced by urban expansion possibilities, frequently emerge in periurban zones, characterized by reduced population density and increased vegetation, facilitating organism influx into urban areas (Snep et al., 2006; Vizzari & Sigura, 2015).

The urban landscape model delineates a gradient of urbanization intensity, spanning from periurban fringes to densely urbanized cores. This gradient significantly influences biodiversity, with birds frequently serving as key indicators due to their varied responses to urban environmental factors. Typically, the urban gradient corresponds to decreasing vegetation from peripheries to city centers, resulting in reduced taxonomic and functional community diversities within urban cores compared to edges (Escobar-Ibáñez et al., 2020; Filloy et al., 2019; McDonnell & Hahs, 2008). This pattern stems from the 'soft edges' of cities offering broader habitat availability, whereas urban centers feature higher human densities and more impermeable surfaces (Bhakti et al., 2021).

However, urban expansion is multifaceted, influenced by historical, political, and socioeconomic factors, challenging the simplistic periurban-urban gradient model (Ramalho & Hobbs, 2012). Biodiversity patterns within cities are not solely defined by this gradient; instead, intra-urban regions host rich taxonomic, phylogenetic, and functional diversities influenced by localized environmental factors. For instance, certain vegetation patches within urban cores can support diverse bird communities based on specific habitat elements (Campos-Silva & Piratelli, 2021; Curzel et al., 2021).

The micro-perceptions framework underscores the importance of local-scale characteristics in shaping biodiversity patterns across urban landscapes, influencing management strategies for various green spaces (Aronson et al., 2017; Rupprecht et al., 2015). However, broader historical, political, and socioeconomic contexts can override local influences, affecting spatial patterns of green spaces and associated biodiversity (Gomes et al., 2023; Ramalho & Hobbs, 2012).

While some understanding exists regarding the relationships between urbanization effects and birds, such as the preference for reduced richness of phylogenetically related species that exhibit generalist traits, like omnivorous birds (Sol et al., 2014, 2020), these findings are primarily derived from temperate cities. Consequently, urban landscapes in other global regions, such as the Neotropics, warrant more in-depth investigations (Pena & Martello, n.d.; Soares, L., Cockle, K., Inzunza, E. R., Ibarra, J. T., Miño, C. I., Zuluaga, S., ... & Martins, 2023). Moreover, despite the prevalent use of the periurban-urban gradient framework in scientific literature, often without accounting for landscape heterogeneity and local variations, it's imperative to acknowledge that such an approach may oversimplify the complexities (Concepción et al., 2017; Rega-Brodsky et al., 2022). In this study, our aim is to underscore that, beyond the overarching influence of urbanization gradients, the localized characteristics of urban green spaces play a pivotal role in shaping the functional and taxonomic compositions of bird communities within urban landscapes. Through surveys conducted in a tropical

metropolis, we endeavor to illustrate that the spatial distribution of green spaces significantly influences avian community compositions, with vegetative fragments closer to city peripheries harboring enhanced species and functional trait diversities.

Methods

Study area and bird surveys

We conducted our study within the municipality of Belo Horizonte (-19.899152, -43.955470), characterized by a predominantly urbanized landscape and lower population density in periurban regions (Belo Horizonte, 2019; Bhakti et al., 2023). Situated within the ecotone of the Atlantic Forest and Cerrado biodiversity hotspots (Brandão & Araújo, 1992; Myers et al., 2000), the municipality boasts over 90 protected areas, encompassing both public (municipal and state) and private reserves (Xavier, 2018). Beyond these formal protected zones, various urban green spaces permeate the municipality, including linear parks, small green areas, wooded streets, recreational spaces, cemeteries, educational institutions, and additional vegetated regions, particularly evident in periurban settings.

Given this diversity of urban green spaces, we established 60-point counts across 33 distinct sites, spanning from periurban fringes to the city's core (Fig. 1 and Table S1 - Supplementary Material I). These spaces were categorized as follows:

- Protected Areas (PAS): Designated by municipal authorities with varying degrees of formal protection, including parks or regions earmarked for their environmental significance (Belo Horizonte, 2019).
- Linear Parks (LPK): Predominantly linear green spaces, often designed for ecological restoration, situated alongside thoroughfares, serving both as recreational trails and potential wildlife corridors (Chin & Kupfer, 2020).
- Small Green Spaces (SGS): Compact vegetated areas, frequently characterized by expansive grass or impermeable surfaces, serving as critical urban biodiversity hubs due to high human footfall (B. F. da Silva et al., 2021).
- Alternative Green Spaces (AGS): Encompassing green areas not classified in the aforementioned categories, including private leisure zones and cemeteries (Morelli, Mikula, Benedetti, Bussi re, & Tryjanowski, 2018).
- Railway Lines (TRL): Strips of vegetation flanking railway tracks, potentially functioning as linear parks or ecological corridors within the urban matrix (Vandavelde & Penone, 2017).

Each selected green space underwent up to four-point counts, with allocation adjusted relative to their dimensions (Table S1 - Supplementary Material I).

Bird surveys spanned from October 2020 to April 2021, a period coinciding with the breeding season of southern hemisphere avifauna, enhancing their detectability due to territorial behaviors (Sick, 1997). Each point count was executed thrice, with a minimum 30-day intersession, conducted during early morning hours, excluding rainy days. Observations spanned a 50-meter radius over 20 minutes, capturing species presence and interactions within the defined area (Pena et al., 2023). Data included species sightings, excluding transitory flyovers devoid of site-specific interactions. Species abundance was derived from the highest observed count across the three sessions. To delineate avian functional traits, we considered parameters such as average

body size, mass, clutch size, nesting preferences, dietary habits, and foraging strata, all pivotal for avian resilience amidst urbanization-induced environmental shifts (Brown & Graham, 2015). Functional data were sourced from established literature (Wilman et al., 2014; Sick, 1997).

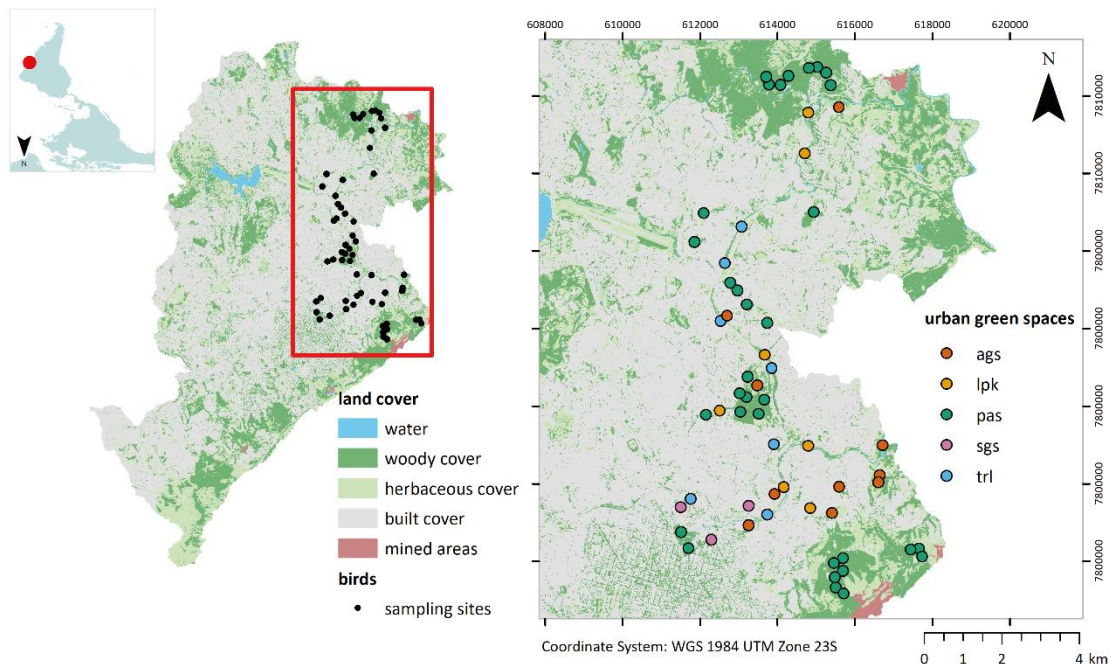


Figure 1. Land cover map and distribution of the 60-point counts classified by the green space type in the municipality of Belo Horizonte (Minas Gerais, Brazil). Green spaces: protected areas (PAS), linear parks (LPK), small green spaces (SGS), alternative green spaces (AGS) and railway line (TRL).

Multi-scale characteristics of green spaces and statistical analysis

To identify the primary factors influencing the taxonomic and functional compositions of urban birds across green spaces, we employed Partial Redundancy Analysis (pRDA). This technique integrates multivariate regression with Principal Component Analysis (PCA), facilitating the exploration of relationships between a set of predictor variables and corresponding response variables (Borcard et al., 2011). Analogous to Multivariate Regression, pRDA quantifies the proportion of variance elucidated by predictor variables—a method termed variance partitioning. In our study, response variables pertain to species abundance and functional traits within survey sites (i.e., point counts), while predictor variables encompass local, landscape, and spatial attributes as delineated below. Utilizing variance partitioning, we gauged the proportion by which each predictor group elucidates trait and species composition across survey sites.

For analyses based on bird species abundance, we exclusively considered the ten most prevalent species. This approach enabled a more nuanced assessment of urban filters predicated on these species' attributes and their interplay with predictor variables across the three categories. By focusing solely on the ten most abundant species, we mitigated potential misinterpretations stemming from rare or less frequent species presence. We subjected the abundance matrix to a Hellinger transformation (Legendre & Gallagher, 2001). Concurrently, we standardized the functional traits matrix and

multiplied it with the abundance matrix encompassing all recorded species, yielding attribute abundance for each point count. We retained predominant functional traits, categorizing diets as insectivores, frugivores, granivores, other plant consumers, and nectar consumers. For foraging strata, classifications included ground, understory, mid-canopy, and canopy levels. We also preserved nesting site preferences: shrubs, trees, and secondary cavity nesters. Additionally, attributes such as clutch size and average species body size were retained.

Local scale characteristics

Local-scale characteristics were delineated by variables assessed within a 50-meter radius surrounding each survey site. From a central point, two additional points were established 50 meters apart, thus creating a 100-meter transect (Fig. 2). Transect delineation was guided by trail presence and the specific morphology of each green space. At each of these three designated points, 3x3 meter quadrants were demarcated for assessing variables associated with vegetation, microclimate, and soil cover (Fig. 2).

To quantify vegetation structure, canopy openness was gauged using a camera equipped with a fisheye lens (Bower 8 mm F3.5) positioned 0.5 meters above ground level. Additionally, trees exceeding a circumference at breast height (CAP) of 10 cm were assessed for height and girth measurements. The presence of standing dead trees, shrubbery (below 100 cm), and lianas were recorded as binary variables (0 or 1) (Fig. 2). These parameters aimed to offer insights into local vegetation structure and intricacy, particularly in relation to bird community functional and taxonomic composition and their habitat utilization patterns (Campos-Silva & Piratelli, 2021; Pena et al., 2023). Microclimatic conditions were evaluated by measuring atmospheric relative humidity on-site using a Brunton Atmospheric Data Center PRO portable meteorological station.

Concurrently, soil cover characterization encompassed litter depth measurements at quadrant vertices and classification of each quadrant's soil cover type. Categories included exposed soil (ESC), managed grass (with frequent pruning) (GMJ), invasive grass with no or little management (ranging from no or occasional pruning) (GIN), native grass (Cerrado) (GNT), rocky soil (RCH), sandy soil (ARE), concrete (CON), asphalt (ASF), and urban garbage/waste (ENT) (Fig. 2). This classification strategy aimed to elucidate site-specific management practices and green space integrity. Such management nuances are pivotal, as avian interactions with soil can vary significantly, and management frequency may influence the habitat suitability for specific bird groups, particularly those relying on soil for nesting or foraging activities.

Data from the three quadrants per survey site were consolidated to derive singular values for each variable. For continuous variables such as tree dimensions, canopy openness, and litter depth, mean values were computed. Conversely, categorical variables—encompassing ground cover, standing dead trees, lianas, and shrub presence—were recorded dichotomously, signifying their presence or absence. For instance, if one quadrant exhibited rocky soil devoid of standing dead trees while another quadrant housed both, the resultant predictors for that survey site would reflect the presence of rocky soil alongside standing dead trees and lianas.

Landscape scale characteristics

Factors encompassed within the landscape-scale category were derived from a land cover map, utilizing supervised classification of Planet Scope satellite imagery

boasting a 3-meter resolution and four spectral bands, acquired in September 2020 (Bhakti et al., 2023; Planet Team, 2017). The imagery underwent classification into categories: woody vegetation, herbaceous vegetation, impermeable surfaces (encompassing urban elements and exposed soil), and mining zones. Hydrographic data for this classification were sourced from vector files accessible on the Belo Horizonte City Hall website (refer to: <http://bhmap.pbh.gov.br/>).

Around each survey site, we established four concentric buffers spanning 50, 100, 150, and 500 meters, as illustrated in Figure 2. Within each buffer zone, we computed the green cover proportion (the cumulative area of woody and herbaceous vegetation) relative to the buffer's total area, denoted as VegCover_50m, VegCover_100m, VegCover_150m, and VegCover_500m. This gradient of green cover serves as a proxy for urbanization intensity. Our methodology was crafted to pinpoint the scale wherein urban vegetation proportion most profoundly influences both taxonomic and functional compositions of avian communities within green spaces (Baguette & Van Dyck, 2007). Prior studies have elucidated that urban sectors boasting increased vegetation across varied scales tend to support richer avian biodiversity (Pena et al., 2023; Threlfall et al., 2017). Furthermore, we quantified the proximity between each survey site and the nearest watercourse. Extant literature underscores that urban green spaces adjacent to watercourses exhibit heightened taxonomic and functional diversities among avian species (Barbosa et al., 2020; Suri et al., 2017; Wong et al., 2023).

Spatial Dimension

To ascertain the influence of spatial dimensions on the composition of urban bird communities within green spaces, we utilized Distance-Based Moran's Eigenvector Maps (dbMEM) as described by Dray et al. (2006). This method facilitated the delineation of spatial predictors (MEMs) derived from the geographic coordinates of survey sites. These MEMs serve as latent variables designed to assess spatial autocorrelation, capturing structures across a spectrum of scales. Specifically, they range from broader scales (encompassing the entire sampled area, denoted as MEM1 to MEM4) to more localized scales (approximating the dimensions of the sampling unit, designated as MEM5 to MEM12) as depicted in Figure 2. Ecologically, these variables offer insights into whether the distributions of species populations and functional traits exhibit spatial aggregation and pinpoint the specific scales at which such aggregation manifests.

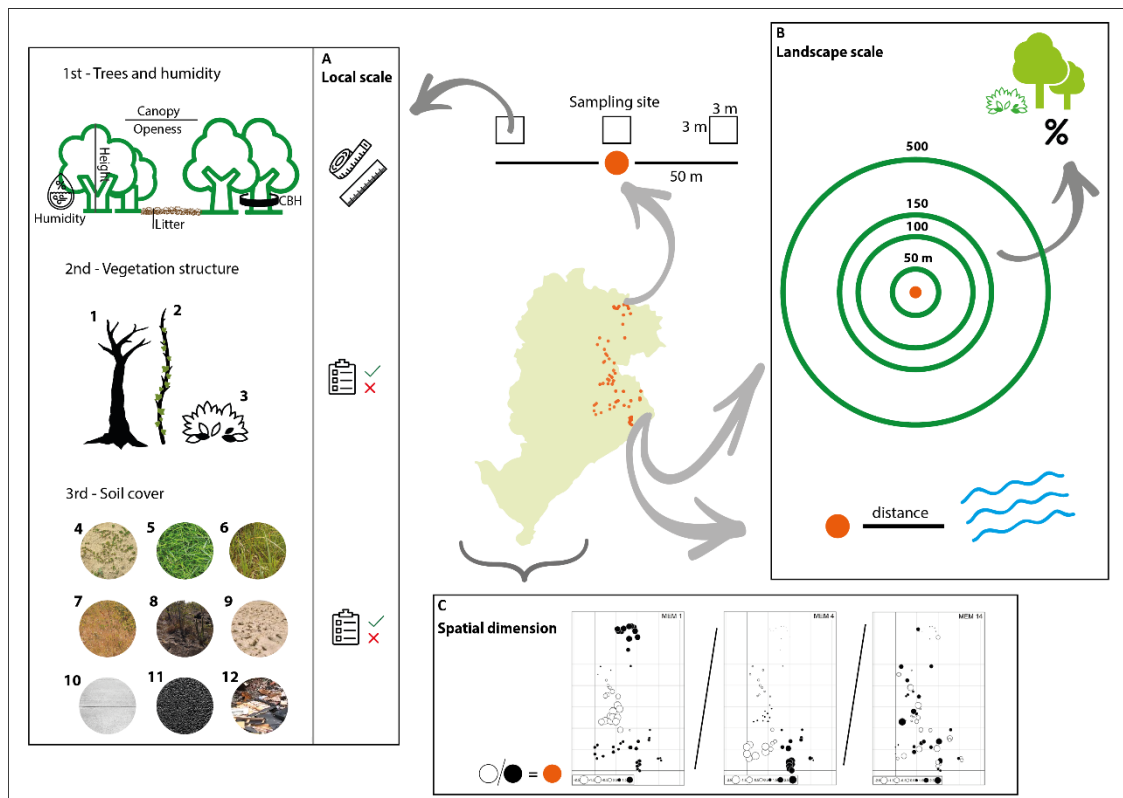


Figure 2. Infographic discriminating the variables extracted from the (A) local scale - quantitative variables (1st) and presence/absence (2nd and 3rd), (B) landscape scale, and (C) the spatial dimension. Circumference in breast height (CBH), relative humidity, standing dead trees (1), lianas (2), shrubs (3), exposed soil (4), managed grass (5), unmanaged grass (6), native grass (7), rocky soil (8), sandy soil (9), concrete (10), asphalt (11), and garbage/urban waste (12). Vectors were obtained from: <https://thenounproject.com/>

Redundancy Analysis and Variance Partition

For each of the three predictor groups, we conducted an independent forward selection procedure, following the methodology outlined by Blanchet et al. (2008). The pRDA analysis was executed using only the significant variables identified within each group. Subsequently, we extracted eight distinct fractions of variation: purely from the local scale (L); purely from the landscape scale (P); exclusively from the spatial dimension (S); spatially structured local variation (SL); spatially structured landscape variation (SP); variation jointly structured by both local and landscape scales (LP); shared variation among all predictor groups (LPS); and the residual or unexplained variation (U) (Borcard et al., 2011). All statistical computations were conducted using R programming language version 4.1.3 (R Core Team, 2021). Specifically, we employed the "rda" and "varpart" functions from the "vegan" package (Oksanen et al., 2013) and the "forward.sel" and "dbmem" functions available in the "adespatial" package (Dray et al., 2018).

