
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA E BIODIVERSIDADE

NEW INSIGHTS ON URBAN ECOLOGY FOR MORE SUSTAINABLE CITIES
integrating nature-based-solutions, human perception and the knowledge on
how the urban landscape influence bird communities

GABRIELA ROSA



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GABRIELA ROSA

Tese apresentada ao Instituto de Biociências do Câmpus de Rio Claro, Universidade Estadual Paulista, como parte dos requisitos para obtenção do título de Doutora em Ecologia e Biodiversidade.

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...
*Eu fui aparelhado
para gostar de passarinhos.
Tenho abundância de ser feliz por isso*
...

(O apanhador de desperdícios, Manoel de Barros)

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ABSTRACT

Due to increasing of urbanization, cities have become the main human settlements, so it is not possible to think about sustainability without considering urban environments. Thus, Urban Ecology has emerged and substantially contributed to strengthen and to improve human wellbeing and biodiversity conservation in urban landscapes across the globe. Considering this context, this thesis is divided into five chapters that address different topics related to Urban Ecology. In the first chapter we aimed to assess how the different elements (tree cover, impervious built-cover, park area, noise and functional connectivity) of urban landscape influence taxonomic (species richness) and functional aspects (functional richness – FRic – and Rao's Quadratic Entropy - RaoQ) of the bird communities that inhabit parks and streets in Neotropical cities. We found that, if well planned, cities can have an important role on bird biodiversity conservation. Connecting fragments of urban vegetation through wooded streets contribute positively to taxonomic and functional richness and can reduce the negative effects of noise in the cities. In Chapter 2, I tested whether the findings of Leveau (2019a) are generalizable to two Neotropical cities (i.e., Bauru, Brazil; Xalapa, México); the autor stated that urbanization leads to the homogenization of bird coloration. Thus, we developed the 'color percentage' method, an approach that considers the birds' whole body, producing continuous descriptions of bird plumage colors based on pixel intervals of scientific illustrations. We quantified the influence of habitat diversity and impervious cover on the richness and diversity of bird color. Our results indicate that it is impossible to generalize that urbanization intensity leads to bird color homogenization. In chapter 3, we suggested a future research regarding towards the influences of urbanization on the diversity of bird color, considering UV spectral characteristics, once birds see more colors than humans and are enable to discriminate a broad range of colors, allowing the perception of the UV wavelength. In chapter 4, we investigated how humans perceive birds in two Neotropical cities (Bauru and Belo Horizonte, Brazil). Our study showed that most people can recognize the most frequent bird species, are aware of the ecological importance of birds for the maintenance of ecosystems and have different feelings according to species: while the majority of bird species were associated with positive sensations, species such as the domestic pigeon were considered pests and generate negative sensations. Finally, in chapter 5, we reported the experience of participating on Challenge Campus 2030 and discussed how science can be used to propose practical solutions to overcome environmental challenges and problems. Nature-Based Solutions (NBS) appear as an efficient alternatives to overcome the urban challenges. Engaging the academic community in the pursuit of improvement in quality of life and conservation of natural resources is of utmost importance for a more sustainable urban future.

Key-words: urban planning, sustainability, Agenda2030, Neotropical región, connectivity

RESUMO

Quando se pensa em sustentabilidade, é fundamental considerar os ambientes urbanos, uma vez que a maioria dos seres humanos vivem nas cidades. Assim, a Ecologia Urbana vem contribuindo substancialmente para fortalecer e melhorar o bem-estar humano e a conservação da biodiversidade em paisagens urbanas em todo o mundo. Partindo-se disso, esta tese está dividida em cinco capítulos que abordam diferentes temas relacionados a Ecologia Urbana. No primeiro, analisamos como os diferentes elementos (cobertura arbórea, cobertura impermeável, área de parque, ruído e conectividade funcional) da paisagem urbana influenciam os aspectos taxonômicos (riqueza de espécies) e funcionais (riqueza funcional – FRic – e Rao's Quadrática Entropy - RaoQ) das comunidades de aves que habitam parques e ruas de cidades neotropicais. Se bem planejadas, as cidades podem ter um papel importante na conservação da biodiversidade de aves. Conectar fragmentos de vegetação urbana por meio de ruas arborizadas contribui positivamente para a taxonomia e riqueza funcional e pode reduzir os efeitos negativos do ruído nas cidades. No capítulo 2, testamos se a urbanização leva à homogeneização da coloração das aves em duas cidades neotropicais (ou seja, Bauru, Brasil; Xalapa, México); para isso, desenvolvemos o método de 'porcentagem de cor', uma abordagem que considera todo o corpo das aves, produzindo descrições contínuas das cores com base em intervalos de pixels de ilustrações científicas. Quantificamos a influência da diversidade de habitat e cobertura impermeável na riqueza e diversidade da cor das aves. Nossos resultados indicam que não é possível generalizar que a intensidade da urbanização leva à homogeneização da coloração das aves. No capítulo 3, sugerimos uma pesquisa futura sobre as influências da urbanização na diversidade de cores das aves, considerando as características espectrais de UV, uma vez que as aves veem mais que os humanos e podem discriminar uma ampla gama de cores, permitindo a percepção do comprimento de onda UV. No capítulo 4, investigamos como a comunidade acadêmica percebe as aves em duas cidades neotropicais (Bauru e Belo Horizonte, Brasil). Nosso estudo mostrou que a maioria das pessoas consegue reconhecer as espécies mais frequentes, tem consciência da importância ecológica das aves para a manutenção dos ecossistemas e tem sentimentos diferentes conforme a espécie: enquanto a maioria das espécies de aves foram associadas a sensações positivas, espécies como o pombo doméstico gerava sensações negativas. Por fim, no capítulo 5, relatamos a experiência de participação no Challenge Campus 2030 e discutimos como a ciência pode ser utilizada para propor soluções práticas para superar desafios e problemas ambientais. As Soluções Baseadas na Natureza (NBS) surgem como uma alternativa eficiente para superar os desafios urbanos. Engajar a comunidade acadêmica na busca pela melhoria da qualidade de vida e conservação dos recursos naturais é de extrema importância para um futuro urbano mais sustentável.

Palavras-chave: planejamento urbano, sustentabilidade, Agenda 2030, região Neotropical, conectividade

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INTRODUCTION

Cities have become increasingly recognized as one of the main drivers of biodiversity loss, once they act as an environmental filter (LA SORTE et al., 2018; SOL et al., 2020). The urban sprawl favored the emergence of Urban Ecology as a science between the 1970s and 1990s (FORMAN, 2016), when ecological aspects of cities have been intensively researched (ANGEOLETTO et al. 2019; SUKOPP, 1998). According to Forman (2016), the Urban Ecology aim to study the “interactions of organisms, built structures and the physical environment where people are concentrated”. This is a very important field of knowledge, since the urbanization process has been responsible for increasing habitat loss and fragmentation (FISCHER; LINDENMAYER, 2007), for contributing to climate change (IPCC 2021) and for reducing taxonomic and phylogenetic diversities, as well as reducing the diversity of functional characteristics of several organisms in cities (SOL et al., 2020; LA SORTE et al., 2018).

However, cities are also highly heterogeneous, dynamic (RAMALHO; HOBBS 2012) and function as a socio-ecological systems of living and nonliving things (MADDOX et al. 2017). If urban landscapes area well-planned, they can play a role in for maintaining biodiversity conservation and ecosystem functioning, which has been increasingly recognized and studied worldwide (GRAVIOLA et al. 2021; SPOTSWOOD et al. 2021; GRIMM et al. 2008). In 1981, in the Man and Biosphere (MAB) program emerged the concept of Green Infrastructure (UNESCO, 2017), which consists of planning and designing urban forests so that they can work as a multifunctional network of ecological corridors that interconnect patches of vegetation and permeable areas, such as parks and other green spaces (HERZOG, 2016).

Ecological corridors provide connectivity, defined as "the degree to which the landscape facilitates or impedes movement among habitat patches" (TAYLOR et al., 1993). Connectivity is an essential attribute of landscapes because it helps to restore the flow of plants and animals and facilitate dispersal across the landscape (BENNETT, 2003). Small forest patches can act as ecological corridors, thus increasing the overall connectivity of the entire community along the urban matrix (BHAKTI et a. 2018; GRAFIUS, et al. 2017). Ecological corridors also promote the variety natural flows and resistance for negative effects of human activity (PENG

et.al. 2017) and facilitate birds' movement (FERNANDEZ-JURICIC, 2000). Green spaces, natural habitat patches (forest or non-forest) and street trees appears as a promising strategy for ensuring the maintenance of biodiversity and promoting healthy environments for human populations (ARONSON et al. 2017). These factors have been explored independently for urban contexts and incorporated into the design of ecological corridors that provide better environments for humans, plants and animals (ALMENAR et al. 2019).

Urbanization results in the loss of biodiversity (SOL et al., 2014), thus leading to a decline in bird richness and an increase in avifauna biomass (SACCO et al., 2015; ARONSON et al., 2014; CHACE; WALSH, 2006). Concepción et al. (2016) found that urban expansion has favored common generalist bird species in detriment of habitat specialist species, contributing for the homogenization of the avifauna. Menon and Mohanraj (2016) found that resource availability in urban areas and successful adaption to human-related resources have made invasive birds the most successful urban dwellers, leading to gradual elimination of native, migratory and rare bird species. Nevertheless, studies about how nature-based solutions address environmental hazards and about the effects of urban landscapes on tropical biodiversity are still scarce (REGA-BRODSKY et al, 2022); both with regard to avifauna, a group widely studied in temperate cities (ORTEGA-ÁLVAREZ; MACGREGOR-FORS, 2009), and with regard to landscape connectivity (LAPOINT et al., 2015). In order to fill this gap, **in chapter 1, we evaluated how the environmental characteristics — tree cover (%), impervious built-cover (%), vegetation patch size (ha), noise (dB) and functional connectivity — of urban landscapes influence the taxonomic and functional diversities of bird communities.**

Since urbanization can act as an environmental filter (LA SORTE et al., 2018; SOL et al., 2020), some scientists hypothesized that this process could also influence the diversity of plumage colors of birds that inhabit urban spaces (LEVEAU, 2019). Bird color variation was analyzed mainly at large geographic scales (DALRYMPLE et al., 2018; DELHEY, 2018). However, only few studies have addressed the influences of urbanization on bird color and they was conducted in subtropical urban landscapes (LEVEAU, 20221, 2019). The author observed that, in these cities, the intensity of urbanization is important to determine the color patterns of the species: highly

urbanized areas were dominated by gray birds, while places with high habitat diversity were inhabited by yellow and green birds. Due to the reduction in color diversity in these areas, Leveau (2019) concluded that urbanization leads to homogenization in the colors of bird plumage. However, Neotropical cities are home to highly diverse and colorful bird species, even in highly urbanized contexts, such as streets and avenues (GUIMARÃES et al., 2020; PENA et al., 2017), thus demonstrating the difficulty of generalize the relationships between urbanization and color diversity in urban bird communities. Considering this issue, **in Chapter 2, we tested whether the findings of Leveau (2019a) are generalizable to two Neotropical cities (i.e., Bauru, Brazil; Xalapa, México) with similar latitudes in both the Southern and Northern Hemispheres.** We also developed the 'color percentage' method, an approach that considers the birds' whole body, producing continuous descriptions of bird plumage colors based on pixel intervals of scientific illustrations.

Related to colors, we consider that studies need to take into account another important aspect: we must consider that birds see differently than humans: while humans have three types of color receptors or cones – which are sensitive to the red, blue and green spectral wavelengths – birds have a different fourth receptor, allowing the perception of the UV wavelength (TEDORE; NILSSON, 2019; CRONIN; BOK, 2016; LIND et al., 2013). Thus, **in chapter 3, we suggest a new approach to analyze the influences of urban landscapes on bird colors, considering the ultraviolet spectrum.** The idea was to describe bird coloration based on spectral characteristics (from visible to UV), using spectrophotometric analyzes of taxidermized specimens in museums.

In chapter 4, we dealt with human perception of birds. According to Merleau-Ponty (1996, p.23), human perception is the way we interpret and apprehend the information transmitted by our senses and sensations in the world. When it comes to the urban landscape, our perception is a multisensory perspective and involves several actors (PALLASMAA, 2011), which also includes the animals that inhabit cities. According to Lynch (1960), a highly 'imaginable' city would invite our eyes and ears to have an active participation in the city, so that the sensory domain would expand and deepen. In this sense, studying birds and perceiving them as part of the urban landscape can be useful to stimulate the imaginability of cities

and, at the same time, contribute to the conservation of a group of animals that is particularly important for ecological balance, seed dispersal and pollination (SICK, 1997). In addition, the avifauna represents a group that is very present in urban areas, especially in Brazil, which is home to the second largest diversity of birds in the world (CBRO, 2017).

Finally, **the chapter 5** provides a discussion about the importance of Urban Ecology, science and its interdisciplinarity for planning sustainable cities. **In this final chapter, we report the process of creation of the Araucaria Project, whose main goal is to bring sustainability by offering new views of planning the landscape, based on Nature Based Solutions (NbS).** “Nature-based Solutions are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (IUCN, 2016, p.4). Understanding how nature-based solutions can drive the mechanisms of biodiversity in cities is still a substantial knowledge gap that need more research (REGA-BRODSKY et al, 2022)

On June 11, 2021, the Araucária team project – representing UNESP/Rio Claro – won the ***Challenge Campus 2030, Edition 2***. Overall, 680 teams and about 2000 people from 79 countries around the world participated in this challenge, organized by Agorize, in partnership with the United Nations (UNRIC) and the Agence Universitaire de la Francophonie (AUF). The aim of this challenge was to encourage students and professors from all over the world to create sustainable solutions for their university campuses that achieve at least 3 out of the 17 UN Sustainable Development Goals (SDGs). Our winning project has the following objectives: (a) creating a network of cycling paths to promote connectivity between the main areas of the campus; b) expanding three thousand square meters of the agroforest area to increase organic food production; and c) restoring 10 ha of the riparian forest of Ribeirão Claro River.

Thereby, thinking about strategies to create and manage green infrastructure is important to mitigate and reduce the effects of urban sprawl. Urban vegetation is important for protection against geological problems and floods, and contributes to the balance of functions related to climate, humidity, air and water quality and acoustic management (FÁLCON, 2008; FONSECA et al. 2015). Green spaces also have a significant impact on urban microclimate (VAILSHERY. et al. 2013) and

provides water protection, reduction of heat island effect, floods and landslides prevention, increase of air quality and reduction of noise pollution (BOLUND; HUNHAMMAR 1999). The increase of air quality consequently prevents cardio respiratory problems such as bronchitis, allergic rhinitis and asthma in childhood (LOUV, 2005; LOVASI et al., 2008).

Proper planning and management of urban forests is indispensable to reduce the impacts of urbanization and meet social and environmental demands; they can also help to enhance the resilience of cities in the face of climate change (GRAVIOLA et al 2021). With the results of this thesis, I expect to produce important scientific information not only on how urbanization influence tropical biodiversity, but also on how people perceive the organisms that live around them in cities. Furthermore, from my experience with the Araucaria project, I expect to turn knowledge into action, assisting in the application of Nature Based Solution for a more sustainable urban future.

CHAPTER I

Urban landscape characteristics and their effects on taxonomic and functional diversities of birds in Neotropical cities



1.1 INTRODUCTION

Urban green spaces have important ecological roles in cities, providing resources and refuges for urban biodiversity (GRAVIOLA et al. 2021; ROSA, 2021; SCHÜTZ; SCHULZE 2015). They form a gradient of management intensity, economic input, and species diversity, leading a continuum of similarity with natural areas: from green roofs to native vegetation patches (ARONSON et al 2017). Green spaces vary in their local and surrounding characteristics, what have important influences on their ability to harbor native biodiversity (ARONSON et al., 2014; FERNÁNDEZ-JURICIC, 2000). Furthermore, green spaces must be planned and managed holistically considering their different socioecological functions across urban landscapes (GRAVIOLA et al. 2021). For example, native vegetation patches are fundamental for the conservation of several animal and plant species in cities (SCHÜTZ; SCHULZE, 2015; IKIN et al. 2013), while wooded streets can connect populations of different organisms between habitat patches (PENG et al. 2017; YOUNG et al. 2007). Therefore, green spaces can be considered as an ecological network that mimics natural processes, being fundamental for the maintenance of the integrity of urban ecosystems (GRAVIOLA et al. 2021; HERZOG et al 2016; PENA et al. 2016).

Birds comprise the most studied group of organisms in cities (REGA-BRODSKY et al 2022). They can be found occupying from native vegetation patches to streetscapes and community composition respond to different degrees of human disturbances (PENA et al. 2017). Thus, studies have been using birds as a model to assess how local and landscape characteristics influence urban biodiversity; for example, factors such as trees density, car traffic, pedestrian density and the surrounding matrix influence patterns of distribution of bird species within cities (FERNÁNDEZ-JURICIC, 2000). The streetscape is usually inhabited by a community dominated by a few species harboring most generalist traits, such as omnivorous birds (PENA et al 2017). Related to streets and highways, the traffic, as well as the noise generated by it, exert negative effects on the avifauna (VAN DER REE et al., 2011). Noise intensity is a proxy for negative effects within streets, once the higher the exposure to noise, the greater the impacts associated with

urbanization, and therefore, the smaller the richness of birds species in the streets (PENA et al., 2017).

Vegetation patches can be inhabited by highly diverse bird communities, even by endangered species (PERILLO et al., 2017; BHAKTI et al 2014). Local characteristics, such as the presence of dead and old trees, vegetation structure, plant diversity and the proximity to parks and squares modulate bird species composition (CAMPOS-SILVA; PIRATELLI 2021; CONCEPCIÓN et al., 2016). The vegetation structure is an important component for the conservation of bird species in cities (ARONSON et al., 2014). Schütz and Schulze (2015) found that the increase in the amount of arboreal vegetation led to an increase in the community's functional aspects (IKIN et al., 2013), and larger amount of bird feeding guilds (WHITE et al., 2005). Further, urban areas with a predominance of native trees have greater bird species richness (IKIN et al., 2013), while the introduction of exotic plants into the urban environment are processes that negatively impact bird communities (CHACE; WALSH, 2006).

Birds can use wooded streets as ecological corridors to move between urban vegetation patches (GRAVIOLA et al. 2021), increasing bird richness and diversity (YOUNG et al. 2007), the community's functional aspects (SCHÜTZ; SCHULZE, 2015) and the number of bird feeding guilds (WHITE et al. 2005). The presence of urban parks and wooded streets can increase urban landscape connectivity (GRAVIOLA et al. 2021), which is essential to link vegetation patches across the landscape (BENNETT, 2003) and to restore the flow of different species (GRAFIUS et al. 2017; PENG et al. 2017).

Up to date, most urban ecological studies have been conducted in native vegetation patches of cities in temperate climate (REGA-BRODSKY et al 2022). It was verified that only 5 out of 174 articles about landscape connectivity in urban areas were carried out in South America (LAPOINT et al., 2015). Only few studies assessed how local and landscape characteristics influence biodiversity in tropical cities, especially the functional composition of communities inhabiting streetscapes (REGA-BRODSKY et al 2022, PENA; MARTELLO *in press*). Furthermore, event that in Brazil birds represent an important fauna group, ranking the second largest diversity of bird population in the world (CBRO, 2017), in South American cities, the

connectivity and urban bird communities are understudied (ORTEGA-ÁLVAREZ; MACGREGOR-FORS, 2009). This further emphasizes the importance of studying the effects of urbanization on landscape connectivity in the Neotropics

The knowledge of how urban landscape influence bird community can be useful to direct conservation plans in cities. In this way, this study aimed to assess how different aspects of urban landscape (proportion of tree cover and impermeable surfaces) and local (vegetation patch size and noise exposure) aspects, as well as the landscape functional connectivity, influence functional and taxonomic aspects of birds inhabiting vegetation patches and the streetscape of a Neotropical city. We expected to find higher species richness and number of individuals, as well as higher values of FRic (i.e.: high functional richness) and RaoQ (i.e.: less dominance of functional traits) within parks with greater area, density of trees, connectivity and percentage of native forest and less noise. In streets, we also expected to find higher species richness and number of individuals, as well as higher values of FRic and RaoQ in streets with higher tree density, higher percentage of native trees and less background noise. Since cities are social-ecological ecosystems of living and nonliving things (MADDOX et al. 2017), the understanding of how humans, biodiversity and ecological processes can coexist in human-dominated systems can help societies to become more sustainable (MARZLUFF et al., 2008).