Results

Bird surveys

We registered 148 bird species across the 60 survey sites with an effort of 60 hours of observation. The 10 most abundant species were: *Pygochelidon cyanoleuca* (238 individuals), *Columbina talpacoti* (171), *Patagioenas picazuro* (170), *Brotogeris*

chiriri (153), *Pitangus sulphuratus* (152), *Estrilda astrild* (147), *Columba livia* (133), *Thraupis sayaca* (99), *Troglodytes musculus* (98), and *Coereba flaveola* (90) (Table S2 - Supplementary Material I). The complete functional attributes of all bird species found can be accessed through Table S3 in Supplementary Material I.

Variance partitioning and redundancy analysis

The 10 most abundant species

The local predictors significantly explaining the distribution of the 10 most abundant species included litter depth, average tree height, and specific soil types such as managed grass, exposed soil, minimally managed grass, and rocky soil (refer to Fig. 3A). Notably, the species *C. flaveola* exhibited higher abundances in protected areas and showed a positive correlation with increased litter depth while inversely correlating with exposed soil. Similarly, *T. musculus* thrived in protected areas, showing a positive correlation with rocky soil but a negative correlation with tree height and managed grass. Conversely, other species displayed positive associations with various green space types, correlating positively with managed grass and exposed soil but negatively with litter depth and rocky soil (see Fig. 3B). Moreover, survey sites along railway lines clustered primarily with unmanaged grass (refer to Fig. 3B). Each species correlated with a spatial dimension predictor (MEM), either on broader scales like MEM2, MEM3, and MEM4, or finer scales such as MEM5 and MEM9 (see Fig. 3A). A comprehensive overview of results pertaining to the three predictor groups is available in Supplementary Materials I and II.

When assessing community structure based on the ten most abundant species, we noted that local predictors accounted for the highest pure fraction of variance (17%), followed by spatial dimension predictors at 4% (refer to Fig. 3B). Landscape variables did not emerge as significant when focusing on the ten most abundant species. A notable observation was the substantial intersection between local and spatial predictors, suggesting that the environmental characteristics at the sampling sites exhibit spatial autocorrelation; in other words, adjacent sites tend to share similar local environmental traits.

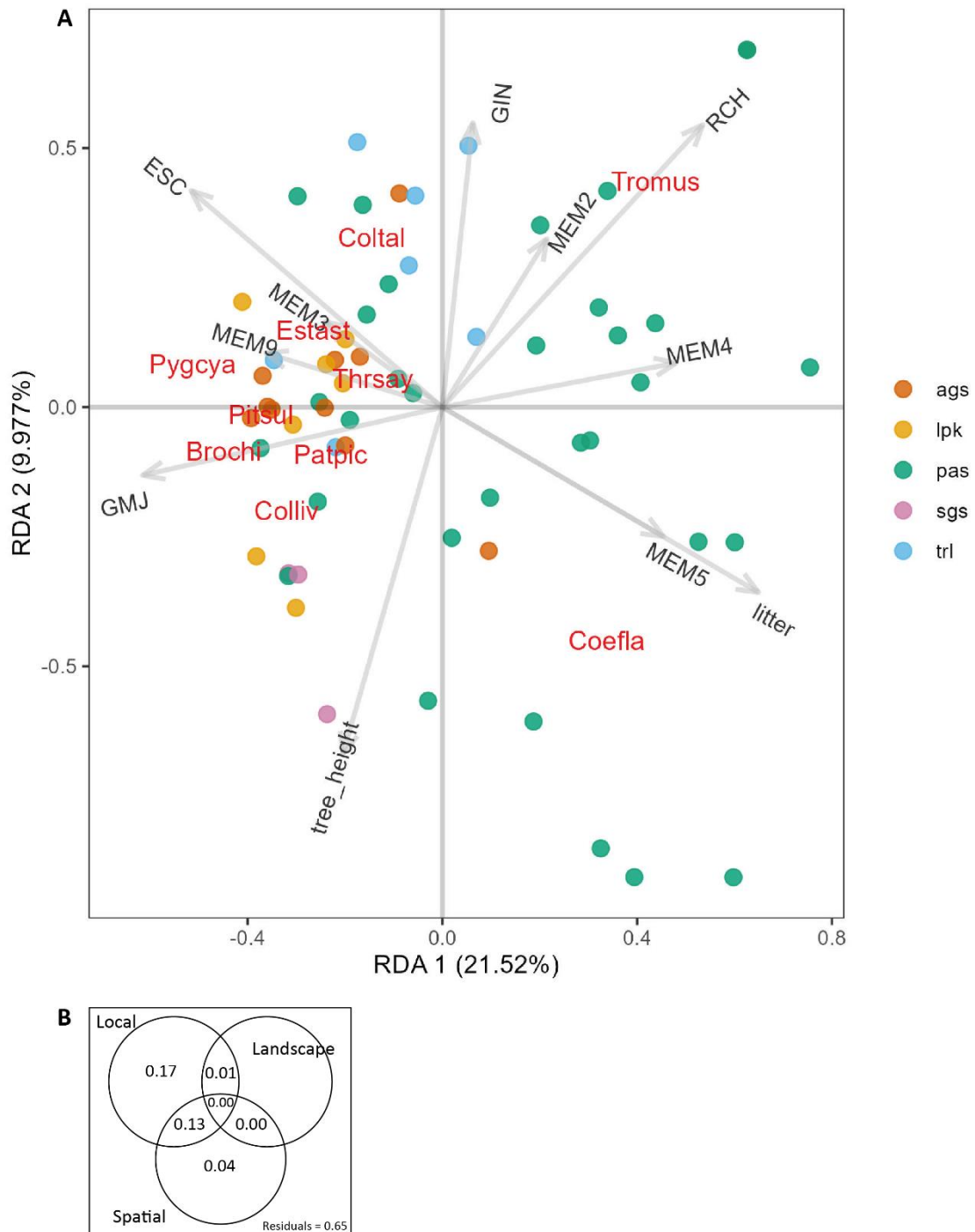


Figure 3. Results of the pRDA considering the predictors at local and landscape scales and the spatial dimension and the relationships with the 10 most abundant bird species observed in green spaces of Belo Horizonte (Minas Gerais, Brazil). Bird species: *Pygochelidon cyanoleuca* (Pygcyta), *Columbina talpacoti* (Coltal), *Patagioenas picazuro* (Patpic), *Brotogeris chiriri* (Brochi), *Pitangus sulphuratus* (Pitsul), *Estrilda astrild* (Estast), *Columba livia* (Columba livia), *Thraupis sayaca* (Thrsay), *Troglodytes musculus* (Tromus) and *Coereba flaveola* (Coefla). Local predictors include unmanaged grass (GIN), rocky (RCH), exposed soil (ESC), managed grass (GMJ), litter (litter), tree height (tree_height).

All MEMs can be viewed in Supplementary Material II. Green spaces: protected areas (PAS), linear parks (LPK), small green spaces (SGS), alternative green spaces (AGS), and railway lines (TRL).

Functional traits

The local predictors that significantly explained the distribution of functional traits were litter depth, relative humidity, canopy openness, and soil covers asphalt, sandy soils, and rocky soils (Fig. 4A). The landscape predictors that significantly explained the distribution of functional traits were distance from water and the proportion of green cover within a 500m radius buffer (i.e., VegCover_500m) (Fig. 4A).

Species that feed on invertebrates were grouped with the trait describing preference for foraging in the understory. Furthermore, there is a group of species that use middle extracts and vegetation canopies and that nest in trees. All of these functional traits are associated with higher litter depth and lower values of canopy openness and asphalt and sandy soil (Fig. 4A). These attributes, more related to higher arboreal cover, were frequent in protected areas (Fig. 4A, green dots). Conversely, species that live on the ground, that consume seeds and other parts of plants, were grouped with species with larger clutches and that nest on secondary cavities. These traits were positively associated with sites where the soil was covered by asphalt and with greater canopy openness, and negatively associated with litter depth and proportion of vegetation in the 500 m radius buffer (Fig. 4A). Species that feed on fruits and nectarines were positively associated with places distant from water and with higher relative humidity, as well as more related to protected areas and other types of green spaces, and negatively associated with places with sandy and rocky soil types.

Evaluating the community structure based on the functional traits, we noticed that the spatial predictors and the local environmental variables presented practically the same pure fraction of variance explanation (11% and 10%, respectively) (Fig. 4B). The pure fraction of explanation for landscape-scale variables was negligible, but with a significant fraction of explanation shared between the three matrices (local, landscape, and spatial predictors - 20%) (Fig. 4B). This result indicates that, for the selected variables, both local and landscape characteristics of the green spaces are spatially structured, i.e. there is a spatial autocorrelation in the selected characteristics of the survey sites both in local and regional levels; thus, sites near each other tend to have similar local and landscape characteristics. We observed two clusters of species based on the composition of functional traits. Species that preferentially use vegetation strata closest to the ground foraging and nesting, and species that use strata closest to the canopy (Fig. 5). All attributes were associated with some spatial predictor (i.e. MEM), whether on a broader scale (MEM1, MEM2, MEM3, and MEM4), or finer scales (MEM5, MEM9, and MEM12).

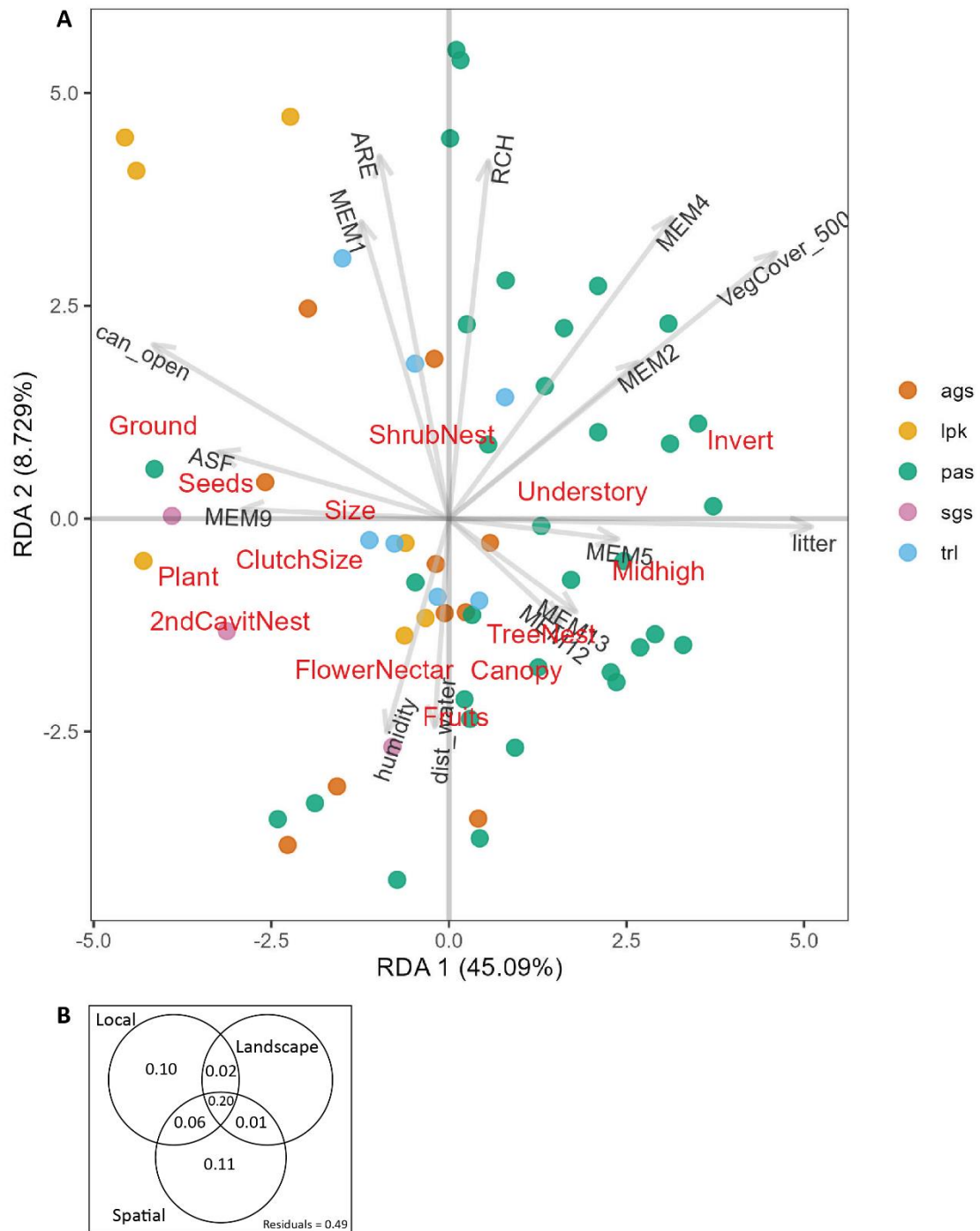


Figure 4. Results of the pRDA for predictors at local and landscape scales and the spatial dimension in relation to the abundance of functional traits of the 148 bird species registered in green spaces across the municipality of Belo Horizonte (Minas Gerais, Brazil). Soil cover: sandy (ARE), rocky (RCH), and asphalt (ASF). Local predictors: canopy openness (can_open), relative humidity (humidity), and litter depth (litter). Landscape predictors: distance from water (dist_water) and proportion of vegetation cover within a 500 m radius buffer (VegCover_500). Functional traits: foraging on the ground (ground), understory (understory), mid-vegetation stratum (midhigh), canopy (canopy). Diet insectivore (invert), frugivore (fruit), nectarivore (FlowerNectar), herbivore (plant), granivore (seeds). Clutch Size (ClutchSize). Body size (size). Nesting: shrub (ShrubNest),

trees (TreeNest), and secondary cavity nester (2ndCavNest). All MEMs can be viewed in Supplementary Material II. Green spaces: protected areas (PAS), linear parks (LPK), small green spaces (SGS), alternative green spaces (AGS), and railway line (TRL).

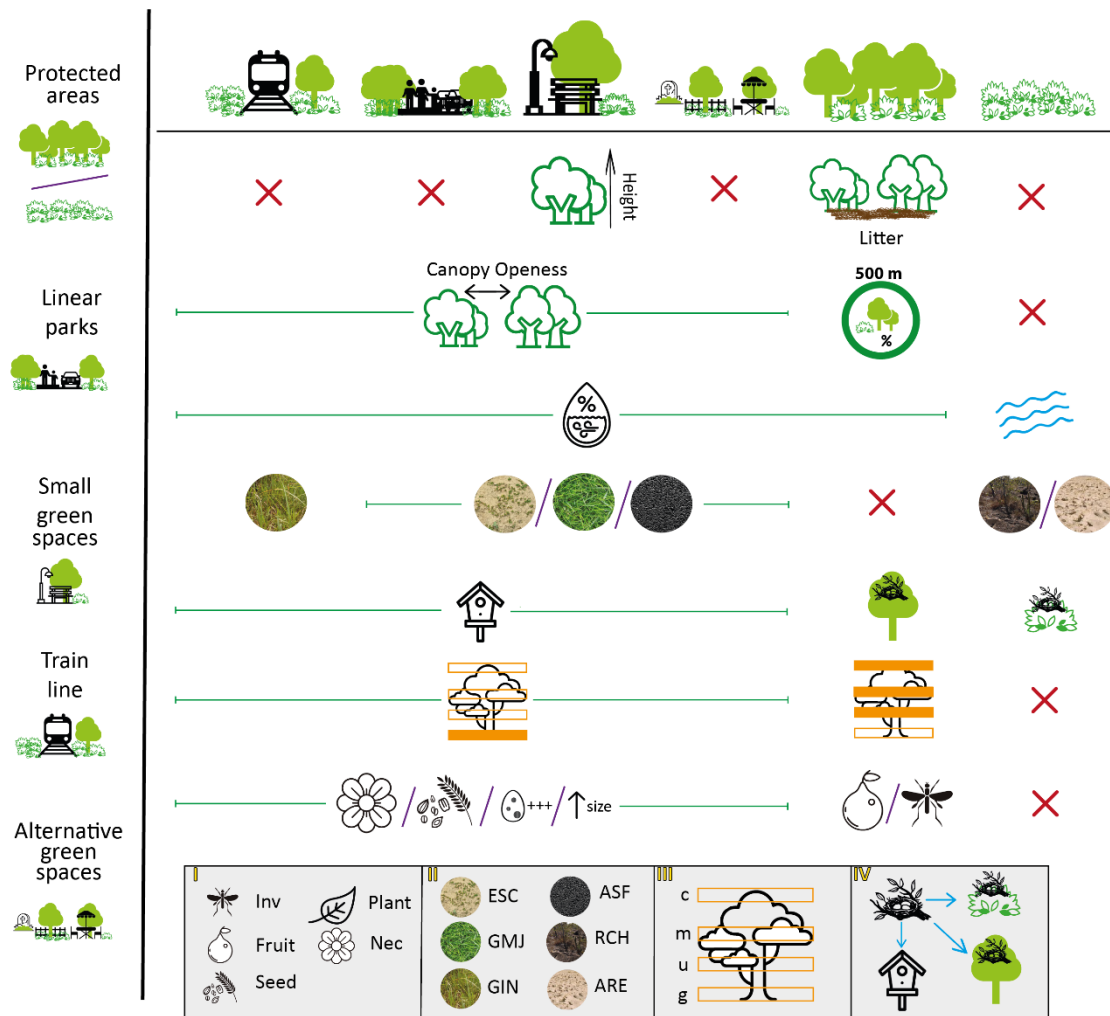


Figure 5. Infographic of the results of the relationships between predictors at local and landscape scales with the 10 most abundant bird species and the distribution of functional traits. Where I – Preferred diet; II – Type of soil cover: exposed soil (ESC), managed grass (GMJ), unmanaged grass (GIN), rocky (RCH), asphalt (ASF), and sandy (ARE); III – Preferential foraging type: ground (g), understory (u), middle (m) and canopy (c); and IV – Nesting site (shrub, tree, secondary cavity nester).