1.2 QUESTIONS, HYPOTHESES AND PREDICTIONS

Question 1: *What is the relative contribution of landscape, vegetation structure and urban noise to explain the taxonomic and functional characteristics of bird communities?*

Hypothesis 1: Urban parks act as refuges for bird species. Larger fragments of vegetation, located in places with higher tree cover, higher percentage of native forest, less noise and more connected positively influence taxonomic (higher species richness and greater number of individuals) and functional aspects (higher values of functional richness – FRic – and Rao's Quadratic Entropy - RaoQ) of urban bird communities.

Hypothesis 2: Streets with higher tree cover, higher percentage of native trees and less background noise positively influence taxonomic (higher species richness and greater number of individuals) and functional (higher values of FRic and RaoQ) aspects of urban bird communities. They also can increase the connectivity between the urban parks.

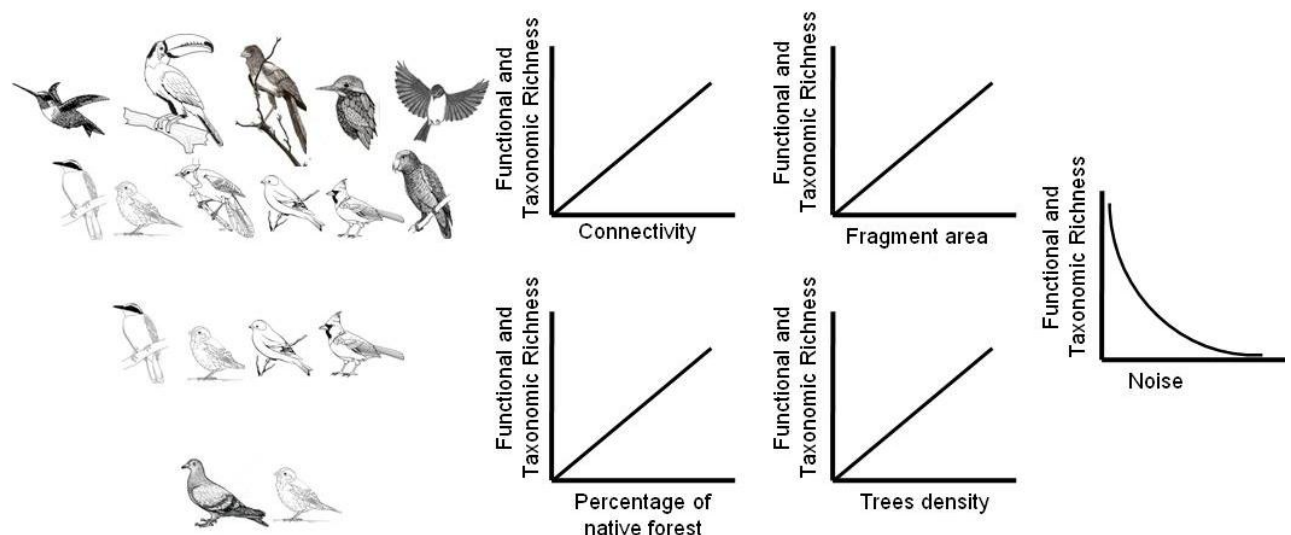


Figure 1.1: Expected influences of connectivity, vegetation patch size, percentage of native forest and tree cover and noise on the functional and taxonomic aspects of the bird community in a Neotropical city. The illustration to the left of the image represents the richness of bird species in the form of an inverted pyramid, showing what is expected to happen for each variable: in the top, there is the higher functional and taxonomic richness and below, there is lower functional and taxonomic richness.

1.3 MATERIAL AND METHODS

1.3.1 Study area

Bauru is the most populous municipality in the central-west region of São Paulo's State, Brazil. The city has more than 371 thousand inhabitants and has an important economy, with the 18th largest GDP (Gross Domestic Product) in the state of São Paulo and the 68th in the whole country (IBGE, 2017). The city is located in the transition zone between Atlantic Rainforest and Brazilian Savanna (Cerrado), two biodiversity hotspots. Due to the presence of streams and rivers with different levels of conservation of their riparian forests (including canalized stretches), fragments of vegetation of different sizes distributed across the city and its periphery, and a streetscape with a heterogeneous distribution of woody cover (SEMMA, 2015). Bauru landscape presents an excellent scenario to test how urban local and landscape characteristics influence bird communities.

1.3.2 Production of land use/land cover map

Firstly, we produced a land use/land cover map using ArcGIS software. Because our focus is urban landscape, for creating the map, we only selected the territory that is within the urban perimeter of Bauru. The satellite imagery was obtained from the PlanetScope satellite with 3 meters of resolution captured in October 2018, from Planet Team¹. Then, we carried out a supervised classification, using the ArcGIS *Maximum Likelihood Classifier* too. This classification uses training sites selected manually according to land/uses classes of interest so that the software is trained and it performs the classification from which all the pixels in the image are classified based on the similarity of their spectral characteristics with those of the training areas (MAGNANI, 2015). In the second stage, we carried out the classification assessment, comparing the classification results with the satellite images. The landscape was classified into four classes: urban, water, woody vegetation and herbaceous vegetation (Figure 1.2).

¹ <https://www.planet.com/pulse/planet-offers-broader-data-access-to-the-academic-community/>

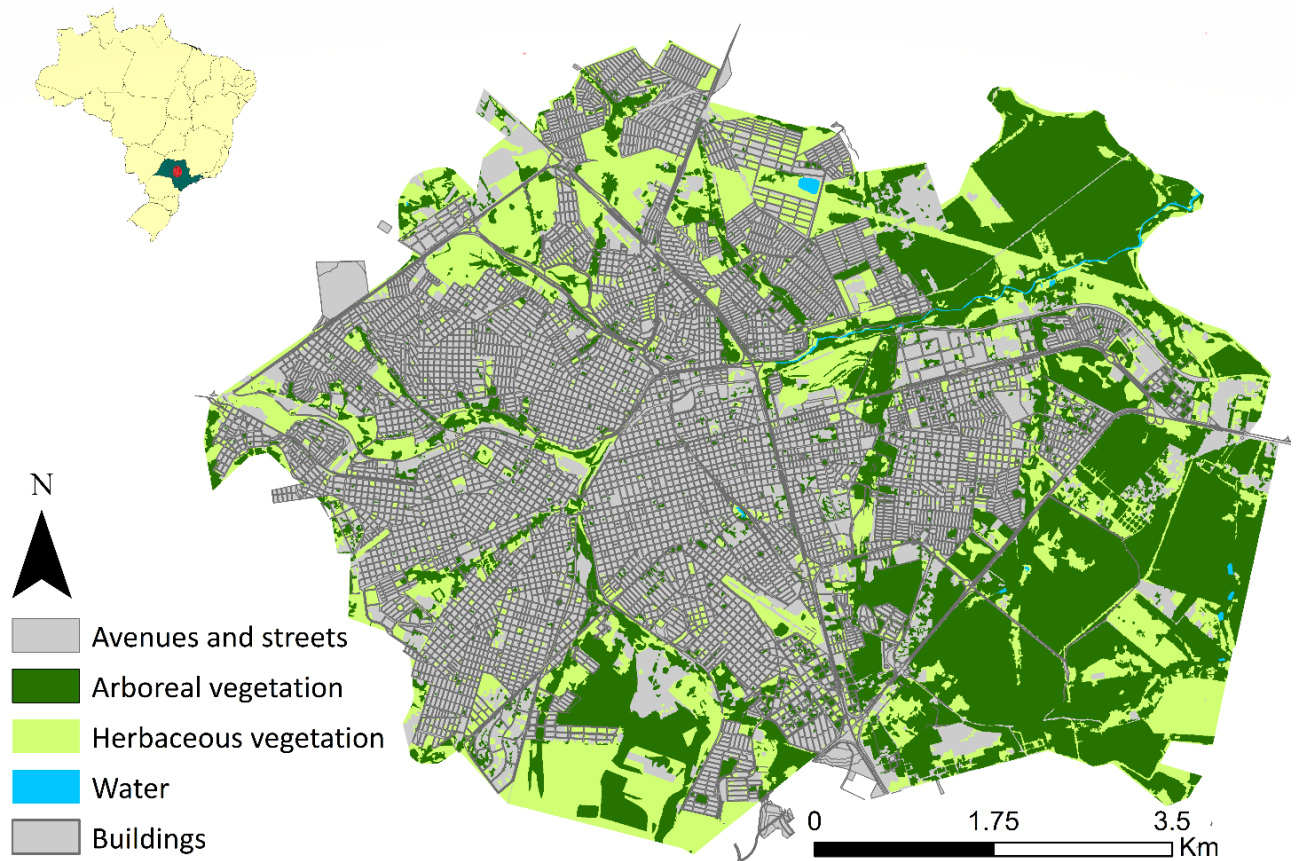


Figure 1.2: land cover map of Bauru's territory, within the urban perimeter (São Paulo, Brazil)

1.3.3 Parks sampling sites

We selected 36 sampling sites distributed through different contexts of Bauru's landscape: 12 in vegetation patches (main parks, squares and small green spaces of the city) and 24 across the streetscape. To select the sites in the streets, we adopt an approach to estimate their ability to connect habitat patches across the urban landscape (i.e. their degree of functional connectivity). By simulating *Multiple Least-Cost Path* (MLCP), using the software LSCorridors (RIBEIRO et al., 2017).

Considering the vegetation patches, the first idea was to choose two or more samples points in each site, considering the area size of each one; however, they have really different sizes and characteristics, and it was difficult to establish a method for choosing the number of sampling points for each one. In discussion with other ornithologists, we concluded that it was not necessary more than one sampling point per park. Thus, for the vegetation patches, we defined as sampling sites a central point created a 25m radius buffer surrounding each central point (Figure 1.3),

an approach used by Barbosa et al., (2017). Once most bird species fly long distances (SICK, 1997), choosing a central point avoids overestimating the occurrences and creating pseudoreplicates (HURLBERT et al., 1984).

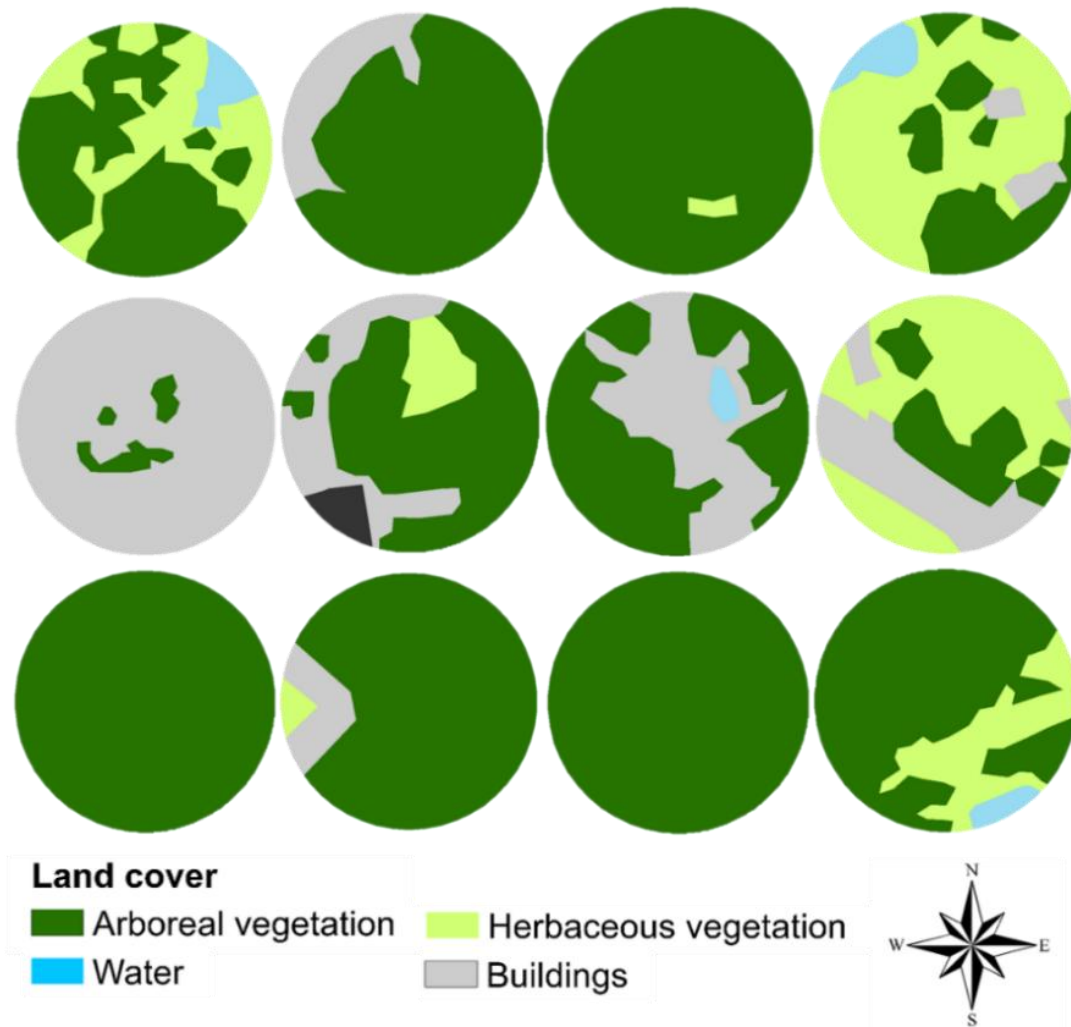


Figure 1.3: 25m radius buffers from 12 sampling sites in Bauru (São Paulo, Brazil)

1.3.4 Simulating Multiple Least-Cost Paths (MLCP) to define sampling points in the streets

To select the 24 streets with different levels of potential connectivity (from very low to high), we simulated Multiple Path Corridors (MLCP), using the software LSCorridors (RIBEIRO et al., 2017), considering regional characteristics. MPC is a more suitable alternative for the design of ecological corridors when compared to the traditional Least-Cost Path (LCP) method (Pinto and Keith 2009). Whereas LCP generates a solution only for paired source-targets, the MLCP method generates multiple alternative routes connecting the source-target areas; it is a more robust

solution when seeking a better distance–cost relationship for a variety of species with different landscape perceptions (RIBEIRO et al., 2017). In this study, we aimed to identify the routes that present the best balance between distance and potential cost of movement by birds in the urban landscape. The software LSCorridors (LSCORR) simulates multiple routes of a focal organism between pairs of sources and targets (habitat patches or other features to be connected), obtaining a map as a proxy for functional connectivity. The output is a set of maps that contain the route selection frequency index (RSFI) of every pixel, which allows us to identify a variety of routes that would guarantee the connectivity within the landscape (RIBEIRO et al. 2017).

To produce the resistance surface, different values were attributed to the four land cover classes: the highest to urban areas (12), intermediate to herbaceous vegetation/agriculture (4) and the lowest to woody cover (1). Then, 50 Multiple Least-Cost Paths simulations were carried out for each of the 78 pairs formed between the 12 vegetation patches in the municipality (i.e. source and target areas). The result from the simulations was a set of raster files with the values of the Route Selection Frequency Index (RSFI; Route Selection Frequency Index), which indicates the frequency in which the area was crossed (Figure 1.4).

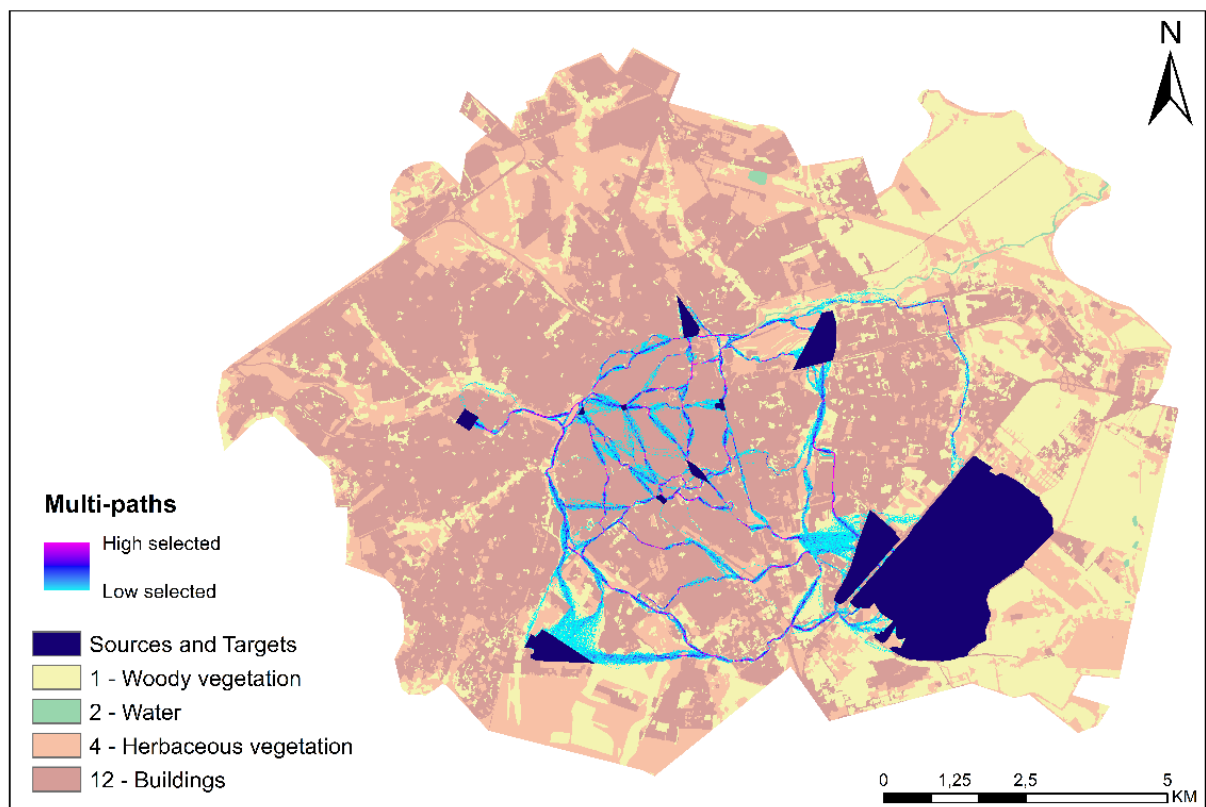


Figure 1.4: Multiple Least-Cost Path generated by LSCORR in the resistance land use map of Bauru, São Paulo, Brazil

We used the intersection of the MLCP that crossed the streets and avenues in urban landscape the city, by performing the *Extract* tool of ArcGis 10.2, to select the streets with different levels of potential connectivity. Then, we classified the RSFI values of the streets and avenues into 5 classes using the Jenk's Natural Breaks method: class 0 [RSFI = 0]; class 1 [RSFI 900 1879]; class 2 [RSFI from 1880 to 2959]; class 3 [RSFI 21960 to 4159]; class 4 [RSFI 4160 to 6049]; class 5 [RSFI 6050 to 8070]. We distributed random points using the *Create Random Points* tool, that selected 4 points for each of those classes 1 to 5 ($4 \times 5 = 20$ points). We also selected 4 sites that were not crossed by MLCP (class 0). At the end, we had 24 sample points in the streets and 5 classes (Figures 1.5).