Discussion

By evaluating the relationships between the bird community and characteristics of urban green spaces at different scales, it is possible to identify that local characteristics have the greatest influence on the occurrence of bird species and the composition of functional traits. This result reinforces the idea of the micro-perceptions framework, where characteristics related to the use and management types of urban green spaces modulate the composition of spaces and traits across urban landscapes. In a complementary way, these green spaces can be grouped according to spatial distribution, which does not necessarily indicate that there is a periurban-urban gradient across an urban landscape. In other words, local vegetation structure and complexity

and types of soil cover (litter or asphalt), can be more important in determining the composition of biodiversity, even when there is an influence of a gradient of urbanization intensity (in this study, described by the proportion of green cover).

Among the most abundant bird species, those with gregarious behavior were more common across the studied green spaces, such as columbids, parrots, and swallows (similar result as (Kark et al., 2007; Silva et al., 2023)). Among the most abundant species we also observed exotic birds and species that share dietary habits already described as abundant in tropical urban landscapes, such as omnivorous, insectivorous, and granivorous species (Pena et al., 2023; Richardson et al., 2023). Therefore, our results demonstrate that the urban environment can favor the occurrence of some groups of species that share some functional traits, either by providing resources or favorable habitats. To highlight this result, we observed patterns of occurrence of species across the landscape, mainly associated with predictors at the local scale. First, the positive association between two of the ten most abundant species with protected areas (*C. flaveola* and *T. musculus*). Protected areas that have rocky soil, found in Cerrado areas for example, favor *T. musculus*, which forages mainly close to the ground (Wilman et al., 2014); but at the same time this species has a reduction in abundance when there are managed grasses, very common in green spaces with greater public use (such as small green spaces). Likewise, the presence of higher litter depth, associated with protected areas, increases the abundance of birds that are more dependent on arboreal vegetation, such as the nectarivore *C. flaveola*. Protected areas may harbor specific local characteristics that are not maintained by the management type of other green spaces – such as litter and understory vegetation (Hwang et al., 2019). Those characteristics not related to the traditional urban landscaping practices can favor the presence of bird species with specific habits, such as forest-dependent nectarivorous birds (Pena et al., 2023). Thus, maintaining litter in green spaces can increase the abundance of more sensitive bird species (Stagoll et al., 2010). This becomes more evident when we focus on the other most abundant bird species that formed the cluster of the other green space types. Such clusters are related to soil types more common across urban landscapes, such as managed grass and exposed soil. Thus, this combination favors an increase in the abundance of birds that permeate the urban environment, probably because they can obtain resources or exploit more anthropogenic structures and surfaces for nesting and foraging.

When we analyze the relationship between the abundance of functional traits and predictors at different scales, we also observe a higher influence of local scale characteristics. Furthermore, we observed the association between protected areas with attributes related to shrub-tree vegetation and another cluster of green spaces related to local predictors linked to the type of soil – such as asphalt – and with less arboreal cover at the landscape scale. For protected areas, we saw that surfaces such as rocky soil increase the abundance of birds that nest on shrubs, which is related to the presence of Cerrado vegetation in the site (which is restricted mostly to some periurban protected areas) (Marini et al., 2012). Other protected areas harbor higher litter depth and understory vegetation, which was related to higher abundances of insectivorous species. This result reinforces that understory insectivore birds are sensitive to urbanization and may be restricted to more preserved vegetated areas within urban landscapes (Avilla et al., 2021; Matsuba et al., 2016; Stagoll et al., 2010). Furthermore, in protected areas, we observed a greater amount of arboreal cover at the landscape scale, which is related to

the increase in the abundance of species that forage in the middle stratum of the canopy and that nest in trees, as well as birds with a frugivorous diet. This is consistent with the positive association between the presence of urban trees and bird species richness (Pena et al., 2017, 2023). On the other hand, in the other cluster of green spaces grouped by the abundance of functional traits, we observed that there is a selection of species less dependent on arboreal vegetation. There is an increase in open habitat bird species due to the greater canopy openness and the presence of asphalt. In this cluster of green spaces, we also observed a higher abundance of traits associated with generalist habits, favoring species that forage on soil, feed on seeds, have larger body sizes, and can exploit human-made structure for nesting (secondary cavity nesters) (Pena et al., 2023). This result indicates that the urban ecosystem can provide habitat and resources for species with different habitat requirements and sensitivities to human disturbances (Richardson et al., 2023). This result is related, for example, to the occurrence of Columbidae species, especially *C. livia*, that are common in tropical urban landscapes (Pena et al., 2023; Zorzal et al., 2021).

The landscape scale, although it did not have a pure influence as a predictor but rather associated with a combination with the local and spatial predictors, had influences on the abundance of functional traits when considering two predictors, the distance from water and green cover within a 500m radius buffer. The proximity to water favored species that use both open habitats and forested areas, mostly in protected areas. However, frugivorous birds were negatively associated with the proximity to water. This result can be related to the increase in niche space and availability of resources (e.g. food sources) for birds near water bodies in urban landscapes (Barbosa et al., 2020; Wong et al., 2023). In fact, in the municipality of Belo Horizonte, there is a practice of maintaining and recovering riparian forests with the creation of protected areas (FPMZB, 2018). On the other hand, the use of fruiting trees in the urban afforestation may increase the availability of resources for frugivorous birds in some regions of the urban landscape, not necessarily near water bodies (Gomes et al., 2023; Pena et al., 2023). Additionally, the greater the proportion of green cover at 500 m radius buffer, the greater the abundance of birds associated with arboreal vegetation, such as understory insectivore species. Furthermore, within a distance of 500 meters, it is also possible to group more than one green space, inferring that there is a connection between areas according to bird functional traits that occur in similar locations. This is possible because the presence of vegetation around green spaces increases the movement of birds across the urban matrix (Horta et al., 2018; Villaseñor et al., 2020).

We have presented several arguments so far that emphasize the effects of local predictors on the taxonomic and functional compositions of urban bird communities. Thus, we reinforce the micro-perceptions framework, which focuses on how birds interact and exploit the urban environment. By grouping multiple types of green spaces based on the abundances of species and functional traits, it was possible to expose the heterogeneity of the green spaces. Our goal was to reflect on the generalization of the use of urban gradients in the biodiversity research in cities, which may ignore local characteristics in favor of merely varying a proxy for urbanization intensity (e.g. proportion of impermeable surfaces). In contrast, there is a global tendency for more studies to include local characteristics when assessing biodiversity patterns across urban landscapes (Callaghan et al., 2021; Morelli, Mikula, Benedetti, Bussièrè, Jerzak, et al., 2018). In this way, it would be possible to measure the complexity of the relationships

between biodiversity and the urban environment, and thus highlight this perspective in search of larger patterns (Rega-Brodsky et al., 2022). However, the regionalization of the surveyed sites (i.e. the influences of the spatial predictors) cannot be excluded nor how the landscape characteristics (i.e. the proportion of vegetation surrounding sites) may mitigate the negative influences of the urbanization process on biodiversity.

In this study, we saw that the local scale is directly related to the management of green spaces. Management types and intensity interfere with the environmental characteristics of the green space (e.g.: maintenance of understory vegetation and higher litter depth) according to their use by the human population. For example, sites across the train line were associated with unmanaged grass; these areas are not accessed by people and possibly receive occasional, but not continuous, management. In contrast, we observed that many green spaces besides protected areas are directly linked to managed grass, which is related to their constant use by people for different activities (as leisure and gathering spaces, for example) (de Toledo et al., 2012; Hwang et al., 2019; Matsuba et al., 2016). Soil cover can also indicate the spatial location of green spaces across the landscape, as more peripheral green spaces may have less access by people and thus maintain a greater presence of litter, for example (Bhakti et al., 2023). All these green space types we surveyed proved to have different influences on the composition of species and function traits of this urban bird community, demonstrating the importance of maintaining a high habitat heterogeneity across urban landscapes to preserve higher biodiversity levels.

Conclusions

Urban landscapes are complex ecosystems and are in constant transformation, which increases the challenge of studying biodiversity patterns in cities. Here we present the idea of micro-perceptions, which highlights the local scale as an illustration of green spaces because it reflects their management and uses by the human population, which modulates urban biodiversity. We also highlighted the need for studies to go beyond the “urban gradient” and see cities as complex and highly heterogeneous ecosystems; an urban continuum may not explain biodiversity patterns. The approach we adopted in our study allowed us to group green spaces by the abundance of species and functional traits. From our results, it is possible to build connections between areas considering their similarities and identify management strategies that favor the occurrence of more diverse bird communities across urban landscapes.

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Supplementary Material I – Tables

Table S1. Complete list of all urban green spaces used for bird sampling, in the municipality of Belo Horizonte (MG) classified by type, being protected areas (PAS), linear parks (LPK), small green spaces (SGS), alternative green spaces (AGS) and the railway line (TRL). It also contains the coordinates of each green space, the total size in hectares and the number of points per area.

ID	UGS NAME	TYPE	POINT_X	POINT_Y	HECTARE	POINTS
22	ADE_CASA_DE_FRANCISCO	pas	614079,6465	7808286,277	750	4
241	ADE_CASA_DE_FRANCISCO	pas	614288,4549	7808521,669	*	
242	ADE_CASA_DE_FRANCISCO	pas	613784,1462	7808299,8	*	
244	ADE_CASA_DE_FRANCISCO	pas	613705,2662	7808494,215	*	
247	ADE_MATA_DA_IZIDORA	pas	615258,9475	7808605,911	*	4
248	ADE_MATA_DA_IZIDORA	pas	615021,7346	7808740,6	*	
249	ADE_MATA_DA_IZIDORA	pas	614805,3759	7808715,774	*	
277	ADE_MATA_DA_IZIDORA	pas	615368,2775	7808280,69	*	
123	CARE_NE	ogs	612697,7114	7802333,808	2	1
250	CBTU_ESTACAO_CENTRAL	trl	611753,7803	7797607,282	**	1
271	CBTU_ESTACAO_HORTO	trl	613910,4798	7799017,393	**	1
160	CBTU_ESTACAO_JOSE_CANDIDO	trl	613853,5029	7800985,227	**	1
228	CBTU_ESTACAO_MINAS_SHOPPING	trl	612537,7937	7802198,031	**	1
161	CBTU_ESTACAO_SANTA_TEREZA	trl	613731,0073	7797204,946	**	1
187	CBTU_PATIO_DE_MANUTENCAO	trl	612642,5029	7803691,405	**	1
188	CBTU_PATIO_DE_MANUTENCAO	trl	613070,3097	7804630,097	**	1
64	CEMITERIO_DA_SAUDADE	ogs	615401,3935	7797249,656	18	1
131	CEVAE	ogs	616634,1531	7798222,155	20	2
133	CEVAE	ogs	616604,9033	7798041,83	*	
61	CLUBE_ASPRA	ogs	615596,7442	7797922,192	8	1
231	COMUPRA	ogs	615584,8419	7807712,271	3	1
191	ETE_ARRUDAS	ogs	616713,4842	7798993,179	5	1
70	FUNDACAO_JOAO_PINHEIRO	ogs	613476,1811	7800538,042	16	1
67	INSTITUTO_RAUL_SOARES	ogs	613256,6848	7796932,215	4	1
141	MERCADO_SANTA_TEREZA	ogs	613922,8267	7797737,975	2	1
100	MHNJB	pas	613038,0209	7799852,327	55	4

ID	UGS NAME	TYPE	POINT_X	POINT_Y	HECTARE	POINTS
105	MHNJB	pas	613199,378	7800231,029	*	
112	MHNJB	pas	613662,2473	7800167,398	*	
240	MHNJB	pas	613507,2303	7799799,284	*	
233	MINAS_TENIS_COUNTRY_CLUBE	pas	617654,5382	7796329,705	35	3
234	MINAS_TENIS_COUNTRY_CLUBE	pas	617443,3475	7796304,664	*	
235	MINAS_TENIS_COUNTRY_CLUBE	pas	617736,5666	7796120,966	*	
237	PARQUE_BALEIA	pas	615479,9008	7795590,827	254	3
238	PARQUE_BALEIA	pas	615503,1695	7795324,822	*	
239	PARQUE_BALEIA	pas	615709,2759	7795168,183	*	
165	PARQUE_BALEIA_HOSPITAL	pas	615691,428	7796082,737	*	3
167	PARQUE_BALEIA_HOSPITAL	pas	615698,1735	7795755,634	*	
169	PARQUE_BALEIA_HOSPITAL	pas	615456,8568	7795955,004	*	
77	PARQUE_BELMONTE	pas	614930,2977	7805002,812	17	1
229	PARQUE_CILIAR_ONCA	lpk	614701,4778	7806520,371	**	1
230	PARQUE_CILIAR_ONCA	lpk	614796,4467	7807565,443	**	1
253	PARQUE_FERNAO_DIAS	pas	613729,9061	7802151,982	3	1
186	PARQUE_FERROVIARIO	lpk	614795,3033	7798978,63	**	1
125	PARQUE_GUILHERME_LAGE	pas	612783,0632	7803188,14	12	2
227	PARQUE_GUILHERME_LAGE	pas	612967,7443	7802986,632	*	
82	PARQUE_LINEAR_JOSE_CANDIDO_DA_SILVEIRA	lpk	612507,9591	7799884,648	**	1
92	PARQUE_LINEAR_JOSE_CANDIDO_DA_SILVEIRA	lpk	613667,0788	7801319,998	**	1
184	PARQUE_LINEAR_VALE_DO_ARRUDAS	lpk	614166,1895	7797914,876	**	1
86	PARQUE_MARCOS_MAZZONI	pas	613022,5532	7800330,003	1	1
89	PARQUE_MATINHA	pas	613230,6316	7800763,215	2	1
152	PARQUE_MUNICIPAL	pas	611696,6846	7796336,443	21	2
154	PARQUE_MUNICIPAL	pas	611504,7889	7796760,894	*	
79	PARQUE_NS_PIEDADE	pas	612098,9562	7804983,815	6	1
218	PARQUE_ORLANDO_DE_CARVALHO	pas	612154,1508	7799778,11	2	1
147	PARQUE_PRIMEIRO_DE_MAIO	pas	611852,7436	7804238,413	3	1
127	PARQUE_SOL	pas	613202,788	7802621,991	3	1

142	PRACA_DUQUE_DE_CAXIAS	sgs	613252,7725	7797430,406	1	1
151	PRACA_HUGO_WERNECK	sgs	612292,5297	7796557,549	2	1
251	PRACA_RUI_BARBOSA	sgs	611500,329	7797395,219	1	1
ID	UGS NAME	TYPE	POINT_X	POINT_Y	HECTARE	POINTS
185	RUA_BELEM	lpk	614845,6344	7797367,704	1	1

* continuous urban green spaces

** urban green spaces without a delimited area

Table S2. The ten most abundant bird species were recorded in the green spaces of Belo Horizonte (MG), separated by sampling points.

id	<i>Brotogeris_chiriri</i>	<i>Coereba_flaveola</i>	<i>Columba_livia</i>	<i>Columbina_talpacoti</i>	<i>Estrilda_astrild</i>	<i>Patagioenas_picazuro</i>	<i>Pitangus_sulphuratus</i>	<i>Pygochelidon_cyanoleuca</i>	<i>Thraupis_sayaca</i>	<i>Troglodytes_musculus</i>
22	4	0	0	2	5	1	2	10	0	3
61	0	1	0	2	4	1	2	5	3	4
64	4	1	10	2	5	3	6	15	2	2
67	15	1	1	3	10	4	5	10	2	2
70	3	1	0	1	5	10	8	10	4	1
77	10	1	0	0	5	2	6	5	1	3
79	2	4	15	15	15	10	4	15	2	0
82	2	1	3	2	0	1	2	4	4	0
86	5	3	0	2	0	2	1	0	2	1
89	0	1	0	0	0	0	1	0	1	3
95	0	1	0	2	0	4	2	10	2	1
100	0	2	0	0	0	0	0	0	1	1
105	0	1	0	0	0	0	0	0	0	2
112	0	1	0	0	0	0	1	0	2	1
123	0	1	1	1	0	4	6	10	2	2
125	0	2	0	2	0	3	3	5	2	2
127	0	3	0	15	15	5	5	15	3	5
131	2	2	0	0	0	2	2	0	2	2
133	5	1	0	0	10	1	2	5	3	2
141	10	2	1	5	3	6	6	10	3	2
142	15	2	15	5	0	10	2	5	4	1
147	0	1	0	1	0	5	4	5	1	1
151	6	2	10	1	0	5	2	0	2	0
152	10	4	5	0	0	6	1	0	1	2
154	10	5	15	15	0	5	5	5	2	0
160	0	1	0	5	5	0	3	0	2	2
161	2	1	0	3	5	4	4	0	3	4
165	0	1	0	0	0	1	0	0	0	0
167	0	1	0	0	0	0	0	1	0	0

169	0	2	0	0	0	0	0	0	0	0	0
184	10	1	10	4	0	3	4	0	3	0	
id	<i>Brotogeris_chiriri</i>	<i>Coereba_flaveola</i>	<i>Columba_livia</i>	<i>Columbina_talpacoti</i>	<i>Estrilda_astrild</i>	<i>Patagioenas_picazuro</i>	<i>Pitangus_sulphuratus</i>	<i>Pygochelidon_cyanoleuca</i>	<i>Thraupis_sayaca</i>	<i>Troglodytes_musculus</i>	
185	10	2	0	2	5	2	4	5	4	3	
186	2	2	15	2	10	2	3	10	2	2	
187	0	0	0	15	0	1	2	4	2	1	
188	0	1	5	3	0	10	4	4	3	2	
191	2	1	0	0	0	1	3	10	1	2	
218	0	3	0	1	5	0	6	15	4	2	
227	5	2	0	1	0	3	5	5	2	1	
228	0	0	3	1	0	2	4	5	2	1	
229	3	0	2	3	10	10	5	10	1	2	
230	0	2	5	4	5	4	3	5	2	3	
231	3	1	0	2	0	2	2	5	4	3	
233	0	0	0	0	0	0	0	0	0	1	
234	0	1	0	0	0	0	3	0	0	1	
235	3	2	0	2	0	2	0	0	3	1	
237	0	1	0	2	0	1	0	0	0	1	
238	0	0	0	0	0	0	0	0	0	1	
239	0	0	0	0	0	0	0	0	0	1	
240	0	2	0	0	0	1	0	0	0	0	
241	2	1	0	2	0	0	0	0	0	2	
242	0	2	0	1	0	1	0	3	1	3	
244	0	1	0	0	0	1	0	0	0	1	
247	0	1	0	1	5	1	0	0	1	2	
248	0	1	0	1	0	1	0	0	0	1	
249	0	1	0	5	0	0	0	0	2	2	
250	0	3	2	10	0	3	5	0	1	4	
251	4	4	15	15	0	15	5	5	0	0	
253	4	2	0	7	0	4	4	0	4	2	
271	0	1	0	1	5	0	3	2	1	2	