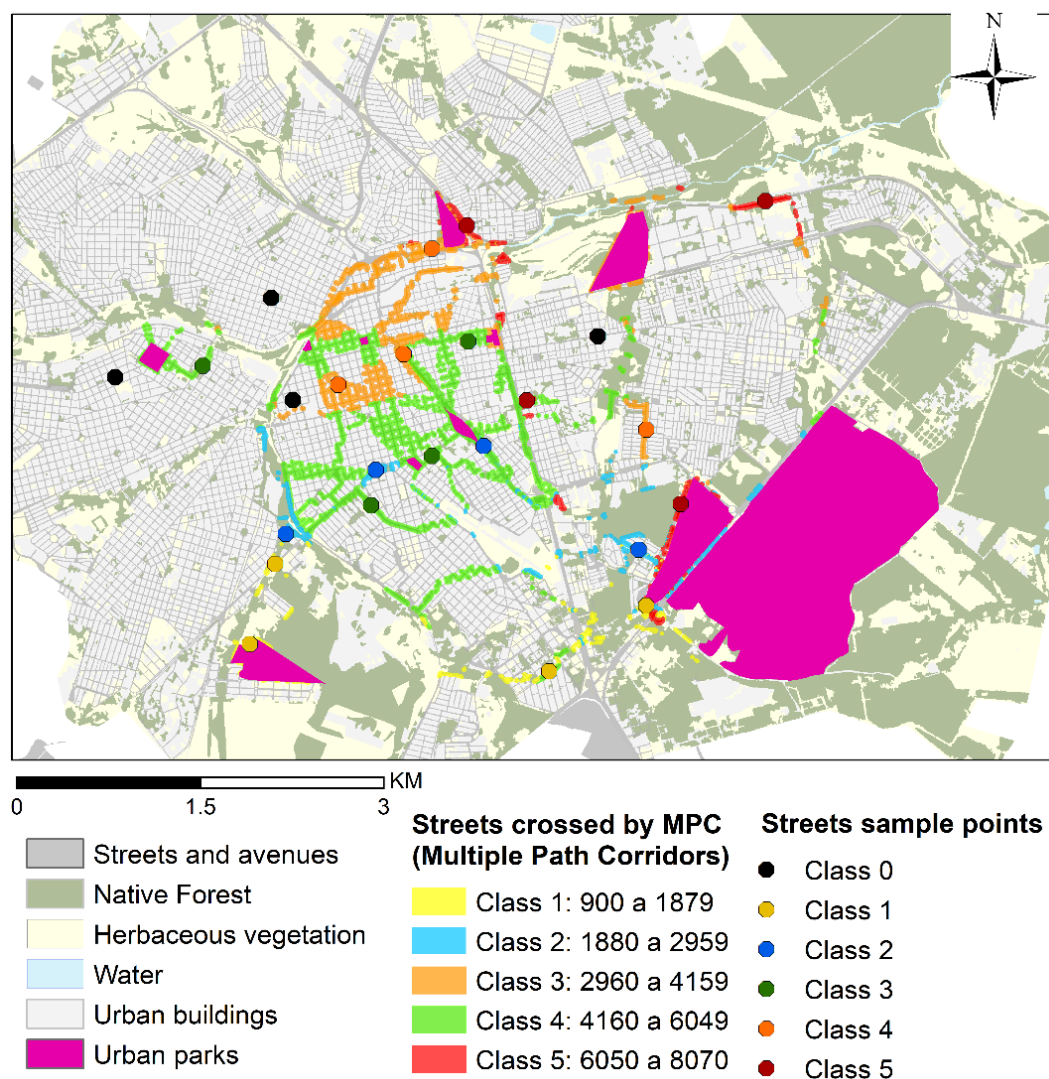


Figure 1.5: Sampling points: 12 parks and squares (pink polygons) e the 24 streets (colorful points) selected considering the 5 classes based on RSFI intervals of *Multiple Least-Cost Path* simulations, in Bauru, São Paulo, Brasil

1.3.5 Estimating local and landscape characteristics

In order to characterize the landscape structure, we considered five variables: tree cover (%), impermeable built-cover (%), vegetation patch size (ha), noise exposure (dB) and functional connectivity. The first three variables were calculated using ArcGIS Map tools considering a 25m radius around each sampling site. The background noise levels were measured using the Tacklife Decibel Meter, donated by Idea Wild² (Figure 1.6). Finally, functional connectivity was calculated using the Probability of Connectivity Index (dPC), with the help of Conefor software. This index calculates the importance of a given fragment (in our case, a vegetation patch) to maintain the overall functional connectivity of the landscape. The dPC is based on a model of probable connections between each pair of parks, considering the distances between them and the probability values of a species moving in these spaces (SAURA; PASCUAL-HORTAL, 2007). In this case, to calculate the distance between the parks and calculate the dPC, we used the average of the length of the MLPC generated by our simulations on LSCorridors (RIBEIRO et al. 2017).



Figure 1.6: material donated by Idea Wild

² The project had the institutional support of the Biodiversity Department, which provided some binoculars and GPSs for use in the field. In addition, the project was selected to be contemplated with the donation of field equipment by Idea Wild, thus we received: 1 Tacklife Decibel Meter, 1 Laser Distance Meter and 2 Vortex brand binoculars.

Table 1.1: Vegetation patches areas with the values of the variables analyzed, considering the buffer radius of 25 meters in Bauru (São Paulo, Brazil)

Vegetation patch (parks and squares)	Vegetation patch size (ha)	Tree cover (%)	Impermeable built-cover (%)	Connectivity (dPC) x 1000	Noise (Decibeis)
Bosque da Comunidade	1,75	100,0	0,0	1,37	59,6
Buffet Fiu-Fiu	13,34	74,6	0,0	20,98	64,2
Estádio Noroeste	8,38	22,6	26,3	7,71	55,7
Horto Florestal	43,62	100,0	0,0	210,21	50,8
Jardim Botânico - Lago	671,77	29,2	4,9	49.544,34	46,1
Jardim Botânico - Mata	671,77	100,0	0,0	49.538,27	48,7
Museu Ferroviário	1,03	5,6	94,4	0,12	48,6
Parque Vitória Régia	5,65	59,0	0,0	3,59	58,3
Praça Rui Barbosa	0,92	57,6	40,3	0,09	68,8
Residencial Jardins do Sul	36,32	82,9	0,0	144,82	44,4
SESC	2,37	61,8	28,5	0,62	64,0
UNESP	69,50	91,9	6,0	536,32	52,5

Table 1.2: Streets with the values of tree cover and impervious built-cover calculated considering the 25-meter radius buffer, as well as the noise values in Bauru (São Paulo, Brazil)

Streets	Tree cover (%)	Impermeable built-cover (%)	Noise (Decibeis)
R. 15 de novembro	0,0	100,0	77,3
R. Afrânio Roberto	48,6	51,4	63,2
R. Castro Alves	47,3	52,7	58,7
Av. Comendador J.S. Marta	42,8	48,5	69,1
Condomínio Samambaia	43,6	56,4	64,5
Av. Cruzeiro do Sul	0,0	100,0	86,7
Av. Elias Miguel Maluf	0,0	100,0	78,3
R. Gerson França	48,2	40,6	64,4
R. Guatemala	71,2	13,5	64,6
R. João Abe Arrage	63,4	36,6	64,1
R. João Ramos Nascimento	19,8	62,8	49,8
Av. Laranjeiras	11,5	88,5	59,9
R. Maranhão	22,9	77,1	53,3
Av. Nações Unidas	36,9	54,8	75,8
Av. Nações Unidas - Leão	20,4	31,8	66,6
Av. Nuno de Assis	34,6	37,6	78,6
R. Olavo Bilac	0,0	100,0	79,0
R. Osvaldo Alvarenga	14,7	72,6	46,8
R. Vigílio Malta	24,3	61,9	66,2
Rotatória Comendador	11,2	25,4	70,5
Rotatória Educação Física	0,0	17,8	61,7
Av. Eng. Luiz E. Carrijo Coube	30,2	23,1	57,1
R. Severino Dantas Souza	14,0	86,0	74,8
R. da Startemp	54,9	40,3	49,5

1.3.6 Bird survey data

Pilot sampling fieldwork was carried out, during September 2018, to confirm if the number of sampling points were enough and also to verify if the sampling vegetation patches selected by satellite image were safe and accessible. When the site was considered unsuitable for carrying out the surveys, a new selection was made from the points extracted from the intersection between the streets and the RSFI. We also verified which of those areas would need authorization to access the site. For public squares and streets, no authorization was required. However, it was necessary to apply for authorization to conduct research in some areas as: SESC, Railway Museum and the private residential condominiums.

For the bird survey, observations were made by *point count* method (LLOYD et al., 2000), used for bird sampling in urban and forest landscapes (PENA et al., 2017; TOLEDO et al., 2012; FONTANA et al., 2011; VOLPATO et al., 2009), in which individual points are selected and the observer stop at predefined spots, recording all the birds seen or heard for a predetermined time (GREGORY et al., 2004), that in our study was 10 min (TOLEDO et al., 2012). The *point count* was used instead of line transects because this is the preferred method for closed forest habitats with high canopies, particularly in rainforests because by standing in a location over a fixed period of time, the observer has a better chance of detecting birds (LLOYD et al., 2000). We considered birds perched in trees and those flying between trees. Birds flying at distances greater than 6 meters in height were not included. To carry out the fieldwork, I had the help of five undergraduate students in Biology (2 or 3 of them assisted me each day; figure 1.7 and 1.8) and the co-adviser and PhD researcher João Carlos Pena (Fapesp: 2018/00107-3).



Figure 1.7: undergraduate students during bird surveys at SESC, in Bauru (São Paulo, Brazil)



Figure 1.8: Bird survey at Botanic Garden Park, Bauru (São Paulo, Brazil)

Bird observations were conducted during the mornings (LLOYD et al., 2000; GREGORY et al., 2004), between December 2018 and March 2019 (summer season in Brazil) and from September to December 2019 (spring season). This period coincides with the breeding period of most species in southeastern Brazil, including migratory species (SICK, 1997). Sites were visited six times, three during the summer and three during the spring, totaling 108 field observations. The selection of one period aimed to avoid the temporal fluctuation caused by the presence of migratory birds (ABILHOA; AMORIN, 2017; PENA et al., 2017). Recent studies also have exclusively sampled during the spring season because it is considered the best time to evaluate the birds responses to the landscape (BANKS-LEITE et al., 2014; MARTENSEN et al., 2012; METZGER et al., 2009; MARTENSEN et al., 2008).

1.3.7 Functional traits and taxonomic aspects

We defined as response variables, bird species richness (SRic; the number of individuals), and the overall abundance (SAbund) observed at each sample point (vegetation patches and streets). Because the bird individuals were not identified, the overall abundance was calculated considering the visit with the highest number of individuals found. In all, 6 visits were made at the same point.

We also calculated community' functional diversity (FD), functional dispersion (FDis), functional richness (FRic), and Rao's Quadratic Entropy (RaoQ). FD is based on the presence/absence of species data (PETCHEY; GASTON, 2002). FDis

considers the relative abundance of species (LALIBERTE; LEGENDRE, 2010). FRic represents the amount of functional space occupied by species in a community (MOUCHET et al., 2010). RaoQ incorporates relative abundances of species and pairwise functional differences between species (BOTTA-DUKÁT, 2005). This last index is an indirect measure of functional uniformity, since the higher the RaoQ value, the greater the difference between species (PENA et al, 2017). To calculate the functional diversity indices, we considered five bird traits: 1) body mass, 2) foraging substrate (soil, medium foliage extract, top foliage extract, air), 3) diet (flowers/nectar, invertebrates, fruits, seeds, carrion, vertebrates) and 4) clutch size and 5) nesting site (cavities, trees, ground) (PENA et al., 2017). We collected data on the functional traits from published literature e.g. Sick (1997), Del Hoyo et al. (2004), Gussoni (2009), Uejima et al. (2012), Wilman et al., (2014), Zima; Francisco (2016) e Pigot et al. (2020).