277	0	2	0	2	15	5	2	5	0	2
Total	153	90	133	171	147	170	152	238	99	98

Table S3. Functional attributes of bird species found in 60 sampling points in green spaces in the city of Belo Horizonte (MG). Part I.

func_traits	size (cm)	clutch_size	Nest						
			tree_nesters	shrub_nesters	primary_excavators	secondary_cavity_nesters	ground_nesters	brood_parasites	
<i>Amazona_aestiva</i>	85	4	0	0	1	3	0	0	
<i>Amazonetta_brasiliensis</i>	40	7	1	0	0	0	3	0	
<i>Ammodramus_humeralis</i>	12	3	0	0	0	0	4	0	
<i>Antilophia_galeata</i>	14	2	3	1	0	0	0	0	
<i>Aramides_cajaneus</i>	35	4	1	2	0	0	1	0	
<i>Ardea_alba</i>	87	4	2	1	0	0	1	0	
<i>Arremon_flavirostris</i>	15,5	3	0	0	0	0	4	0	
<i>Athene_cunicularia</i>	25	11	0	0	2	3	3	0	
<i>Basileuterus_culicivorus</i>	12,5	4	0	0	0	0	3	0	
<i>Brotogeris_chiriri</i>	25	5	0	0	1	3	0	0	
<i>Bubulcus_ibis</i>	50	3	2	1	0	0	1	0	
<i>Camptostoma_obsoletum</i>	10,5	2	3	3	0	0	0	0	
<i>Caracara_plancus</i>	59	2	3	0	0	0	3	0	
<i>Cariama_cristata</i>	80	2	1	3	0	0	0	0	
<i>Chaetura_meridionalis</i>	14	3	2	0	0	2	0	0	
<i>Chionomesa_lactea</i>	11	2	3	3	0	0	0	0	
<i>Chiroxiphia_caudata</i>	15	2	3	1	0	0	0	0	
<i>Chloroceryle_americana</i>	20	5	0	0	4	0	0	0	
<i>Chlorostilbon_lucidus</i>	10,5	2	3	0	0	0	0	0	
<i>Chrysomus_ruficapillus</i>	18,5	4	1	3	0	0	0	0	
<i>Clibanornis_rectirostris</i>	20	2	0	0	4	0	0	0	
<i>Coereba_flaveola</i>	11	4	3	3	0	0	0	0	
<i>Colaptes_campestris</i>	31	5	3	0	3	0	2	0	

<i>Colaptes_melanochloros</i>	30	4	3	0	3	0	0	0
<i>Colonia_colonus</i>	28	3	0	0	0	3	0	0
<i>Columba_livia</i>	34	2	0	0	0	3	0	0
<i>Columbina_squamata</i>	20	2	4	0	0	0	0	0
<i>Columbina_talpacoti</i>	18	2	3	0	0	0	0	0
<i>Conirostrum_speciosum</i>	10,5	3	4	0	0	0	0	0
func_traits			Nest					
	size (cm)	clutch_size	tree_nesters	shrub_nesters	primary_excavators	secondary_cavity_nesters	ground_nesters	brood_parasites
<i>Coragyps_atratus</i>	68	2	0	0	0	3	3	0
<i>Coryphospingus_pileatus</i>	13,3	2	2	2	0	0	0	0
<i>Corythopsis_delalandi</i>	14	2	0	0	0	0	4	0
<i>Crotophaga_ani</i>	35	7	3	0	0	0	0	0
<i>Crypturellus_parvirostris</i>	26	4	0	0	0	0	4	0
<i>Cyanocorax_cristatellus</i>	33	3	4	0	0	0	0	0
<i>Cyclarhis_gujanensis</i>	15	2	4	0	0	0	0	0
<i>Cypsnagra_hirundinacea</i>	16	3	1	3	0	0	0	0
<i>Dacnis_cayana</i>	12	2	3	0	0	0	0	0
<i>Donacobius_atricapilla</i>	23	2	0	4	0	0	0	0
<i>Dryocopus_lineatus</i>	33	2	4	0	0	0	0	0
<i>Dysithamnus_mentalis</i>	12	2	1	3	0	0	0	0
<i>Egretta_thula</i>	58	2	2	2	0	0	2	0
<i>Elaenia_cristata</i>	14,5	2	4	0	0	0	0	0
<i>Elaenia_flavogaster</i>	17	2	3	0	0	0	0	0
<i>Emberizoides_herbicola</i>	20	3	0	4	0	0	0	0
<i>Empidonomus_varius</i>	19	3	3	0	0	0	0	0
<i>Estrilda_astrild</i>	10,5	3	0	3	0	0	0	0
<i>Eucometis_penicillata</i>	16,5	2	1	3	0	0	0	0
<i>Eupetomena_macroura</i>	17	2	3	3	0	0	0	0
<i>Euphonia_chlorotica</i>	10	5	3	0	0	0	0	0
<i>Eupsittula_aurea</i>	27	3	0	0	3	1	0	0
<i>Falco_sparverius</i>	31	7	0	0	0	3	0	0

<i>Fluvicola_nengeta</i>	14	3	3	0	0	0	0	0
<i>Forpus_xanthopterygius</i>	13	7	0	0	0	3	0	0
<i>Furnarius_figulus</i>	15	2	4	0	0	0	0	0
<i>Furnarius_rufus</i>	23	4	3	0	0	0	0	0
<i>Galbula_ruficauda</i>	22	3	0	0	4	0	0	0
<i>Geothlypis_aequinoctialis</i>	14	2	0	3	0	0	3	0
<i>Glaucidium_brasilianum</i>	17	3	0	0	0	4	0	0
func_traits			Nest					
	size (cm)	clutch_size	tree_nesters	shrub_nesters	primary_excavators	secondary_cavity_nesters	ground_nesters	brood_parasites
<i>Gnorimopsar_chopi</i>	23	4	4	0	0	0	0	0
<i>Guira_guira</i>	36	10	0	3	0	0	1	0
<i>Hemithraupis_ruficapilla</i>	13	2	3	0	0	0	0	0
<i>Herpsilochmus_atricapillus</i>	11,5	2	4	0	0	0	0	0
<i>Himantopus_melanurus</i>	38	4	0	0	0	0	4	0
<i>Hirundinea_ferruginea</i>	17	2	0	0	0	4	0	0
<i>Hylophilus_amaurocephalus</i>	12,5	2	4	0	0	0	0	0
<i>Icterus_pyrrhopterus</i>	20	3	4	0	0	0	0	0
<i>Ilicura_militaris</i>	12,5	2	4	0	0	0	0	0
<i>Knipolegus_lophotes</i>	21	3	0	0	0	0	3	0
<i>Lathrotriccus_euleri</i>	13,5	3	3	0	0	0	0	0
<i>Legatus_leucophaeus</i>	15,5	2	4	0	0	0	0	4
<i>Lepidocolaptes_angustirostris</i>	20	3	0	0	0	4	0	0
<i>Leptotila_verreauxi</i>	26,5	2	2	2	0	0	0	0
<i>Machetornis_rixosa</i>	19,5	4	3	0	0	0	0	0
<i>Megaceryle_torquata</i>	40	4	0	0	4	0	0	0
<i>Megarynchus_pitangua</i>	24	3	3	0	0	0	0	0
<i>Melanerpes_candidus</i>	26,5	3	0	0	3	1	0	0
<i>Melanopareia_torquata</i>	13,5	2	0	4	0	0	0	0
<i>Microspingus_cinereus</i>	13,3	2	0	4	0	0	0	0
<i>Milvago_chimachima</i>	45	2	3	0	0	0	2	0
<i>Mimus_saturninus</i>	26	4	3	3	0	0	0	0

<i>Molothrus_bonariensis</i>	21,5	5	0	0	0	0	0	3	
<i>Myiarchus_ferox</i>	18	2	0	0	0	3	0	0	
<i>Myiarchus_tyranneulus</i>	20	5	0	0	0	3	0	0	
<i>Myiodynastes_maculatus</i>	23	3	0	0	0	3	0	0	
<i>Myiopagis_caniceps</i>	12	2	4	0	0	0	0	0	
<i>Myiothlypis_flaveola</i>	14,5	3	0	0	0	0	4	0	
<i>Myiozetetes_similis</i>	18,5	4	3	0	0	1	0	0	
<i>Nannopterum_brasilianum</i>	65,5	3	2	2	0	0	2	0	
func_traits			Nest						
	size (cm)	clutch_size	tree_nesters	shrub_nesters	primary_excavators	secondary_cavity_nesters	ground_nesters	brood_parasites	
<i>Nemosia_pileata</i>	12	2	4	0	0	0	0	0	
<i>Nycticorax_nycticorax</i>	60	4	2	2	0	0	2	0	
<i>Pachyramphus_polychopterus</i>	15	3	4	0	0	0	0	0	
<i>Passer_domesticus</i>	15	4	0	0	0	3	0	0	
<i>Patagioenas_picazuro</i>	34	1	3	3	0	0	0	0	
<i>Penelope_superciliaris</i>	64	3	4	0	0	0	0	0	
<i>Phacellodomus_rufifrons</i>	16	3	4	0	0	0	0	0	
<i>Phaethornis_pretrei</i>	14	2	3	0	0	1	0	0	
<i>Phimosus_infuscatus</i>	50	3	2	2	0	0	0	0	
<i>Piaya_cayana</i>	49,2	6	3	0	0	0	0	0	
<i>Picumnus_cirratu</i>	10	4	3	0	3	0	0	0	
<i>Pionus_maximiliani</i>	27	4	0	0	1	3	0	0	
<i>Pipraeidea_melanonota</i>	14	2	4	0	0	0	0	0	
<i>Piranga_flava</i>	18	3	3	1	0	0	0	0	
<i>Pitangus_sulphuratus</i>	23,5	4	3	0	0	1	0	0	
<i>Polioptila_dumicola</i>	12,5	4	4	0	0	0	0	0	
<i>Porphyrio_martinica</i>	31,5	4	0	0	0	0	4	0	
<i>Porphyrospiza_caerulescens</i>	12,5	2	0	4	0	0	0	0	
<i>Progne_tapera</i>	16	4	0	0	0	3	0	0	
<i>Psittacara_leucophthalmus</i>	35	4	0	0	1	3	0	0	
<i>Pygochelidon_cyanoleuca</i>	13	4	0	0	0	3	0	0	

<i>Ramphastos_toco</i>	58	3	0	0	3	1	0	0
<i>Rupornis_magnirostris</i>	41	2	3	0	0	0	0	0
<i>Satrapa_icterophrys</i>	16,5	3	3	3	0	0	0	0
<i>Serpophaga_subcristata</i>	11	2	3	0	0	0	0	0
<i>Sicalis_citrina</i>	12,3	2	0	4	0	0	0	0
<i>Sicalis_flaveola</i>	15	4	0	0	0	3	0	0
<i>Sporophila_nigricollis</i>	10,3	2	1	3	0	0	0	0
<i>Stelgidopteryx_ruficollis</i>	13	5	0	0	1	3	0	0
<i>Stilpnia_cayana</i>	14	2	3	0	0	0	0	0
func_traits			Nest					
	size (cm)	clutch_size	tree_nesters	shrub_nesters	primary_excavators	secondary_cavity_nesters	ground_nesters	brood_parasites
<i>Synallaxis_albescens</i>	14,5	3	0	4	0	0	0	0
<i>Synallaxis_frontalis</i>	15	3	0	4	0	0	0	0
<i>Synallaxis_spixi</i>	16,5	4	1	3	0	0	0	0
<i>Syrigma_sibilatrix</i>	53	3	4	0	0	0	0	0
<i>Tachyphonus_coronatus</i>	16	2	1	3	0	0	0	0
<i>Tangara_cyaniventris</i>	13	2	4	0	0	0	0	0
<i>Taraba_major</i>	19,5	2	0	4	0	0	0	0
<i>Tersina_viridis</i>	14	3	0	0	2	2	0	0
<i>Thamnophilus_caerulescens</i>	16	3	3	3	0	0	0	0
<i>Thlypopsis_sordida</i>	13	2	4	0	0	0	0	0
<i>Thraupis_ornata</i>	18	3	3	3	0	1	0	0
<i>Thraupis_palmarum</i>	17	2	3	0	0	3	0	0
<i>Thraupis_sayaca</i>	17	2	3	0	0	0	0	0
<i>Todirostrum_cinereum</i>	9,6	2	4	0	0	0	0	0
<i>Todirostrum_poliocephalum</i>	9,6	3	4	0	0	0	0	0
<i>Tolmomyias_sulphurescens</i>	14	2	4	0	0	0	0	0
<i>Trichothraupis_melanops</i>	16	2	1	2	0	1	0	0
<i>Troglodytes_musculus</i>	12,5	4	0	0	0	3	0	0
<i>Turdus_amaurochalinus</i>	25	3	0	3	0	0	0	0
<i>Turdus_leucomelas</i>	27	3	3	3	0	0	0	0

<i>Turdus_rufiventris</i>	82	3	3	0	0	0	0	0	0	0
<i>Tyrannus_melancholicus</i>	24	3	3	2	0	0	0	0	0	0
<i>Tyrannus_savana</i>	40,5	3	3	3	0	0	0	0	0	0
<i>Vanellus_chilensis</i>	37	2	0	0	0	0	0	4	0	0
<i>Veniliornis_passerinus</i>	14,5	2	0	0	4	0	0	0	0	0
<i>Vireo_chivi</i>	14	3	4	0	0	0	0	0	0	0
<i>Volatinia_jacarina</i>	10,9	3	0	3	0	0	0	0	0	0
<i>Xenops_rutilans</i>	12	2	1	0	2	2	0	0	0	0
<i>Zonotrichia_capensis</i>	13,4	3	3	3	0	0	0	3	0	0

Table S3. Functional attributes of bird species found in 60 sampling points in green spaces in the city of Belo Horizonte (MG). Part II.

	Diet									Foraging strata						body_mass (g)
	invertebrates	mammals birds	amphibians reptiles	fish	carrion	fruits	flowers nectar	seeds	plant	water	ground	understory	midhigh	canopy	air	
<i>Amazona_aestiva</i>	0	0	0	0	0	3	0	3	0	0	0	2	2	2	0	451
<i>Amazonetta_brasiliensis</i>	1	0	0	0	0	2	0	0	2	1	4	0	0	0	0	499,99
<i>Ammodramus_humeralis</i>	1	0	0	0	0	0	0	4	0	0	3	2	1	0	0	15,99
<i>Antilophia_galeata</i>	2	0	0	0	0	3	0	0	0	0	0	2	2	0	0	21,48
<i>Aramides_cajaneus</i>	3	0	1	0	0	1	0	1	0	3	3	0	0	0	0	397
<i>Ardea_alba</i>	2	1	2	0	0	0	0	0	0	3	3	0	0	0	0	871,33
<i>Arremon_flavirostris</i>	2	0	0	0	0	2	0	2	0	0	4	1	0	0	0	26,13
<i>Athene_cunicularia</i>	1	3	1	0	0	0	0	0	0	1	4	1	0	0	0	150,61
<i>Basileuterus_culicivorus</i>	4	0	0	0	0	1	0	0	0	0	0	3	1	0	0	10,5
<i>Brotogeris_chiriri</i>	0	0	0	0	0	3	1	1	1	0	2	2	1	1	0	61,6
<i>Bubulcus_ibis</i>	3	1	1	1	1	0	0	0	0	0	2	3	0	0	0	365,95
<i>Camptostoma_obsoletum</i>	3	0	0	0	0	2	0	0	0	0	0	0	4	1	0	8,1
<i>Caracara_plancus</i>	1	0	1	0	3	0	0	0	0	0	4	0	0	0	0	1078,62
<i>Cariama_cristata</i>	3	1	1	0	0	1	0	0	1	0	3	2	0	0	0	1400
<i>Chaetura_meridionalis</i>	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4	22,2
<i>Chionomesa_lactea</i>	1	0	0	0	0	0	4	0	0	0	0	2	2	2	1	4,6

<i>Chiroxiphia_caudata</i>	3	0	0	0	0	3	0	0	0	0	0	3	3	0	0	25,6		
<i>Chloroceryle_americana</i>	2	0	0	3	0	0	0	0	0	4	1	1	0	0	0	33,73		
<i>Chlorostilbon_lucidus</i>	1	0	0	0	0	0	4	0	0	0	0	0	4	1	0	3,5		
<i>Chrysomus_ruficapillus</i>	0	0	0	0	0	0	0	4	0	0	4	1	0	0	0	32		
<i>Clibanornis_rectirostris</i>	4	0	0	0	0	0	0	0	0	0	4	0	0	0	0	48		
<i>Coereba_flaveola</i>	2	0	0	0	0	0	3	0	0	0	0	4	1	0	0	10,01		
<i>Colaptes_campestris</i>	4	1	0	0	0	0	0	0	0	0	4	0	0	0	0	158		
<i>Colaptes_melanochloros</i>	4	0	0	0	0	1	1	0	0	0	0	3	3	0	0	127,27		
<i>Colonia_colonus</i>	4	0	0	0	0	0	0	0	0	0	0	2	3	0	0	18,3		
<i>Columba_livia</i>	1	0	0	0	0	0	0	3	2	0	4	1	0	0	0	354,2		
<i>Columbina_squamata</i>	1	0	0	0	0	0	0	4	0	0	4	0	0	0	0	52,9		
<i>Columbina_talpacoti</i>	1	0	0	0	0	0	0	4	0	0	4	0	0	0	0	46,04		
			Diet							Foraging strata								
			mammals		amphibians		flowers										body_mass	
			invertebrates	birds	reptiles	fish	carrion	fruits	nectar	seeds	plant	water	ground	understory	midhigh	canopy	air	(g)
<i>Conirostrum_speciosum</i>	3	0	0	0	0	1	0	1	0	0	0	3	1	1	0	0	0	8,4
<i>Coragyps_atratus</i>	0	1	1	1	3	0	0	0	0	0	0	4	0	0	0	0	0	1881,69
<i>Coryphospingus_pileatus</i>	3	0	0	0	0	0	0	3	0	0	0	0	3	2	0	0	0	21
<i>Corythopis_delalandi</i>	4	0	1	0	0	0	0	0	0	0	0	0	4	1	0	0	0	15
<i>Crotophaga_ani</i>	2	1	1	0	0	1	0	1	0	0	0	2	2	2	0	0	0	110,09
<i>Crypturellus_parvirostris</i>	2	0	0	0	0	0	0	3	0	0	0	4	0	0	0	0	0	198,99
<i>Cyanocorax_cristatellus</i>	2	0	0	0	0	2	1	0	0	0	0	3	1	1	0	0	0	178
<i>Cyclarhis_gujanensis</i>	4	0	0	0	0	0	0	0	0	0	0	0	2	2	1	0	0	28,8
<i>Cypsnagra_hirundinacea</i>	4	0	0	0	0	1	0	0	0	0	0	2	3	1	0	1	0	31,4
<i>Dacnis_cayana</i>	3	0	0	0	0	2	0	0	1	0	0	0	0	2	3	1	0	13
<i>Donacobius_atricapilla</i>	4	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	36,8
<i>Dryocopus_lineatus</i>	4	0	0	0	0	1	0	1	0	0	0	1	1	3	0	0	0	183,19
<i>Dysithamnus_mentalis</i>	4	0	0	0	0	1	0	0	0	0	0	0	2	2	1	0	0	14,87
<i>Egretta_thula</i>	3	0	2	1	0	0	0	0	0	0	3	2	0	0	0	0	0	371
<i>Elaenia_cristata</i>	3	0	0	0	0	3	0	0	0	0	0	0	2	2	2	0	0	18,2
<i>Elaenia_flavogaster</i>	3	0	0	0	0	3	0	0	0	0	0	0	1	2	2	0	0	24,8

<i>Emberizoides_herbicola</i>	2	0	0	0	0	1	0	2	1	0	3	2	0	0	0	30,1	
<i>Empidonomus_varius</i>	3	0	0	0	0	2	0	0	0	0	0	2	3	0	0	27,1	
<i>Estrilda_astrild</i>	0	0	0	0	0	0	0	4	0	0	3	3	0	0	0	8,29	
<i>Eucometis_penicillata</i>	4	0	0	0	0	1	0	0	0	0	0	4	1	0	0	27	
<i>Eupetomena_macroura</i>	1	0	0	0	0	0	4	0	0	0	0	0	3	2	1	9	
<i>Euphonia_chlorotica</i>	0	0	0	0	0	4	0	0	0	0	0	0	1	4	0	11	
<i>Eupsittula_aurea</i>	1	0	0	0	0	2	0	2	2	0	3	2	0	0	0	84,62	
<i>Falco_sparverius</i>	3	1	1	0	0	0	0	0	0	0	3	2	1	0	0	208,17	
<i>Fluvicola_nengeta</i>	4	0	0	0	0	0	0	0	0	0	3	2	0	0	0	21	
<i>Forpus_xanthopterygius</i>	0	0	0	0	0	3	0	3	0	0	3	0	1	1	0	31	
<i>Furnarius_figulus</i>	4	0	0	0	0	0	0	0	0	0	4	0	0	0	0	28	
<i>Furnarius_rufus</i>	4	0	0	0	0	0	0	1	0	0	3	2	0	0	0	46,42	
<i>Galbula_ruficauda</i>	4	0	0	0	0	0	0	0	0	0	0	3	3	0	0	26,5	
<i>Geothlypis_aequinoctialis</i>	4	0	0	0	0	0	0	0	0	0	0	4	0	0	0	13,1	
		Diet								Foraging strata							
		mammals		amphibians		flowers										body_mass	
		invertebrates	birds	reptiles	fish	carrion	fruits	nectar	seeds	plant	water	ground	understory	midhigh	canopy	air	(g)
<i>Glaucidium_brasilianum</i>	3		1		1	0	0	0	0	0	0	4	1	1	0	0	75,1
<i>Gnorimopsar_chopi</i>	2		0		0	0	0	1	0	2	1	0	3	1	2	0	65,9
<i>Guira_guira</i>	2		2		2	0	0	0	0	0	0	3	1	1	0	0	451
<i>Hemithraupis_ruficapilla</i>	4		0		0	0	0	1	0	0	0	0	0	1	4	0	11
<i>Herpsilochmus_atricapillus</i>	4		0		0	0	0	0	0	0	0	0	0	4	0	0	9,85
<i>Himantopus_melanurus</i>	4		0		0	0	0	0	0	0	4	0	0	0	0	0	176,82
<i>Hirundinea_ferruginea</i>	4		0		0	0	0	0	0	0	0	0	2	2	2	0	30,6
<i>Hylophilus_amaurocephalus</i>	3		0		0	0	0	1	0	0	1	0	0	2	2	0	11,59
<i>Icterus_pyrrhopterus</i>	3		0		0	0	0	0	2	0	0	0	0	1	2	0	35,44
<i>Ilicura_militaris</i>	3		0		0	0	0	3	0	0	0	0	0	3	3	0	12,7
<i>Knipolegus_lophotes</i>	4		0		0	0	0	1	0	0	0	0	3	3	0	0	31,8
<i>Lathrotriccus_euleri</i>	4		0		0	0	0	0	0	0	0	0	4	0	0	0	11,33
<i>Legatus_leucophaeus</i>	2		0		0	0	0	3	0	0	0	0	0	1	4	0	22,2
<i>Lepidocolaptes_angustirostris</i>	4		0		0	0	0	0	0	0	0	0	2	3	0	0	29,59

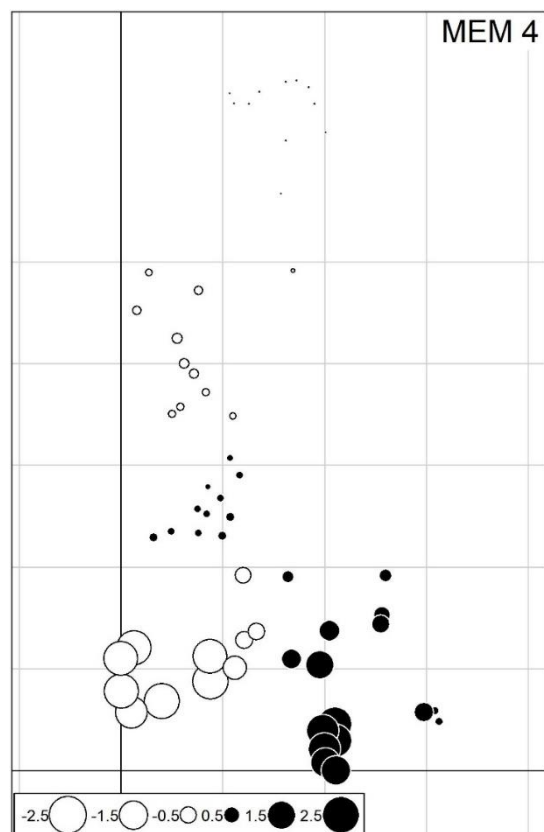
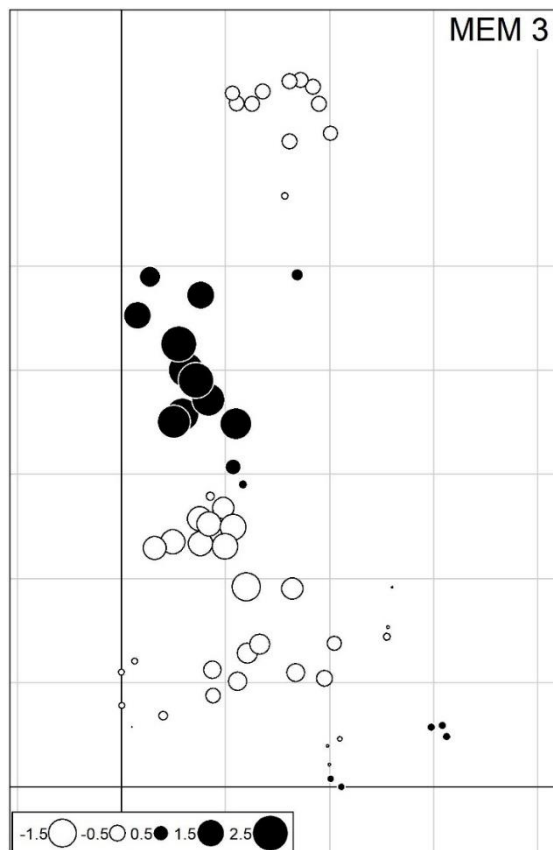
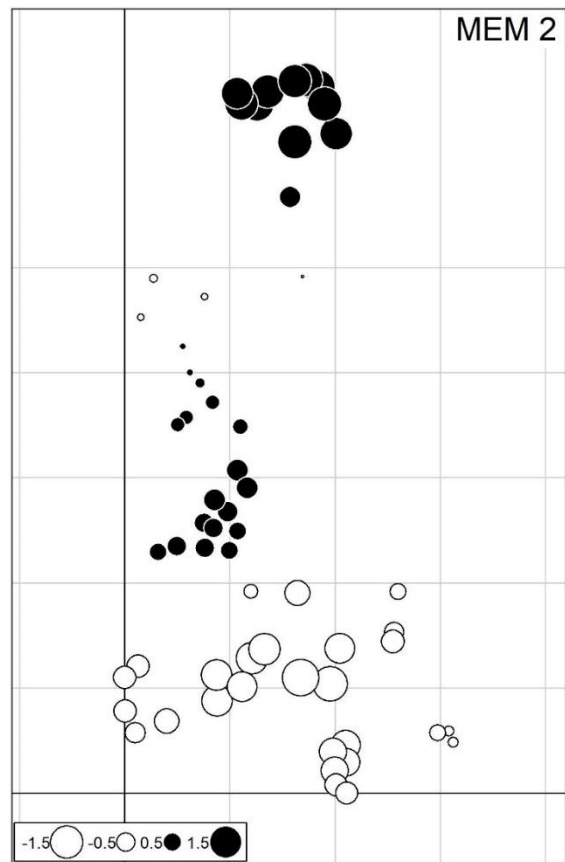
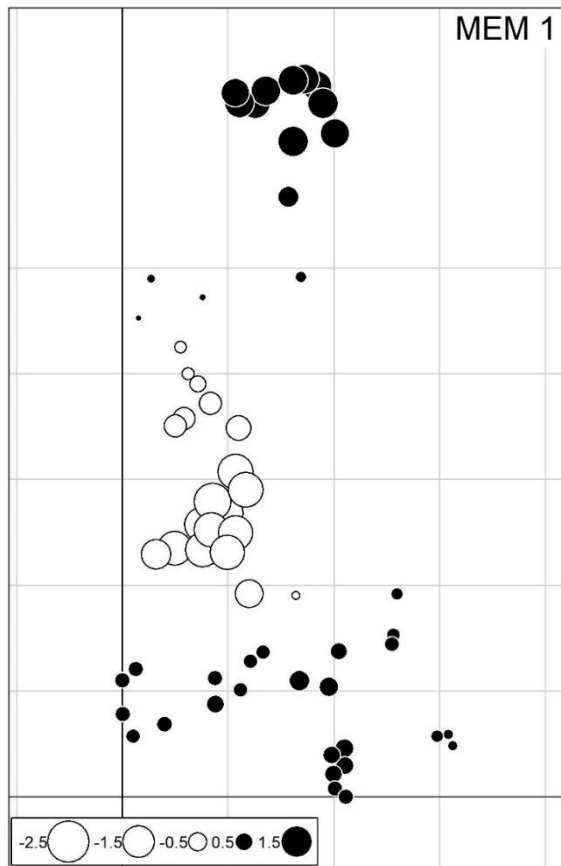
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<i>Megaceryle_torquata</i>	1	0	1	3	0	0	0	0	0	4	1	0	0	0	0	317		
<i>Megarynchus_pitangua</i>	3	0	0	0	0	1	0	1	0	0	0	1	3	2	0	69,91		
<i>Melanerpes_candidus</i>	1	0	0	0	0	3	0	1	0	0	0	3	3	0	0	108		
<i>Melanopareia_torquata</i>	4	0	0	0	0	0	0	0	0	0	3	2	0	0	0	17,2		
<i>Microspingus_cinereus</i>	2	0	0	0	0	1	0	2	0	0	1	3	2	0	0	11,6		
<i>Milvago_chimachima</i>	1	1	1	1	1	1	0	0	0	0	4	0	0	0	0	315,21		
<i>Mimus_saturninus</i>	4	0	0	0	0	0	0	0	0	0	4	0	0	0	0	63,7		
<i>Molothrus_bonariensis</i>	3	0	0	0	0	0	0	2	0	0	4	0	0	0	0	41,49		
<i>Myiarchus_ferox</i>	3	0	0	0	0	3	0	0	0	0	0	3	1	0	0	27,5		
<i>Myiarchus_tyrannulus</i>	3	0	1	0	0	1	0	0	0	0	1	4	0	0	0	35,45		
<i>Myiodynastes_maculatus</i>	2	0	2	0	0	2	0	0	0	0	0	0	4	0	0	43,2		
<i>Myiopagis_caniceps</i>	4	0	0	0	0	1	0	0	0	0	0	0	0	4	0	10,5		
<i>Myiothlypis_flaveola</i>	4	0	0	0	0	0	0	0	0	0	3	2	0	0	0	13,19		
<i>Myiozetetes_similis</i>	2	0	1	0	0	2	0	1	0	0	1	1	2	1	0	28		
			Diet							Foraging strata								
			mammals	amphibians			flowers									body_mass		
			invertebrates	birds	reptiles	fish	carrion	fruits	nectar	seeds	plant	water	ground	understory	midhigh	canopy	air	
<i>Nannopterum_brasilianum</i>	2	0				1	3	0	0	0	0	4	0	0	0	0	0	1239,29
<i>Nemosia_pileata</i>	4	0				0	0	0	0	0	0	0	0	2	3	0	0	16
<i>Nycticorax_nycticorax</i>	2	1				2	1	0	0	0	0	3	3	0	0	0	0	810
<i>Pachyramphus_polychopterus</i>	3	0				0	0	0	3	0	0	0	0	0	4	0	0	20,8
<i>Passer_domesticus</i>	1	0				0	0	0	0	3	2	0	3	3	0	0	0	26,51
<i>Patagioenas_picazuro</i>	1	0				0	0	0	2	0	2	0	2	2	2	1	0	279
<i>Penelope_superciliaris</i>	1	0				0	0	0	4	0	0	0	2	0	2	2	0	894,99
<i>Phacellodomus_rufifrons</i>	4	0				0	0	0	0	0	0	0	3	1	1	0	0	24,6
<i>Phaethornis_pretrei</i>	1	0				0	0	0	0	4	0	0	0	4	0	0	0	5,4
<i>Phimosus_infuscatus</i>	3	0				0	0	0	0	0	1	1	4	1	0	0	0	559
<i>Piaya_cayana</i>	4	0				0	0	0	0	0	0	0	0	0	1	4	0	101,98
<i>Picumnus_cirratu</i>	4	0				0	0	0	0	0	0	0	0	3	3	0	0	10,2