After defining the indices, we constructed a matrix containing two continuous traits and three categorical (fuzzy) traits (PENA et al. 2017). Prior to calculating the functional diversity indices, we converted the fuzzy variables into proportional variables (PAVOINE et al., 2009). This was done using the *prep.fuzzy* function of the R package (R CORE TEAM, 2020) and *ade4* (DRAY et al., 2020). Subsequently, the feature matrix was converted into a distance matrix using the *dist.ktab* function. This final matrix was used to calculate the functional diversity indices in R using the *dbFD* function of the FD package (LALIBERTE; LEGENDRE, 2010). Thus, the values of richness and functional diversity were obtained (Tables 1.3 and 1.4).

Table 1.3: Functional diversity indices obtained for bird communities in 12 parks in Bauru (São Paulo, Brazil). FD: functional diversity; FRic: functional richness; FDis: functional dispersion; RaoQ: Rao's quadratic entropy. FRic values are multiplied by 100 only to facilitate numerical representation.

Vegetation patches (parks and squares)	FD	FRic*100	FDis	RaoQ
Bosque da Comunidade	0,931	0,63	0,355	0,132
Buffet Fiu-Fiu	0,914	1,84	0,382	0,149
Estádio Noroeste	0,929	1,59	0,392	0,157
Horto Florestal	0,894	3,42	0,400	0,164
Residencial Jardins do Sul	0,918	0,42	0,366	0,138
Jardim Botânico - Lago	0,868	19,60	0,395	0,160
Jardim Botânico - Mata	0,902	0,95	0,378	0,147

Museu Ferroviário	0,903	0,05	0,306	0,109
Praça Rui Barbosa	0,963	0,32	0,286	0,101
SESC	0,873	1,34	0,383	0,150
UNESP	0,885	5,18	0,389	0,154
Parque Vitória Régia	0,936	1,02	0,396	0,159

Table 1.4: Functional diversity indices obtained for bird communities in 24 streets and avenues of Bauru (São Paulo, Brazil). FD: functional diversity; FRic: functional richness; FDis: functional dispersion; RaoQ: Rao's quadratic entropy. FRic values are multiplied by 100 only to facilitate numerical representation.

Streets	FD	FRic*1000	FDis	RaoQ
R. 15 de novembro	0,808	0,00	0,319	0,111
R. Afrânio Roberto	0,952	0,07	0,351	0,129
R. Castro Alves	0,892	0,48	0,299	0,106
Av. Comendador J.S. Marta	0,880	0,87	0,357	0,134
R. Condomínio Samambaia	0,946	1,14	0,365	0,138
Av. Cruzeiro do Sul	0,886	0,04	0,375	0,149
Av. Elias Miguel Maluf	0,828	0,09	0,323	0,115
R. Gerson França	0,910	1,62	0,378	0,147
R. Guatemala	0,892	39,80	0,401	0,163
R. João Abe Arrage	0,950	2,19	0,355	0,132
R. João Ramos Nascimento	0,948	2,65	0,373	0,142
Av. Laranjeiras	0,939	1,30	0,373	0,146
R. Maranhão	0,931	1,34	0,366	0,139
Av. Nações Unidas	0,883	1,16	0,334	0,126
Av. Nações Unidas - Leão	0,930	1,92	0,392	0,157
Av. Nuno de Assis	0,918	3,94	0,376	0,148
R. Olavo Bilac	0,807	0,09	0,327	0,119
R. Osvaldo Tav	0,944	4,36	0,340	0,127
R Virgílio Malta	0,915	3,54	0,392	0,156
Rotatória Comendador	0,907	5,99	0,345	0,134
Rotatória Educação Física	0,925	6,69	0,396	0,162
Av. Eng. Luiz E. Carrijo Coube	0,923	7,29e	0,370	0,144
R. Severino Dantas Souza	0,911	0,60	0,355	0,134
R. da Startemp	0,909	5,24	0,389	0,153

1.4 DATA ANALYSIS

1.4.1 Assessing the relationships between local and landscape characteristics and the bird community

First, we calculated the average and medians of bird species richness per sampling site. Then, the richness found in the streets and parks were compared, through analysis of variance, modeled and calculated with the aid of the Rstudio program.

To understand how the landscape influences the functional and taxonomic characteristics of the bird community, we built Generalized Linear Models (GLM) between each response variable (SRic; the number of individuals; SAbund: overall abundance; FD: functional diversity; FDis: functional dispersion; FRic: functional richness and RaoQ: Rao's Quadratic Entropy) and each one of the five predictor variables (tree cover, vegetation patch size, exposure to noise, and functional connectivity). The linear regression was used to analyze continuous variables and describe the linear relationship between a predictor variable, represented graphically by the X axis, and a response variable, represented graphically by the Y axis (GOTELLI & ELLISON, 2013). Prior to the modelling approach, we performed a Person's correlation analysis between each pair of predictor variables, using the *cor* function available in R. and only kept variables that presented Person's $R < 0.6$.

For each GLM, the Akaike information criterion for small samples (AICc) was calculated. Models with $\Delta AICc < 2.0$ are considered to have substantial support (BEIER; BURNHAM; ANDERSON, 2001). For this, we used the RStudio: psych packages to correlate the urban environmental variables and the MuMIn and AICcmodavg packages to assess which were the significant models of interaction between the independent variables and which of these interactions actually influence the functional and taxonomic richness observed in the parks and on the streets. We used P values smaller than 0.05 as a level of significance.

1.4.2 Verifying if the streets most selected by LSCorridors simulation present better taxonomic and functional aspects of the bird community

It was verified if the streets crossed by a high number of modeled paths coincide with the streets where the higher taxonomic and functional diversities were observed. For this, new GLMs were built considering the street classes, separated according to RSFI values of the streets and avenues using the Jenk's Natural Breaks method: white class (RSFI=0); yellow class (RSFI of 900 1879); blue class (RSFI from 1880 to 2959); class orange (RSFI from 21960 to 4159); class green (RSFI from 4160 to 6049); red class (RSFI from 6050 to 8070). Next, it was verified whether the different classes of functional connectivity are related with the different degrees of bird community functional and taxonomic diversities observed in the selected streets.

1.4.3 Multiscale influence of the landscape on the avifauna

Finally, we analyzed the multiscale influence of the landscape on the richness and number of species records in streets and parks. For this, we used the *rgdal* (BIVAND et al., 2020), *raster* (HIJMANS et al., 2020), *tidyverse* (WICKHAM, 2019) and *landscapemetrics* (MAXIMILLIAN et al., 2020) packages in RStudio to analyze the correlation between the results of the richness and number of records with the tree and herbaceous cover of the ground cover map, in a scale of 25m, 50m, 100m, 250m, 500m and 750m, in relation to the sample observation point.

1.5 RESULTS

A total of 2342 bird records were counted across streets and vegetation patches of Bauru. They belong to 96 species, 35 families and 16 orders (Appendix A). The families with the highest number of species were Tyrannidae (18 species) and Thraupidae (10). On the WikiAves website, 270 bird species are registered in the municipality (including rural, forest and urban areas) of Bauru, of which we recorded 36% in the urban area. The most frequent species were all native from the Brazilian territory (with one exception: House Sparrow): Great Kiskadee (*Pitangus sulphuratus*, 149 records), Eared Dove (*Zenaida auriculata*, 141), White-eyed Parakeet (*Psittacara leucophthalmus*, 139), House Sparrow (*Passer domesticus*, 136), Blue-and-white Swallow (*Pygochelidon cyanoleuca*, 132), Picazuro Pigeon (*Patagioenas picazuro*, 123) and Yellow-chevroned Parakeet (*Brotogeris chiriri*, 89).

1.5.1. Comparison between richness and bird records between streets and parks

Comparing the species richness found in the streets and green areas, we confirmed our hypothesis that green areas present higher richness compared to the streets. Analysis of variance showed that parks has significantly better richness ($F=41.23$; $p<0.0001$; $df=35$) when compared to streets. For the number of records, parks again presented significantly higher values ($F=71.41$; $p<0.0001$; $df=35$), when compared to streets (Figure 1.9).

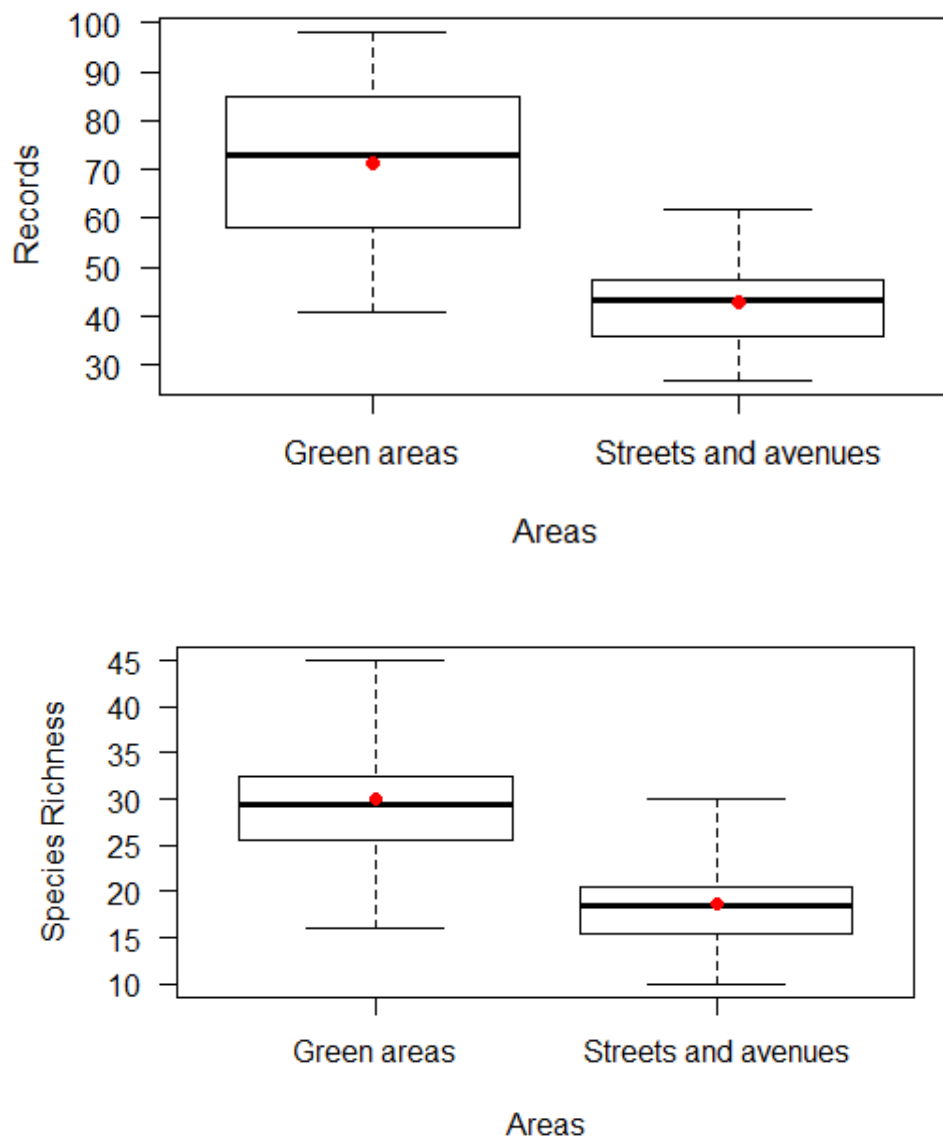


Figure 1.9: Number of records and species richness for urban avifauna of green areas and streets in Bauru (São Paulo, Brazil)