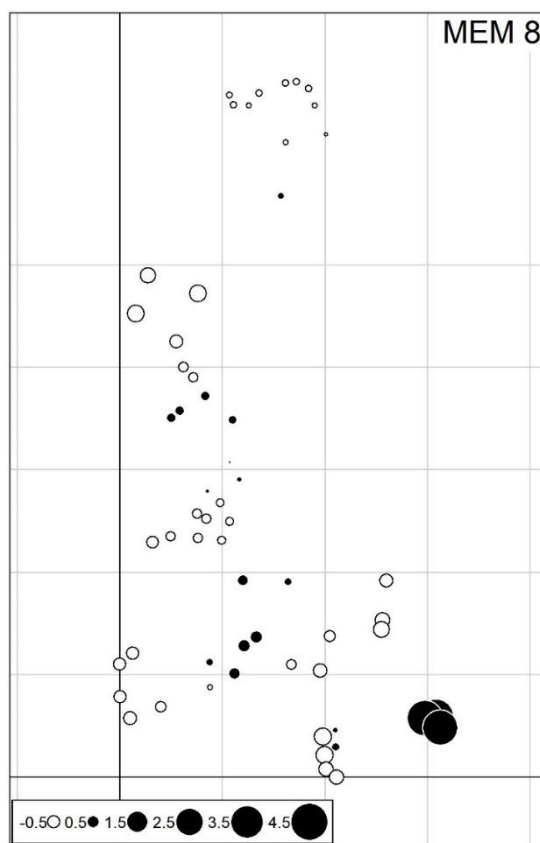
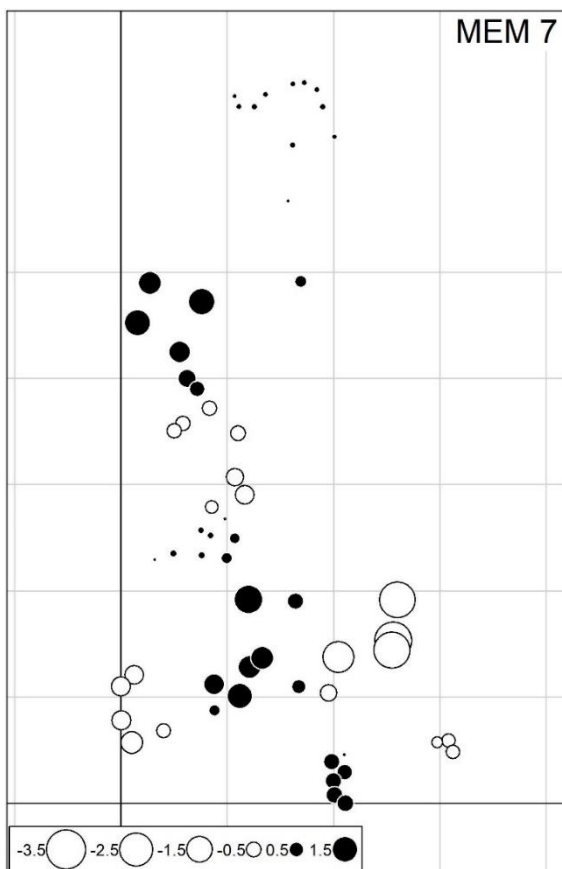
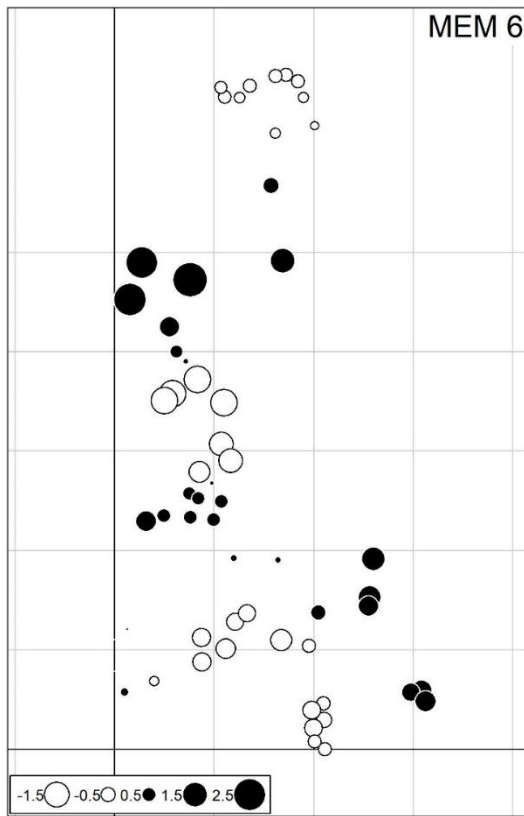
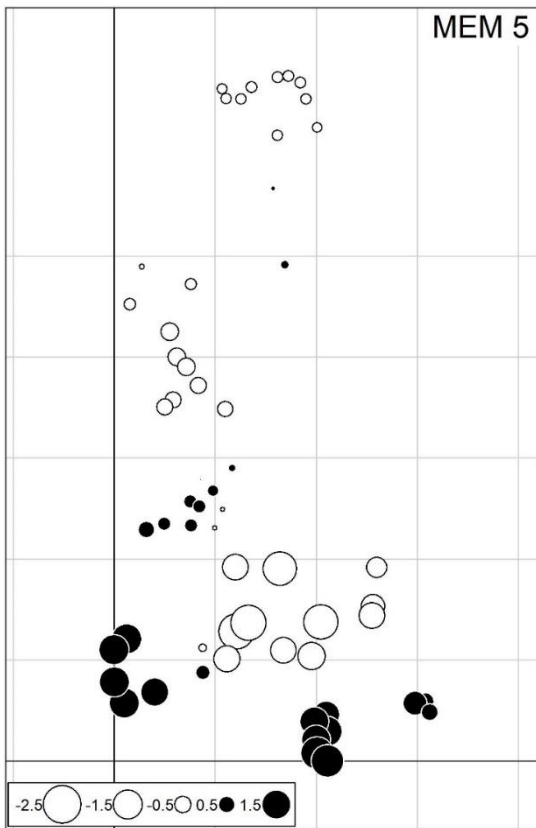
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<i>Pipraeidea_melanonota</i>	2	0	0	0	0	3	0	1	0	0	0	1	1	3	1	21
<i>Piranga_flava</i>	4	0	0	0	0	2	0	0	0	0	0	1	2	3	0	37,7
<i>Pitangus_sulphuratus</i>	2	1	1	1	0	2	0	0	0	0	3	2	1	0	0	62,85
<i>Polioptila_dumicola</i>	4	0	0	0	0	0	0	0	0	0	0	0	1	3	0	7
<i>Porphyrio_martinica</i>	2	0	0	0	0	0	0	0	3	1	2	2	1	0	0	235,06
<i>Porphyrospiza_caerulescens</i>	2	0	0	0	0	1	0	2	1	0	4	0	0	0	0	9,56
<i>Progne_tapera</i>	4	0	0	0	0	0	0	0	0	0	0	2	1	1	2	32
<i>Psittacara_leucophthalmus</i>	1	0	0	0	0	2	0	2	2	0	1	1	2	1	0	158
<i>Pygochelidon_cyanoleuca</i>	4	0	0	0	0	0	0	0	0	0	0	0	1	0	3	9,7
<i>Ramphastos_toco</i>	1	1	0	0	0	3	0	0	0	0	1	1	1	3	0	617,99
<i>Rupornis_magnirostris</i>	2	2	2	0	0	0	0	0	0	0	2	2	2	0	0	269
<i>Satrapa_icterophrys</i>	4	0	0	0	0	0	0	0	0	0	0	3	2	0	0	21,5
<i>Serpophaga_subcristata</i>	4	0	0	0	0	0	0	0	0	0	0	2	2	2	0	6,6
<i>Sicalis_citrina</i>	0	0	0	0	0	0	0	4	0	0	1	3	2	0	0	11,6
<i>Sicalis_flaveola</i>	0	0	0	0	0	0	0	4	0	0	2	3	0	0	0	15,4
<i>Sporophila_nigricollis</i>	1	0	0	0	0	0	0	4	0	0	2	3	0	0	0	9,6
<i>Stelgidopteryx_ruficollis</i>	4	0	0	0	0	0	0	0	0	0	0	2	3	0	0	16,1
		Diet								Foraging strata						
		mammals	amphibians				flowers									body_mass
		birds	reptiles	fish	carrion	fruits	nectar	seeds	plant	water	ground	understory	midhigh	canopy	air	(g)
<i>Stilpnia_cayana</i>	1	0	0	0	0	0	4	0	0	0	0	2	2	2	0	18
<i>Synallaxis_albescens</i>	4	0	0	0	0	0	0	0	0	0	2	3	0	0	0	11,2
<i>Synallaxis_frontalis</i>	4	0	0	0	0	0	0	0	0	0	1	4	0	0	0	14
<i>Synallaxis_spixi</i>	4	0	0	0	0	0	0	0	0	0	1	4	0	0	0	12,6
<i>Syrigma_sibilatrix</i>	3	0	1	1	0	0	0	0	0	4	1	0	0	0	0	463
<i>Tachyphonus_coronatus</i>	3	0	0	0	0	1	0	1	0	0	0	1	2	2	0	29,3
<i>Tangara_cyanoventris</i>	3	0	0	0	0	3	0	0	0	0	0	1	2	2	0	16,5
<i>Taraba_major</i>	3	1	1	0	0	0	0	0	1	0	2	2	1	0	0	59,2
<i>Tersina_viridis</i>	2	0	0	0	0	3	0	0	0	0	0	1	3	2	0	29
<i>Thamnophilus_caerulescens</i>	4	0	0	0	0	1	0	1	0	0	0	3	2	0	0	21,1
<i>Thlypopsis_sordida</i>	3	0	0	0	0	2	0	1	0	0	0	0	3	2	0	17

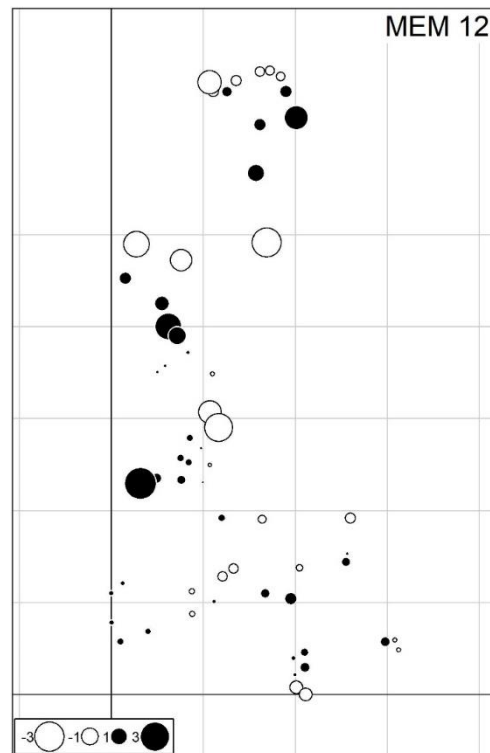
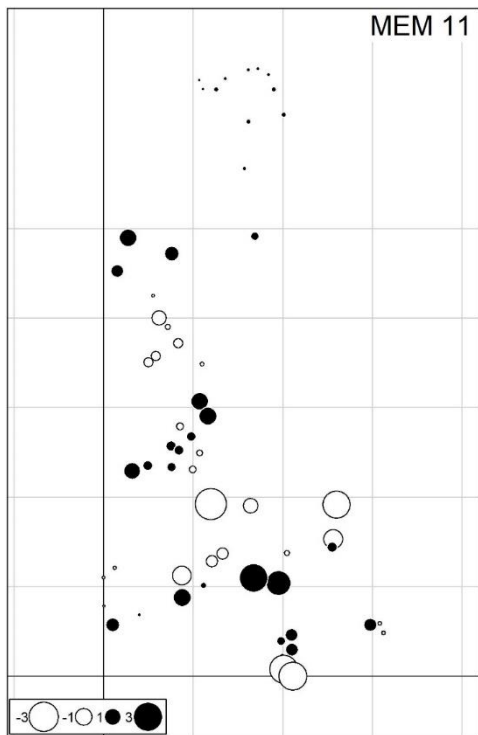
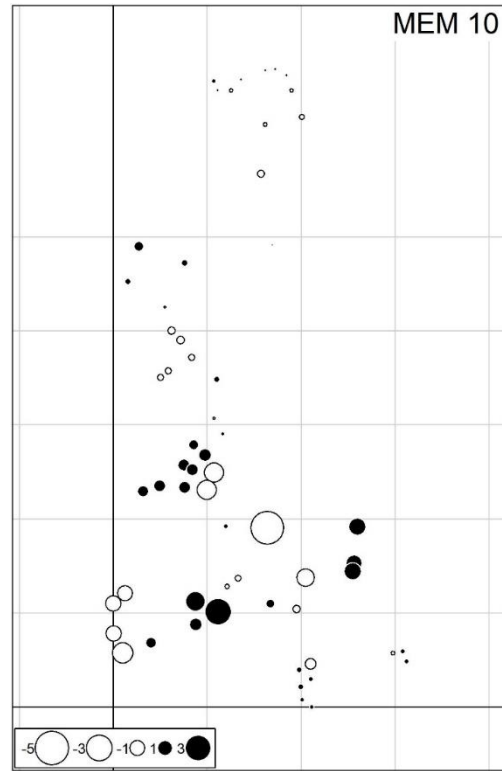
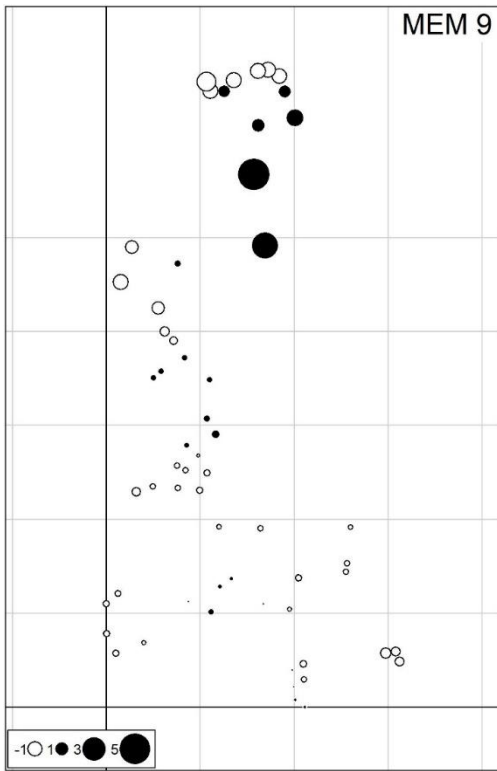
<i>Thraupis_ornata</i>	1	0	0	0	0	4	0	0	0	0	1	1	1	3	0	33
<i>Thraupis_palmarum</i>	1	0	0	0	0	3	1	1	0	0	0	0	1	3	1	39
<i>Thraupis_sayaca</i>	1	0	0	0	0	3	0	2	0	0	1	0	1	3	0	32,49
<i>Todirostrum_cinereum</i>	4	0	0	0	0	1	0	0	0	0	0	2	2	2	0	6,29
<i>Todirostrum_poliocephalum</i>	4	0	0	0	0	0	0	0	0	0	0	2	3	0	0	6,96
<i>Tolmomyias_sulphurescens</i>	4	0	0	0	0	1	0	0	0	0	0	2	3	0	0	14,3
<i>Trichothraupis_melanops</i>	3	0	0	0	0	1	0	1	0	0	2	2	1	1	1	22,58
<i>Troglodytes_musculus</i>	4	0	0	0	0	0	0	0	1	0	0	4	0	0	0	10,85
<i>Turdus_amaurochalinus</i>	2	0	0	0	0	3	0	0	0	0	1	1	2	2	0	57,9
<i>Turdus_leucomelas</i>	3	0	0	0	0	2	0	0	0	0	3	1	1	0	0	69,1
<i>Turdus_rufiventris</i>	3	0	0	0	0	3	0	0	0	0	4	0	0	0	0	69,44
<i>Tyrannus_melancholicus</i>	4	0	0	0	0	0	0	0	0	0	0	0	3	3	0	37,4
<i>Tyrannus_savana</i>	3	0	0	0	0	2	0	0	0	0	3	3	0	0	0	31,9
<i>Vanellus_chilensis</i>	4	0	0	1	0	0	0	0	0	1	4	0	0	0	0	327
<i>Veniliornis_passerinus</i>	4	0	0	0	0	0	0	0	0	0	0	2	2	2	0	32,1
<i>Vireo_chivi</i>	3	0	0	0	0	1	0	1	0	0	0	0	1	4	0	15
<i>Volatinia_jacarina</i>	2	0	0	0	0	1	0	2	1	0	4	0	0	0	0	9,7
<i>Xenops_rutilans</i>	4	0	0	0	0	0	0	0	0	0	0	1	4	0	0	11,2
<i>Zonotrichia_capensis</i>	2	0	0	0	0	0	0	3	1	0	4	0	0	0	0	20,31

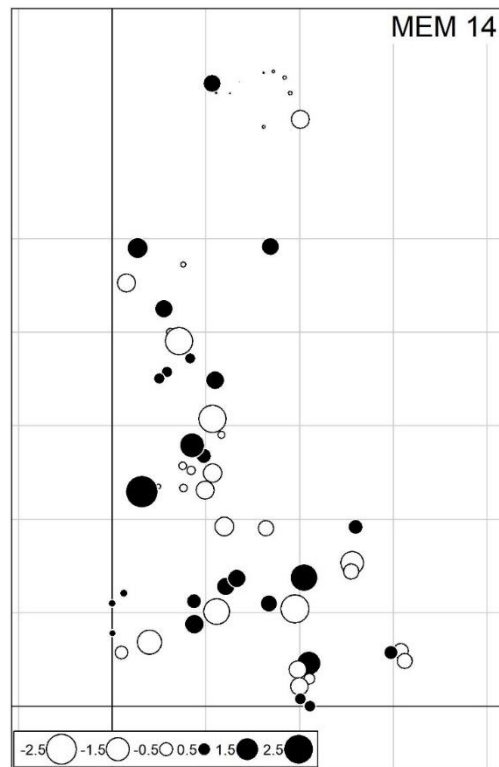
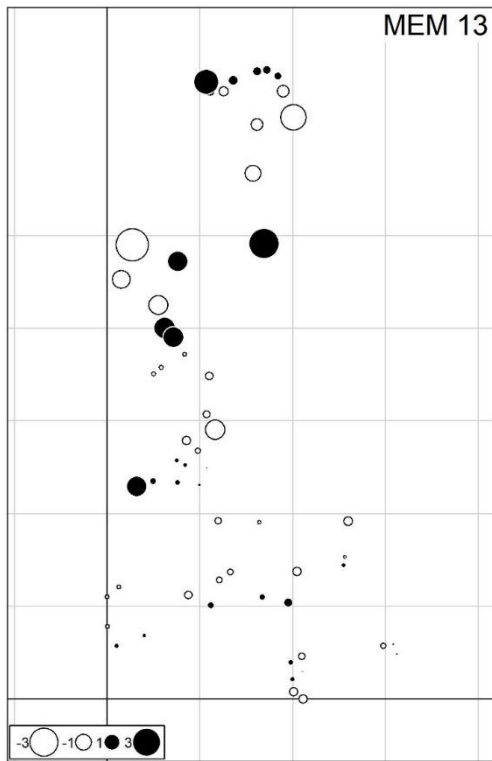
Supplementary Material II – MEM

Distance-Based Moran's Eigenvector Maps – dbMEM









Interlúdio parte III: Flanar como uma ave

Recentemente eu uma conversa com uma pessoa que acho bastante perspicaz e que tem me ajudado com alguns comentários bem pertinentes sobre a pesquisa que desenvolvo (momento quebra da quarta parede, estilo Fleabag, “achou que não iria aparecer aqui, Bárbara?”). Voltando, ela me disse que o meu projeto é como eu me relaciono com a cidade, andando por todos os lados e observando todas as mudanças e os espaços que a cidade proporciona aos meus olhos. Talvez eu tenha floreado um pouquinho, mas de fato faz muito sentido, e foi isso que me deu a ideia para este texto aqui, lembram da eterna caderneta e a mania de anotar todas as coisas? Dito isso, o que de fato era a ideia do projeto como um todo? De uma certa forma era realmente ver dinossauros pela cidade e de quebra conhecer mais áreas verdes que eu nunca tinha entrado. Pois é jovem padawans, escrever um projeto pode te permitir ir a lugares que sem ele vocês jamais entrariam ou pelo menos facilita. E eu adoro andar pela cidade, como diria um grande amigo rabugento Marcos, o ato de flanar, sim, andar por aí e ver os detalhes seja do que mudou ou do que permanece mesmo em ruínas, é ver as cores, cheiros e achar cantos gostosos para repousar ou beber (estamos em BH, certo?). Agora pensem nisso como uma ave, como ela percebe essa cidade, o que a atrai de um lado para o outro, e ainda, porque algumas estão no ponto A mas não são vistas no ponto B? Teria algo que a gente pode fazer para facilitar essas conexões? Existem milhares de perguntas que podem seguir infinitamente e isso é o que torna a ciência o que ela é, e pelo menos essa é minha razão por fazer o que faço, e apesar de toda a loucura que as coisas podem ficar as vezes, difícil me ver fazendo outra coisa. Sem perder completamente o fio da meada aqui, minha ideia ao longo do andar do projeto foi de fato andar procurando passarinhos, medindo tudo que via na frente e anotando (sempre) tudo que via ou que chamava minha atenção. E ao procurar por esses bichos incríveis encontrei muito mais da cidade do que imaginava, achei locais super escondidos, senti de perto como a terra é algo que mexe com a vida de todo mundo e aceitei meu lado ativista ambiental de vez dando minha cara a tapa como pesquisador que se envolve nas lutas ambientais. E mais, ao procurar pela visão das aves sobre a cidade eu também encontrei outras visões, das pessoas que também vivem nela, dos gestores que lidam com outro plano de problemas, e como esses dois atores podem até não conversar, mas são importantes de serem ouvidos, pois pesquisar ecologia urbana é mais do que simular uma coleta ou uma análise do que seriam feitas em qualquer parque nacional. Existem variáveis que tornam as cidades únicas e que sim, as transformam em um ecossistema em constante transformação. Não pretendo fazer dessa crônica uma ode à vida urbana, mas o quanto mais a gente entende os mecanismos e os atores envolvidos nesse contexto melhor será sua saída e quem sabe, mais aplicável também. Exaltei alguns detalhes, e de fato vi coisas muito legais, embora também tenha ficado assustado em alguns momentos, como não poder chegar no ponto por causa de batida policial ou precisar literalmente de ficar ao lado do guarda municipal para não ter minhas

coisas mexidas. E claro, o fatídico dia do ataque das formigas em pleno metrô, foi bizarro, como é possível doer tanto, e olha que também fui atacado por uma ave, um *Mimus* bravo numa praça no Centro. Pareceu uma vida tudo até aqui, e de fato foi, e nas palavras do Peter Pan “que se é para morrer que morrer seja uma grande aventura”.

Capítulo 4: Beyond birds' conservation: Engaging communities for the conservation of urban green Spaces

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Abstract

Urban green spaces are important for birds conservation, functioning as a buffer against the impacts of human actions on their surroundings. However, green spaces also provide several benefits to humans, such as the improvement of climatic conditions and a more intimate contact with nature. In this point of view, divided into three sections, we describe how ornithological research in a peri-urban vegetation patch in a tropical metropolis culminated in an environmental protection movement. This vegetation patch is composed of a mosaic of typical phytophysionomies of the transition zone between two biodiversity hotspots: Cerrado and Atlantic Forest. Its vegetation presents characteristics that indicate high degradation, but the region still harbors 108 bird species (including threatened and endemic species), suggesting that even under intense impacts, the area presents characteristics of resilience to shelter the local biodiversity. Given these findings, we discuss the potential of this urban green space for scientific research, environmental education, and birdwatching. We highlight the possibility of influencing community engagement in the conservation of the area, whether for the preservation of charismatic species or for leisure and educational activities. Reducing the gap between academia and society can assist in the conservation of urban green spaces, especially in a region that presents high social environmental vulnerability.

Keywords: urban ecology; environmental education; social environmental; citizens participation

Introduction

Urban green spaces have been identified as fundamental for biodiversity conservation as they represent heterogeneous environments modulated by human management (Kowarik and von der Lippe 2018), and provide habitat for several species, including threatened ones (Ives et al. 2016, Luna et al. 2018). At the same time, green spaces and the natural heritage, in general, are public properties that are fundamental for human quality of life due to their role in the maintenance of public health and climatic stability through the realization of ecosystem services (McDonald et al. 2013). There is a close relationship between the existence of green spaces and human well-being, especially due to the associated ecosystem services (such as pollution absorption and attenuation of climatic conditions), which brings even more importance to the preservation, maintenance, and restoration of these areas (Tratalos et al. 2007, McDonald et al. 2013).

In the context of urban development, areas in the vicinity of the city, such as peri-urban vegetation patches, can be strategic from ecological and biodiversity conservation perspectives, since their location can form a continuum of vegetation with rural areas, in addition to presenting lower human population density (Fournier et al. 2020). This proximity could facilitate the movement of organisms into and out of the urban matrix (Bhakti et al. 2021) and serving as a shelter for a larger pool of species compared to the central regions of the city (Escobar-Ibáñez et al. 2020). However, from an urbanistic perspective, peri-urban regions may represent areas with higher rates of illegal settlements and unplanned urban growth (Aguilar 2008), resulting in environmental degradation, either through the pollution of water courses or the reduction of native vegetation (Yankson and Gough 2013).

Due to their important ecological role in cities, there is a growing interest to understand the characteristics of urban green spaces that can maximize their positive influences on the integrity of urban ecosystems (Zipperer and Pickett 2012), and the necessary actions to reduce the negative human impacts caused by urban growth. Since urban ecology also considers the human dimensions into biodiversity research, it is possible to adopt interdisciplinary approaches (such as architecture, urbanism, and sociology) to explore, besides the influences of urban green spaces on biodiversity and human quality of life, how people may be engaged in their preservation. Interdisciplinarity is important, especially in human dominated ecosystems, because the value of landscapes, forests, water resources, and the flora and fauna are not easily measured (Eriksson et al. 2018). Their importance goes far beyond their exploitation as resources, reaching the affective side of those who know and live near to or within them (Silva et al. 2022). Furthermore, by assessing the community engagement in urban environmental issues, it is possible to evaluate how different actors (local community, academy, economic sectors) may influence the formulation of public policies (Pena et al. 2017a).

In this point of view, divided into three sections, we describe how ornithological research enhanced community engagement for the preservation of a peri-urban vegetation patch in a tropical metropolis (locally known as the Izidora Forest). The academic activities in the area culminated into an environmental protection movement formed by actors from different sectors of society (academics, neighborhood associations, environmental activists and educators). First, we present the Izidora Forest, the vegetation patch that we hope can be protected through the creation of a new urban green space. Then, in section two, we describe the results of the bird survey we conducted in Casa de Francisco, a religious institution that has been supporting scientific research and developing environmental educational activities within the boundaries of the Izidora Forest. Finally, in section three, we address the relationships between academic research, decision-makers, and communities, and how the combination of these three actors can influence the search for the protection of urban green spaces.

Section 1: The Izidora Forest

The Izidora Forest is a peri-urban vegetation patch located in the northern portion of Belo Horizonte, Minas Gerais state capital, Southeastern Brazil. The area comprehends a complex ecological system, formed by a mosaic of grassland and forest patches and several water courses with different levels of conservation, in addition to peripheral human settlements ranging from traditional communities, religious institutions, and irregular occupations (Senra 2018). The area represents the last non-occupied portion of the municipality's territory, and it is located nearby the state administrative district. Thus, in addition to the great socio-environmental relevance, there is an intense real estate speculation in the region, increasing environmental degradation and threatening the local biodiversity (Horta et al. 2018, Bhakti et al. 2020).

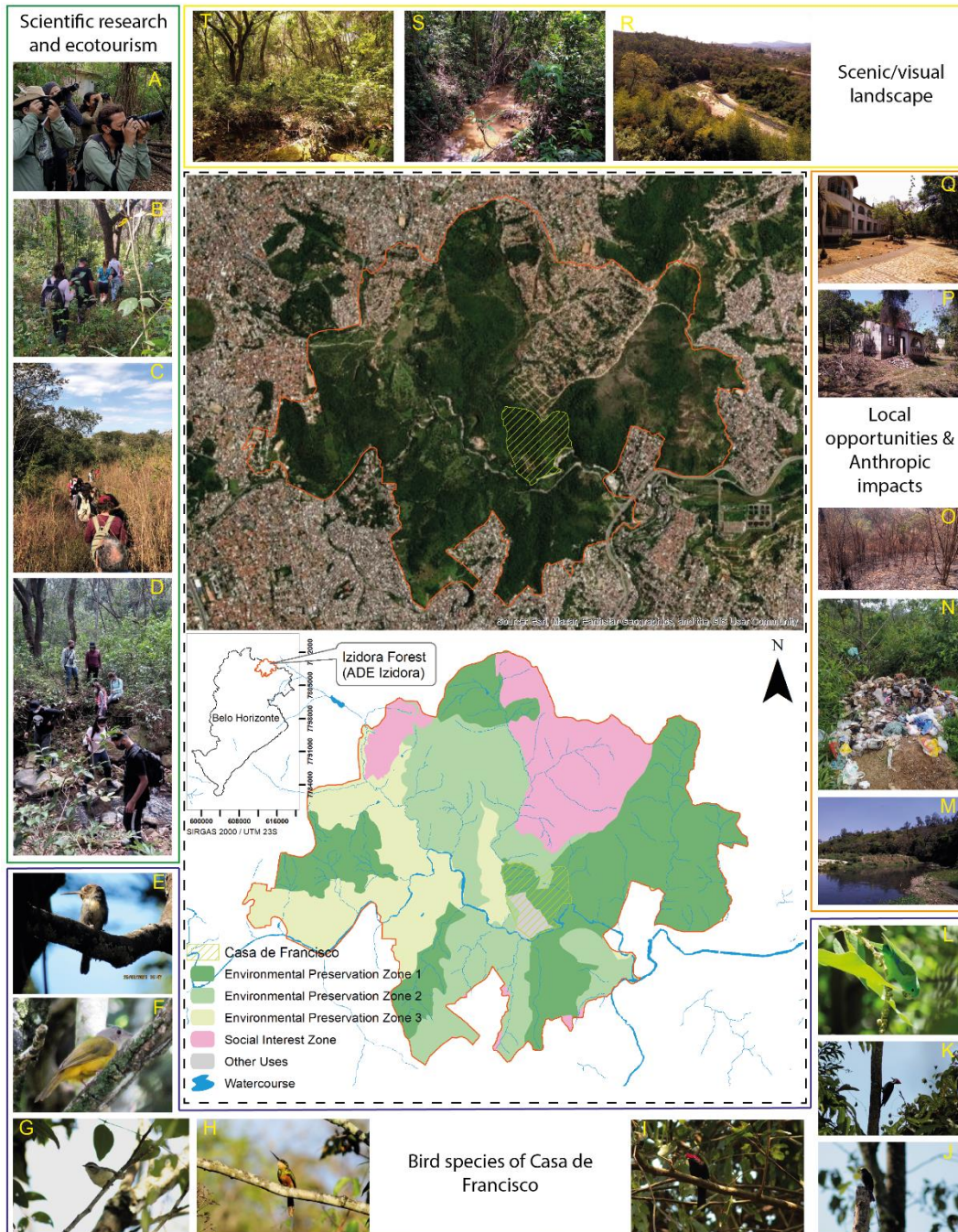


Figure 1. Infographic of the Casa de Francisco region, municipality of Belo Horizonte, state of Minas Gerais, Brazil. In the center is delimited the Izidora Special Attention Area (ADE Izidora) - or Izidora Forest, being above the satellite image with the location of Casa de Francisco and below the the Izidora Forest land cover with the macrozoning according to the Belo Horizonte Municipal Master Plan. Side images counterclockwise - Scientific research and ecotourism: (A) Birdwatching, (B-D) Ecotourism Trails; Bird species of Casa de Francisco: (E) *Jacamaralcyon tridactyla*, (F) *Eucometis penicillata*, (G) *Basileuterus culicivorus*, (H) *Galbula ruficauda*, (I) *Antilophia galeata*, (J) *Colonia colonus*, (K) *Dryocopus lineatus*, (L) *Forpus xanthopterygius*; Local opportunities & Anthropic impacts: (M) Water pollution, (N) Illegal dumping, (O) Wildfires results, (P-Q) Physical structure of Casa de Francisco as an opportunity for restoration and ecological use; and Scenic/visual landscape (R-T). Credits: ML (A); CH (E, F, L); TB (G-K, M-T); and Parque Izidora Movement (PIM) archives (B-D).

The Izidora Forest is not classified as a protected area (e.g.: parks or reserves)

according to the municipal government (Belo Horizonte 2019). However, according with the Belo Horizonte macro-zonig, the area is called the Izidora Special Attention Area (originally “Área de Diretrizes Especiais”, ADE Izidora) with 935 ha (Fig. 1). An ADE is a public policy instrument determined by the Belo Horizonte Municipal Master Plan that aims to delimit a region that needs stricter rules regarding proposals for human occupation (Belo Horizonte 2019). The ADE Izidora contains two main classes of micro-zoning (named zoning). The first is related to relevant areas for potential environmental protection (which is subdivided into three levels of protection - Fig. 1). These zones do not represent parks or other types of protected areas but indicate that human occupations should be sustainable and reduce their impacts on the local native vegetation and water resources. The second class of this micro-zoning describes regions with high social vulnerability, i.e. mostly areas irregularly occupied that have social problems such as lack of public sanitation and risk of landslides (Fig. 1). This classification is important because the northern region of Belo Horizonte has one of the lowest Human Development Indexes - IDHM (PBH 2018) in the municipality. Thus, the macro-zoning can assist in the definition of public policies that may bring social justice in association with high environmental quality.

The environmental relevance attributed to the Izidora Forest area is due to the large area of continuous native vegetation in addition to the presence of several watercourses and springs with different levels of conservation. The combination of vegetation and the presence of water is already recognized by the municipality as important for the city's climate, with the Izidora Forest being included in a climate vulnerability study for 2030 (SMMA 2014). The high vegetation amount of the area contributes to a more balanced atmospheric moisture and temperature, reduces the intensity of floods (providing soil absorption of rainwater), and prevents landslides in the region and its surroundings (Depietri et al. 2012). Although its environmental importance is recognized, the absence of formal protected areas in Izidora Forest prevents conservation measures from being implemented, such as an adequate structure for visitation, action plans for the protection of species, and monitoring of several anthropogenic impacts such as illegal logging, garbage disposal, and fire outbreaks (Luck 2007) (Fig. 1).

Section 2: The birds of Casa de Francisco

Casa de Francisco for Integral Ecology (hereafter Casa de Francisco) was founded in 2020 as an environmental education unit located in the interior of Izidora Forest and belonging to the local archdiocese. The Casa de Francisco is an area of approximately 30 ha that was used as a hospital for the treatment of tuberculosis during the first decades of the 20th century and later as a nursing home, being unused for almost ten years (Senra 2018). Today the Casa de Francisco works as an environmental education center and is legally inserted within the ADE Izidora.

Among the groups of organisms most associated with studies on the effects of urbanization on biodiversity, birds stand out as good bioindicators (Morelli et al. 2021). Based on ornithological research developed in cities, it is highlighted the importance of urban green spaces for birds' conservation, ranging from parks and large remnants of native vegetation, to more urbanized habitats such as squares, vacant lots, and wooded streets (Pena et al. 2017b, 2023, Villaseñor et al. 2020). We conducted a survey for the avifauna of Casa de Francisco between October 2020 and September 2021. Bird surveys consisted of regular visits, and in each of them, we used a different trail to cover a larger tract of forest. Casa de Francisco has several trails that connect the administrative buildings to the forested areas and to two nearby streams. We used the trails in an exploratory way, together with point counts for observation with binoculars and photography. We also recorded the vocalization of the birds we found. Fieldwork was always done in the morning (between 6 am and 10 am).

We recorded a total of 108 bird species only in the Casa de Francisco forest patch (Table 1), which represents 85.71% (126) of all species ever recorded in the entire Izidora Forest area during previous studies (Bhakti et al. 2020). Among the observed species, one is endemic to the Cerrado and four to the Atlantic Forest biomes (Table 1). We also recorded the Three-toed Jacamar (*Jacamaralcyon tridactyla*), which is considered Vulnerable by the International Union for Conservation of Nature and is the only globally threatened species registered in the whole Izidora Forest (BirdLife International 2020). Other species, such as the Gray-headed kite (*Leptodon cayanensis*) and the Gray-headed tanager (*Eucometis penicillata*) are considered rare in urban landscapes to their specificity to some habitat features, such as the availability of larger tracks of natural vegetation (Beninde et al. 2015, Canedoli et al. 2018). In the Casa de Francisco area, we also recorded species associated with other specific habitat features, such as aquatic species (e.g.: Green Ibis - *Mesembrinibis cayennensis*).

The Casa de Francisco, probably due to its location in a peri-urban vegetation patch comprised by a mosaic of phytophysiognomies typical of the ecotone between the Cerrado and the Atlantic Forest, is inhabited by a large diversity of species from both biomes - including endemic species (Silva 1995, Vale et al. 2018) (Table 1). The importance of the Casa de Francisco for the occurrence and maintenance of bird species in Belo Horizonte and its surroundings is remarkable, despite its small size and the environmental degradation of the area. Although not all the species described here are classified under a threatened status, all of them require some habitat features for their occurrence in an urbanized area. Thus, Casa de Francisco is able to provide a high heterogeneity of environments, harboring a high proportion of the bird diversity that inhabits the whole Izidora Forest. Through the knowledge about which species occur in the region, their ecology, and natural histories, it is possible to determine public policies and actions to allow them to occupy the area in the long long-term, such as the preservation of both grassland and forest patches, reducing the fast occupation of the Cerrado vegetation in Izidora Forest (Bhakti et al 2020). Such actions would benefit not

only the bird community, but also other animal groups that need different habitat types to thrive in a region that borders one of the largest Brazilian urban landscapes. By preserving the Izidora Forest and its biodiversity, the area would be able to provide several ecosystem services not only for the surrounding communities, but for the whole city, such as pollution control, the protection of water bodies, and be a new focus for sustainable economic activities, such as ecotourism and birdwatching. Thus, Casa de Francisco, due its high ecological quality, despite degradation, has been a source of encouragement and engagement for different environmental protection movements of the Izidora Forest's surrounding communities.

Section 3: Strengthening ties between academic research and society

Here, we present how communities that live in the surroundings of Casa de Francisco got engaged in the preservation of the whole Izidora Forest area during our research on the local bird diversity. We also describe difficulties we faced during the process of community engagement, since we expected to turn the results of the bird survey into environmental education actions and conservation basis for the whole Izidora Forest.