We also compared the richness species and records between the different classes selected by the MLCC simulations at LSCorridors: white class (RSFI=0); yellow class (RSFI from 900 to 1879); blue class (RSFI from 1880 to 2959); class orange (RSFI from 21960 to 4159); class green (RSFI from 4160 to 6049); red class (RSFI from 6050 to 8070). Thus, the classes go from the least frequent to the most frequent. As a result of the statistical analysis, we concluded that the different connectivity classes also explain the number of records ($F=58.29$; $p=0.001$; $df=23$) and species richness ($F=19.63$; $p=0.001$; $df=23$). Furthermore, the streets not selected by any route (Class 0 = white) had considerably fewer records and species compared to the others selected ($F=56.65$; $p<0.001$; $df=23$. Figure 1.10).

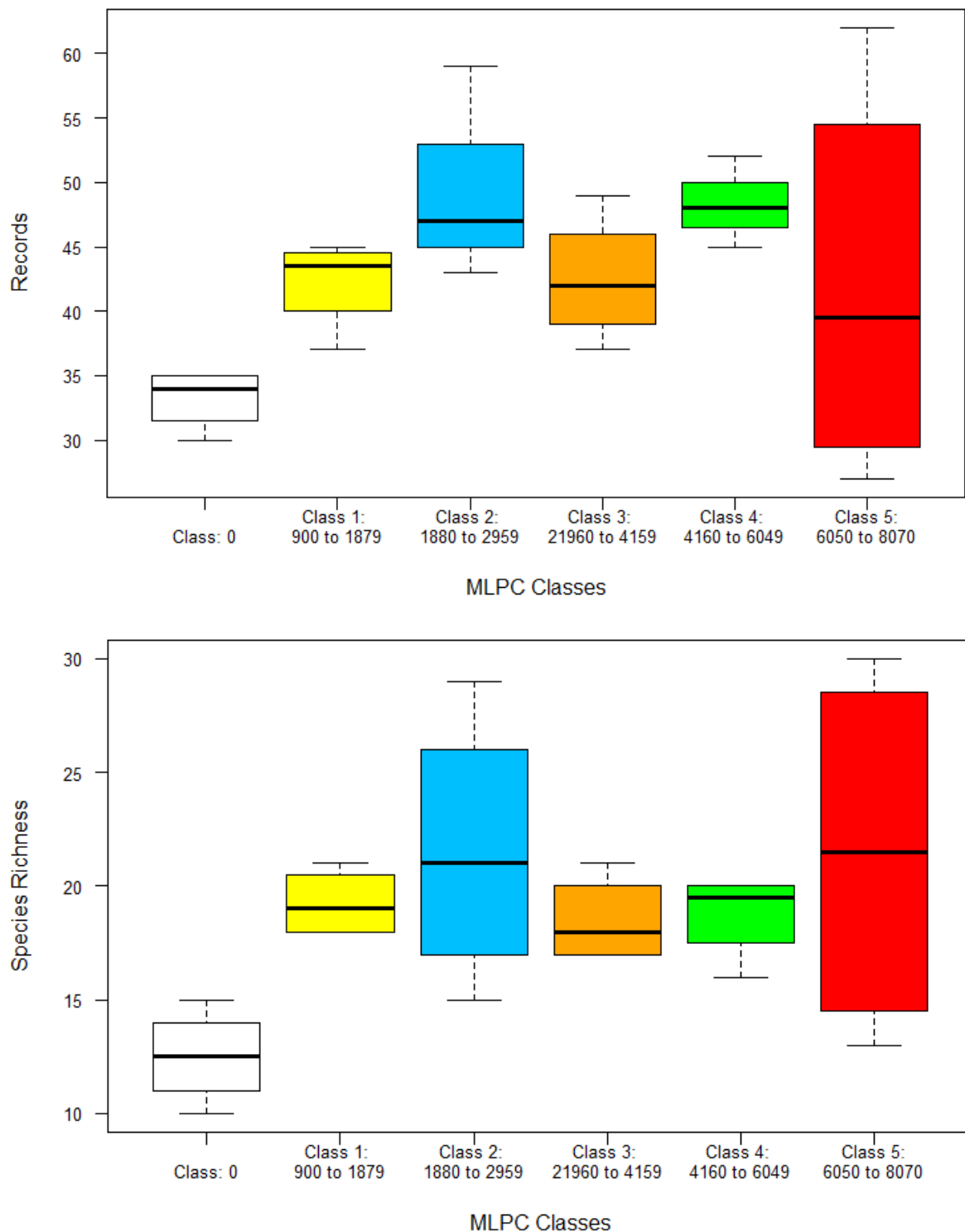
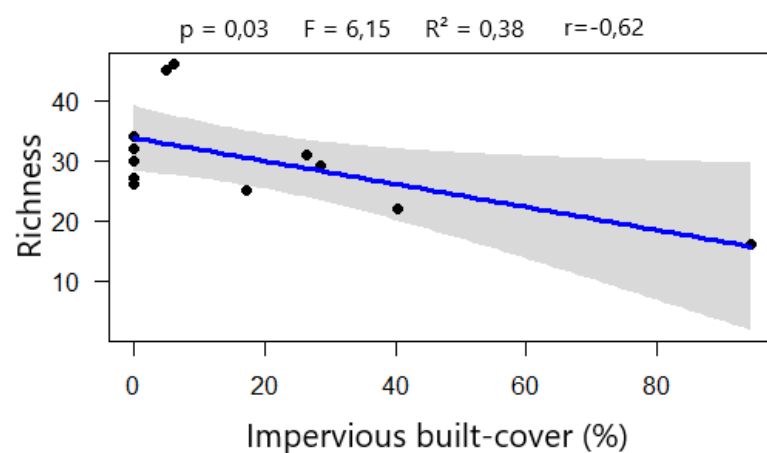


Figure 1.10: Number of records and richness of bird species, considering the different levels of potential connectivity of streets. The RSFI values refer to the frequency in which the MLCP crossed the streets, simulated by LSCorridos. The value 0 represents streets that were not selected, and the values 1 to 5 represent a gradient of connectivity from low to high, considering the landscape context in Bauru (São Paulo, Brazil)

1.5.2. Taxonomic richness and urban environmental variables

The results showed that the impermeable built-cover negatively influences the species richness in streets ($r=-0.65$; $F = 16.05$; $p = 0.0006$) and in parks ($r=-0.62$; $F = 6, 15$; $p = 0.03$; figure 1.11).

Parks



Streets

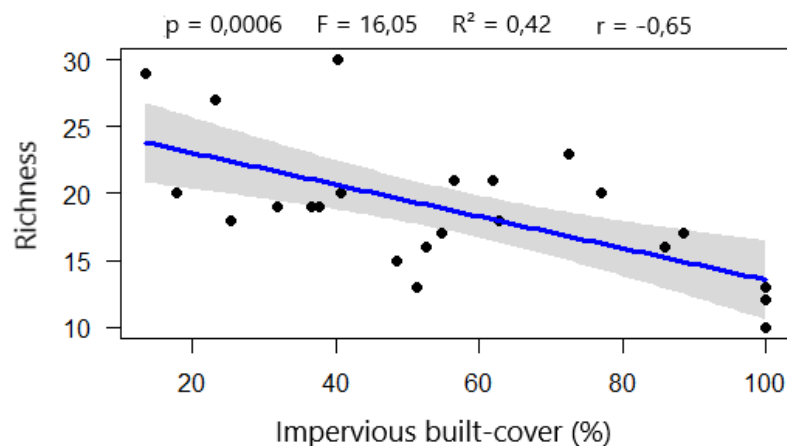


Figure 1.11: Influence of impervious built-cover (%) and taxonomic richness on streets in parks

Regarding the other variables, none - apart from the impermeable built-cover variable (%) - had a significant influence on the taxonomic richness in the parks. However, the same does not occur in the case of streets: both noise ($r=-0.62$; $F =$

14.10; $p = 0.001$) and tree cover ($r=0.53$; $F = 8.52$; $p = 0.008$) are correlated with the taxonomic richness of birds (Figure 1.12).