Due to the locally endangered species we found in the area, the Three-toed Jacamar, we started a working group with members of the Ornithology Laboratory of the Federal University of Minas Gerais and the Casa de Francisco with the aim of evaluating the possibilities of legally enhancing the protection of the area with the help of different stakeholders: neighborhood associations, environmental organizations, schools, companies, religious institutions, and traditional communities. We invited representatives to a meeting that led to the creation of an environmental protection group called Parque Izidora Movement (PIM). The PIM, whose symbol is the Three-toed Jacamar perched in the shoulder of a quilombola woman, aims to seek the creation of a protected area in the region of Izidora Forest. Due to the high bird species diversity and easy accessibility for all sorts of people, the Izidora Forest and the Casa de Francisco can be considered with high potential for environmental education activities, ecotourism, and birdwatching. The latter has already proved to be a hobby that is friendly to beginners, has a low ecological impact, and helps conservation projects (Castillo-Aguilar and Roa-Angulo 2021). Attracting visitors to the region would provide visibility to the environmental movement and demands of the local populations.

Since 2020, several meetings and events have been held at the Izidora Forest, such as tracks through local walking trails and seminars, with the goal of making the surrounding communities aware of the importance of protecting this vegetation patch, and taking this message to the Belo Horizonte municipal government. The core of the PIM is based on an idea widespread in urbanism theories (Jacobs 2011), which highlights the importance of occupying a space to create an identity and thus increasing its value for the local communities and consequently their engagement in its protection. This involvement of the surrounding communities is an important step towards the creation

of new protected areas, especially when they are supported by scientific research (Constantino 2020). PIM's involvement also occurred in other spheres, interacting with other environmental and social movements that operate in the region with complementary goals. Different groups emerged to fight and demand a more sustainable development of the region due to the presence of critical social environmental issues in the Izidora Forest area. The group “Deixe o onça beber água limpa” (or “Let the Jaguar River drink clean water”) is a collective of residents who are interested in the ecological cause and in an urban development plan that considers the needs of local communities. Another example is the “Quilombo das Mangueiras” nearby Casa de Francisco, a traditional black community that occupied the Izidora Forest area at the end of the XIX century (CBH Velhas 2021), and is also essential for protecting social interests in the region as their movement has been focused on solving severe social problems, such as the lack of public sanitation and urban infrastructure and protecting the local human heritage.

Even if the local community desires to create a green space, it is the public administration that has the function of managing and/or creating urban green spaces through elected representatives. Although they do not always have access to scientific data, they should work in collaboration with researchers to obtain adequate information about the urban ecosystem (Parris et al. 2018). As members of PIM, we participated in several meetings with representatives from the municipality (mainly from the Secretary of Environment), adding technical knowledge regarding the importance of preserving the Izidora Forest area for the urban biodiversity (with focus on the bird community) and for the human population. Despite the positive feedback, our meetings still did not result in any action from Belo Horizonte municipality for the creation of an urban green space or conservation unit in the Izidora Forest. PIM also approached city council representatives to expose the importance of creating a green space in the Izidora Forest. We also received positive feedback from some of the aldermen we met, but a bill to create a new law is a long process that needs the approval of several city council members and sectors of the society. The main issue regarding actions from stakeholders is that they are elected or appointed every four years, which hinders the continuity of actions such as the creation of green space in a region that is under high social and economic pressure.

For the sustainable use and conservation of the water resources in the Izidora Forest region, a collaboration between the local communities and the municipal government is of paramount importance. The fast and disorderly urban population growth in the Izidora Forest area already culminated in the destruction or degradation of the riparian vegetation (Bhakti et al 2020), which may have led to the contamination of streams by domestic sewage. More studies, especially regarding other taxa and the physical environment of Izidora Forest, are still needed to properly measure the degree of degradation of the whole area and to give support to the creation of a green space. For future urban interventions of the Izidora Forest, we hope our research in Casa de

Francisco to assist in reducing the social and ecological vulnerabilities and the lack of public infrastructure by bringing education, attention, resources, and closure to the problems associated with the area while conserving the important ecosystem services provided by this remnant of native vegetation, which still harbors diverse fauna and flora.

As researchers, we aim to reduce the gap between scientific knowledge and public action, and we understand that it is a process that requires interacting with a variety of stakeholders. Thus, we would like to highlight some general difficulties that researchers may face when taking their work outside the academic environment:

- As researchers, one of our main difficulties is translating information for a broader and diverse audience. Scientific knowledge can be useful during interactions with schools and the local community, but it is not easily understandable by the general public, due to its specific and sometimes complicated vocabulary and technicalities (Pedretti 1999). Thus, PIM have been promoting lectures during the events and maintaining social media profiles to talk about birds, their characteristics and ecological roles in urban green spaces, and the importance of the conservation of the native vegetation in the Izidora Forest in accessible vocabulary and using photos and figures (such as land cover maps of the Izidora Forest) as supporting material.

- It is necessary to understand that the pace and expectations are different for each social sector involved (Cunha et.al 2017). In academia it takes time – often years – to develop and conclude research (conducting fieldwork, analyzing data, writing reports, and publishing papers). Therefore, within the scale of government cycles (four years in the case of the three executive spheres in Brazil – municipal, state, and federal) it is difficult to provide consistent results and to give feedback to a community that sometimes needs fast information to help in the fight for the protection of a green space. In the same way, decision-makers work under regulatory legislation and a political agenda that often changes after each four-year cycle. Our research team have been using the available knowledge we have about the Izidora Forest (such as the presence of endangered and endemic species and the land cover maps that show the loss of natural habitats) as the basis to demonstrate for decision makers the need of a more sustainable development of the area. Nevertheless, long-term basic scientific research in the area is key to produce a base line of knowledge sufficient to help fighting for the conservation of the Izidora Forest (and hopefully we will be able to enhance the local academic engagement by disseminating our experience in this highly important urban vegetation patch through a scientific publication).

The Casa de Francisco, acting as a headquarters, has the potential to unite its surrounding communities to engage and fight for the protection of the natural and human heritage of the whole Izidora Forest. Furthermore, the academic research developed in the region can provide technical support for the creation of public policies for sustainable urban development. We expect that the combination of the social

movements, the environmental education activities, and the academic research in the region, would represent the first steps towards the sustainable urban development of the Izidora Forest as a whole. Hopefully, future generations will be able to live in a neighborhood – and in a city – that managed to preserve a vegetation patch of almost 1000 hectares, inhabited by animal and plant species typical of two of the most biodiverse terrestrial biomes of the planet, the Atlantic Forest and the Cerrado.

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Table 1. List of bird species recorded at Casa de Francisco between October 2020 and September 2021. Below are shown the species' scientific names and English names, also species endemic to the Cerrado vegetation are marked as CE, and those endemic to the Atlantic Forest vegetation are marked as AF. Birds species classification follows the Brazilian Ornithological Records Committee (Pacheco et al. 2021).

Taxon	English Name	Endemism
Tinamiformes		
Tinamidae		
<i>Crypturellus parvirostris</i>	Small-billed Tinamou	
Anseriformes		
Anatidae		
<i>Cairina moschata</i>	Muscovy Duck	
<i>Amazonetta brasiliensis</i>	Brazilian Teal	
Galliformes		
Cracidae		
<i>Penelope superciliaris</i>	Rusty-margined Guan	
Columbiformes		
Columbidae		
<i>Columbina talpacoti</i>	Ruddy Ground-Dove	
<i>Patagioenas picazuro</i>	Picazuro Pigeon	
<i>Leptotila verreauxi</i>	White-tipped Dove	
<i>Leptotila rufaxilla</i>	Gray-fronted Dove	
Cuculiformes		
Cuculidae		
<i>Piaya cayana</i>	Squirrel Cuckoo	
<i>Crotophaga ani</i>	Smooth-billed Ani	
<i>Guira guira</i>	Guira Cuckoo	
Apodiformes		
Trochilidae		
<i>Phaethornis pretrei</i>	Planalto Hermit	
<i>Eupetomena macroura</i>	Swallow-tailed Hummingbird	
<i>Colibri serrirostris</i>	White-vented Violetear	
<i>Chlorostilbon lucidus</i>	Glittering-bellied Emerald	
<i>Chionomesa lactea</i>	Sapphire-spangled Emerald	
Gruiformes		
Rallidae		
<i>Aramides cajaneus</i>	Gray-necked Wood-Rail	
Charadriiformes		
Charadriidae		
<i>Vanellus chilensis</i>	Southern Lapwing	
Pelecaniformes		
Ardeidae		

<i>Ardea alba</i>	Great Egret	
Threskiornithidae		
<i>Mesembrinibis cayennensis</i>	Green Ibis	
<i>Phimosus infuscatus</i>	Bare-faced Ibis	
Cathartiformes		
Cathartidae		
<i>Coragyps atratus</i>	Black Vulture	
Accipitriformes		
Accipitridae		
<i>Leptodon cayanensis</i>	Gray-headed Kite	
<i>Rupornis magnirostris</i>	Roadside Hawk	
<i>Buteo brachyurus</i>	Short-tailed Hawk	
Strigiformes		
Strigidae		
<i>Megascops choliba</i>	Tropical Screech-Owl	
<i>Glaucidium brasilianum</i>	Ferruginous Pygmy-Owl	
Coraciiformes		
Alcedinidae		
<i>Chloroceryle amazona</i>	Amazon Kingfisher	
Galbuliformes		
Galbulidae		
<i>Jacamaralcyon tridactyla</i>	Three-toed Jacamar	AF
<i>Galbula ruficauda</i>	Rufous-tailed Jacamar	
Piciformes		
Ramphastidae		
<i>Ramphastos toco</i>	Toco Toucan	
Picidae		
<i>Picumnus cirratus</i>	White-barred Piculet	
<i>Melanerpes candidus</i>	White Woodpecker	
<i>Veniliornis passerinus</i>	Little Woodpecker	
<i>Colaptes melanochloros</i>	Green-barred Woodpecker	
<i>Dryocopus lineatus</i>	Lineated Woodpecker	
Cariamiformes		
Cariamidae		
<i>Cariama cristata</i>	Red-legged Seriema	
Falconiformes		
Falconidae		
<i>Caracara plancus</i>	Southern Caracara	
<i>Milvago chimachima</i>	Yellow-headed Caracara	
<i>Herpetotheres cachinnans</i>	Laughing Falcon	
Psittaciformes		
Psittacidae		
<i>Psittacara leucophthalmus</i>	White-eyed Parakeet	
<i>Forpus xanthopterygius</i>	Blue-winged Parrotlet	
<i>Brotogeris chiriri</i>	Yellow-chevroned Parakeet	

<i>Pionus maximiliani</i>	Scaly-headed Parrot	
<i>Amazona aestiva</i>	Turquoise-fronted Parrot	
Passeriformes		
Thamnophilidae		
<i>Dysithamnus mentalis</i>	Plain Antvireo	
<i>Herpsilochmus atricapillus</i>	Black-capped Antwren	
<i>Thamnophilus caerulescens</i>	Variable Antshrike	
<i>Taraba major</i>	Great Antshrike	
Furnariidae		
<i>Furnarius figulus</i>	Wing-banded Hornero	
<i>Furnarius rufus</i>	Rufous Hornero	
<i>Phacellodomus rufifrons</i>	Rufous-fronted Thornbird	
<i>Synallaxis frontalis</i>	Sooty-fronted Spinetail	
<i>Synallaxis spixi</i>	Spix's Spinetail	
Pipridae		
<i>Ilicura militaris</i>	Pin-tailed Manakin	AF
<i>Antilophia galeata</i>	Helmeted Manakin	CE
Tityridae		
<i>Pachyrhamphus polychopterus</i>	White-winged Becard	
Rhynchocyclidae		
<i>Tolmomyias sulphurescens</i>	Yellow-olive Flycatcher	
<i>Todirostrum poliocephalum</i>	Gray-headed Tody-Flycatcher	
<i>Todirostrum cinereum</i>	Common Tody-Flycatcher	
Tyrannidae		
<i>Camptostoma obsoletum</i>	Southern Beardless-Tyrannulet	
<i>Elaenia flavogaster</i>	Yellow-bellied Elaenia	
<i>Phyllomyias fasciatus</i>	Planalto Tyrannulet	
<i>Serpophaga subcristata</i>	White-crested Tyrannulet	
<i>Myiarchus ferox</i>	Short-crested Flycatcher	
<i>Pitangus sulphuratus</i>	Great Kiskadee	
<i>Myiodynastes maculatus</i>	Streaked Flycatcher	
<i>Megarynchus pitangua</i>	Boat-billed Flycatcher	
<i>Myiozetetes similis</i>	Social Flycatcher	
<i>Tyrannus melancholicus</i>	Tropical Kingbird	
<i>Empidonomus varius</i>	Variiegated Flycatcher	
<i>Colonia colonus</i>	Long-tailed Tyrant	
<i>Fluvicola nengeta</i>	Masked Water-Tyrant	
<i>Cnemotriccus fuscatus</i>	Fuscous Flycatcher	
<i>Lathrotriccus euleri</i>	Euler's Flycatcher	
Vireonidae		
<i>Cyclarhis gujanensis</i>	Rufous-browed Peppershrike	
<i>Hylophilus amaurocephalus</i>	Gray-eyed Greenlet	
<i>Vireo chivi</i>	Chivi Vireo	
Hirundinidae		
<i>Pygochelidon cyanoleuca</i>	Blue-and-white Swallow	

<i>Stelgidopteryx ruficollis</i>	Southern Rough-winged Swallow	
Troglodytidae		
<i>Troglodytes musculus</i>	Southern House Wren	
Poliophtilidae		
<i>Poliophtila dumicola</i>	Masked Gnatcatcher	
Turdidae		
<i>Turdus leucomelas</i>	Pale-breasted Thrush	
<i>Turdus rufiventris</i>	Rufous-bellied Thrush	
<i>Turdus amaurochalinus</i>	Creamy-bellied Thrush	
Estrildidae		
<i>Estrilda astrild</i>	Common Waxbill	
Fringillidae		
<i>Euphonia chlorotica</i>	Purple-throated Euphonia	
Passerellidae		
<i>Arremon flavirostris</i>	Saffron-billed Sparrow	
Icteridae		
<i>Psarocolius decumanus</i>	Crested Oropendola	
Parulidae		
<i>Geothlypis aequinoctialis</i>	Masked Yellowthroat	
<i>Basileuterus culicivorus</i>	Golden-crowned Warbler	
<i>Myiothlypis flaveola</i>	Flavescent Warbler	
Cardinalidae		
<i>Cyanoloxia brissonii</i>	Ultramarine Grosbeak	
Thraupidae		
<i>Thraupis sayaca</i>	Sayaca Tanager	
<i>Thraupis palmarum</i>	Palm Tanager	
<i>Stilpnia cayana</i>	Burnished-buff Tanager	
<i>Nemosia pileata</i>	Hooded Tanager	
<i>Conirostrum speciosum</i>	Chestnut-vented Conebill	
<i>Sicalis flaveola</i>	Saffron Finch	
<i>Hemithraupis ruficapilla</i>	Rufous-headed Tanager	AF
<i>Volatinia jacarina</i>	Blue-black Grassquit	
<i>Eucometis penicillata</i>	Gray-headed Tanager	
<i>Coryphospingus pileatus</i>	Pileated Finch	
<i>Tachyphonus coronatus</i>	Ruby-crowned Tanager	AF
<i>Tersina viridis</i>	Swallow Tanager	
<i>Coereba flaveola</i>	Bananaquit	
<i>Sporophila nigricollis</i>	Yellow-bellied Seedeater	
<i>Sporophila caerulescens</i>	Double-collared Seedeater	

Epílogo: O desfecho de uma tese

Estabelecer uma conclusão definitiva para esta tese não foi uma tarefa fácil. Se por um lado acredito que tenha abordado alguns temas interessantes dentro da área da ecologia e ornitologia urbanas, por outro sei que muito ainda há para ser feito. Ao final, consigo enxergar apenas parte de um mundo ainda mais complexo, mas a ciência é de fato uma constante adição de propostas, perguntas e muitas vezes de se arriscar na busca de compreender melhor o mundo ao nosso redor. Ideias não me faltam, ainda mais com o enorme banco de dados gerados durante esta pesquisa. Embora desdobramentos ainda possam ser feitos, seja através de novos projetos e novos artigos, creio que foi possível produzir um documento final conciso. Iniciei esta tese com o desenvolvimento de uma ferramenta de gestão que une informações urbanísticas e ecológicas sobre a paisagem de Belo Horizonte. A partir daí, decidi avaliar a importância e o papel dos diferentes tipos de áreas verdes urbanas para a conservação da biodiversidade, mostrando que as características locais relacionadas com a estrutura e a complexidade da vegetação possuem maior influência sobre a avifauna urbana do que a paisagem ao redor. Tal resultado pode ser considerado uma importante fonte de informação para o manejo mais sustentável das áreas verdes urbanas, em especial as áreas de proteção ambiental. Finalmente, contei minha experiência como membro de um movimento em pró da conservação do último e maior remanescente de vegetação nativa não protegida de Belo Horizonte. Mostrei como engajamos as comunidades ao redor a partir de ações de educação ambiental e a realização de atividades científicas e de lazer pela região. O título “Ornitologia urbana: aplicações, desafios e perspectivas” não poderia fazer mais sentido para mim agora, pois a aves foram tanto a minha musa inspiradora quanto meus guias em todas as questões que busquei responder ao longo dos quatro capítulos.

A partir do que foi apresentado espero poder ter agregado um pouco ao atual estado da arte do conhecimento sobre a biodiversidade urbana, sobretudo sobre as aves. Esta afirmação pode ser baseada nos métodos que foram utilizados ao longo do projeto, tanto nas análises espaciais e estatísticas empregadas quanto para os métodos de amostragens realizados. As amostragens merecem inclusive um capítulo à parte, pois além de serem fundamentais para um bom projeto de pesquisa, ainda existem muitas variáveis pouco exploradas em estudos urbanos. Neste tópico, acredito que tenha adicionado maior relevância a esta tese com os procedimentos e variáveis escolhidos.

Assim, esta tese representa somente o início de inúmeras possibilidades. Aquilo que desenvolvi pode ser considerado como um modelo, ou quem sabe inspiração, para outros projetos focados em estudar as paisagens urbanas. Espero que futuros cientistas que ousem se enveredar pelos aspectos ecológicos das cidades, passem a enxergar o ambiente urbano como um ecossistema mutável, intrigante e cheio de oportunidades.