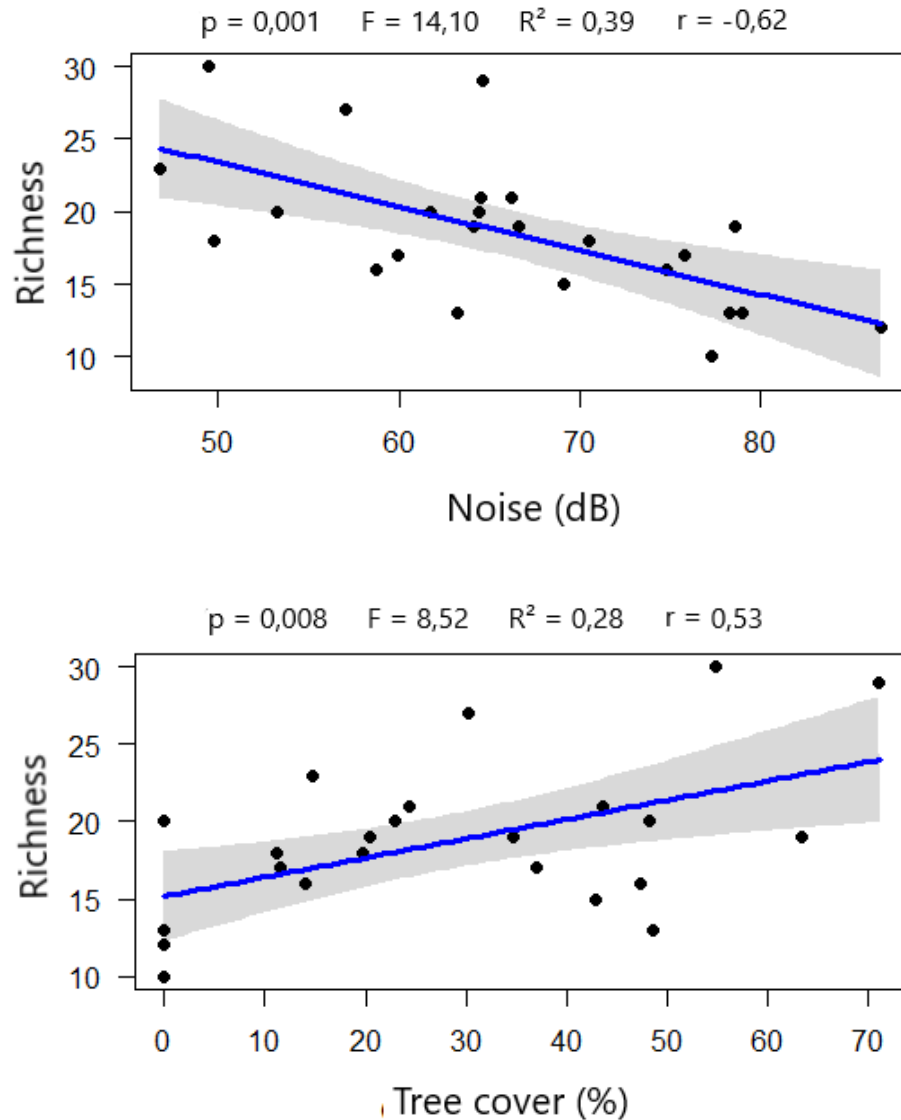


Figure 1.12: Influence of noise and tree cover on taxonomic richness in the streets

1.5.3. Functional diversity indices (FD, FDis, FRic and RaoQ) and urban environmental variables

The GLM results for the functional diversity (FD index) on streets were significant for all quantitative variables (impermeable cover, tree cover and noise; figure 1.13). On the streets, FD is negatively correlated with noise ($r = -0.62$; $F = 14.11$; $p = 0.001$), 38% correlated with tree cover ($r = 0.38$; $F = 3.76$; $p = 0.05$) and -

48% correlated with waterproof coverage ($r = -0.48$; $F = 6.57$; $p = 0.01$). However, considering the parks, these three variables, as well as the functional connectivity and size variables, do not have a significant influence on the FD index.

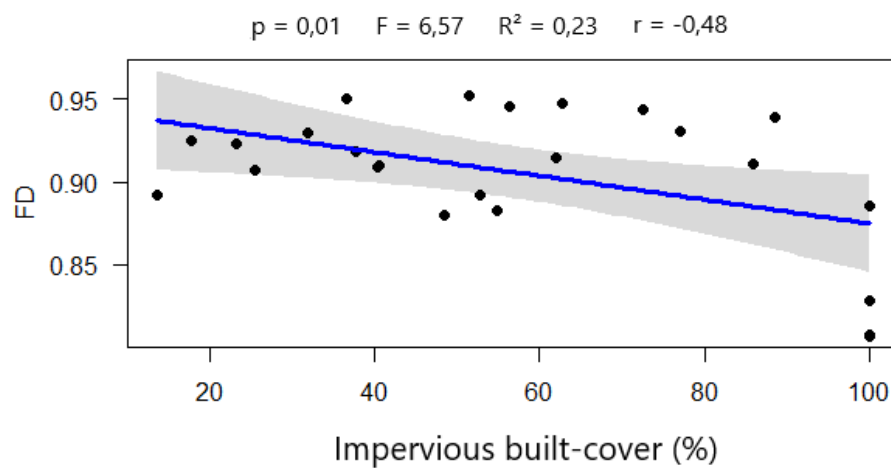
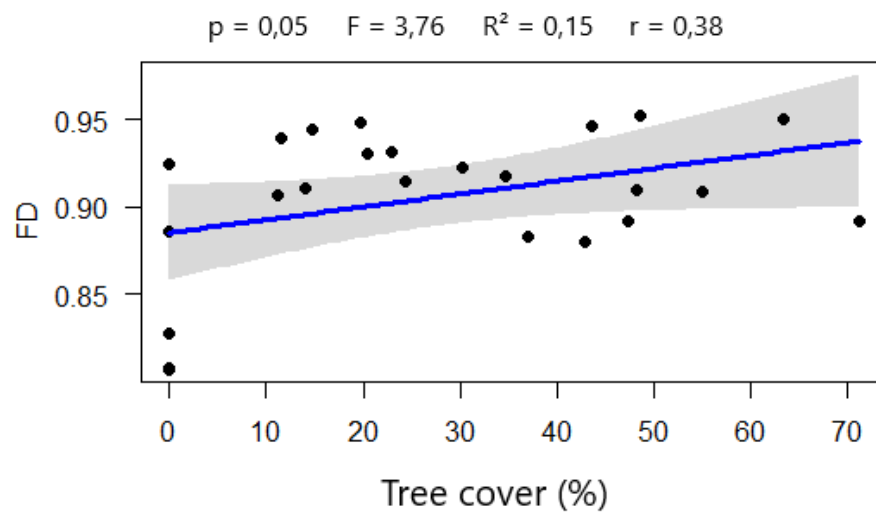
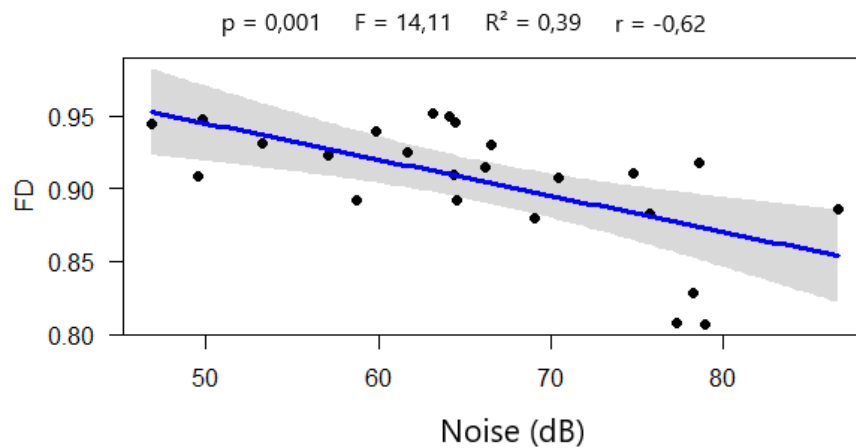
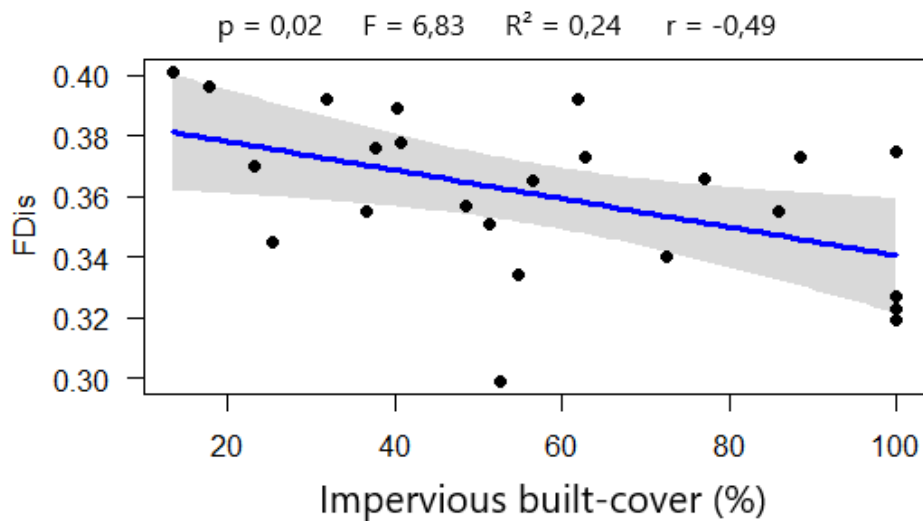


Figure 1.13: Influence of noise, tree cover and impervious built-cover on FD index, in the streets.

Considering the functional dispersion (FDis index), only the impervious built-cover variable showed a significant correlation in the streets ($r = -0.49$; $F = 6.83$; $p = 0.02$) and in the parks ($r = -0.72$; $F = 10.99$; $p = 0.008$; figure 1.14).

Streets



Parks

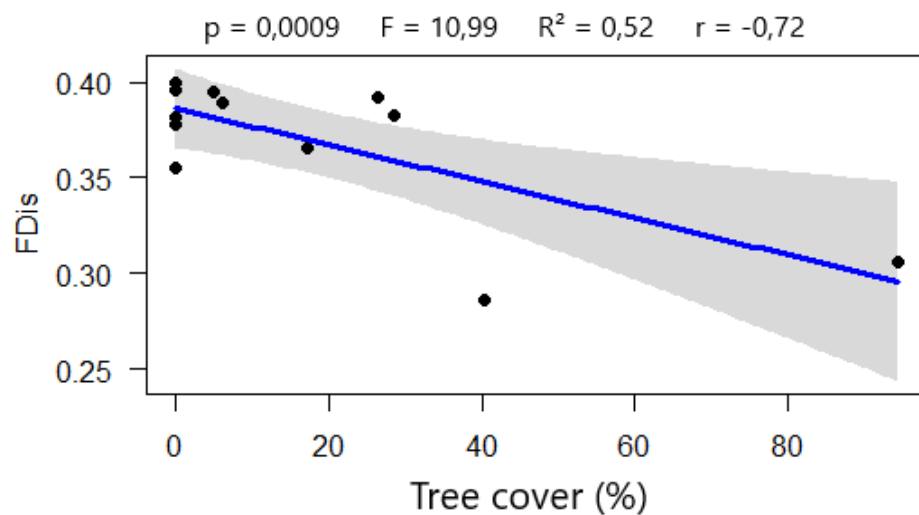


Figure 1.14: Influence of impervious built-cover on FDis, in streets and in parks.

In relation to functional richness (FRic index), it was found that noise has no significant relationship ($F = 0.50$; $p = 0.48$). However, in the streets, FRic is correlated

with impermeable cover ($r = -0.51$; $F = 7.63$; $p = 0.01$) and with tree cover ($r = 0.42$; $F = 4.8$; $p = 0.04$; figure 1.15).

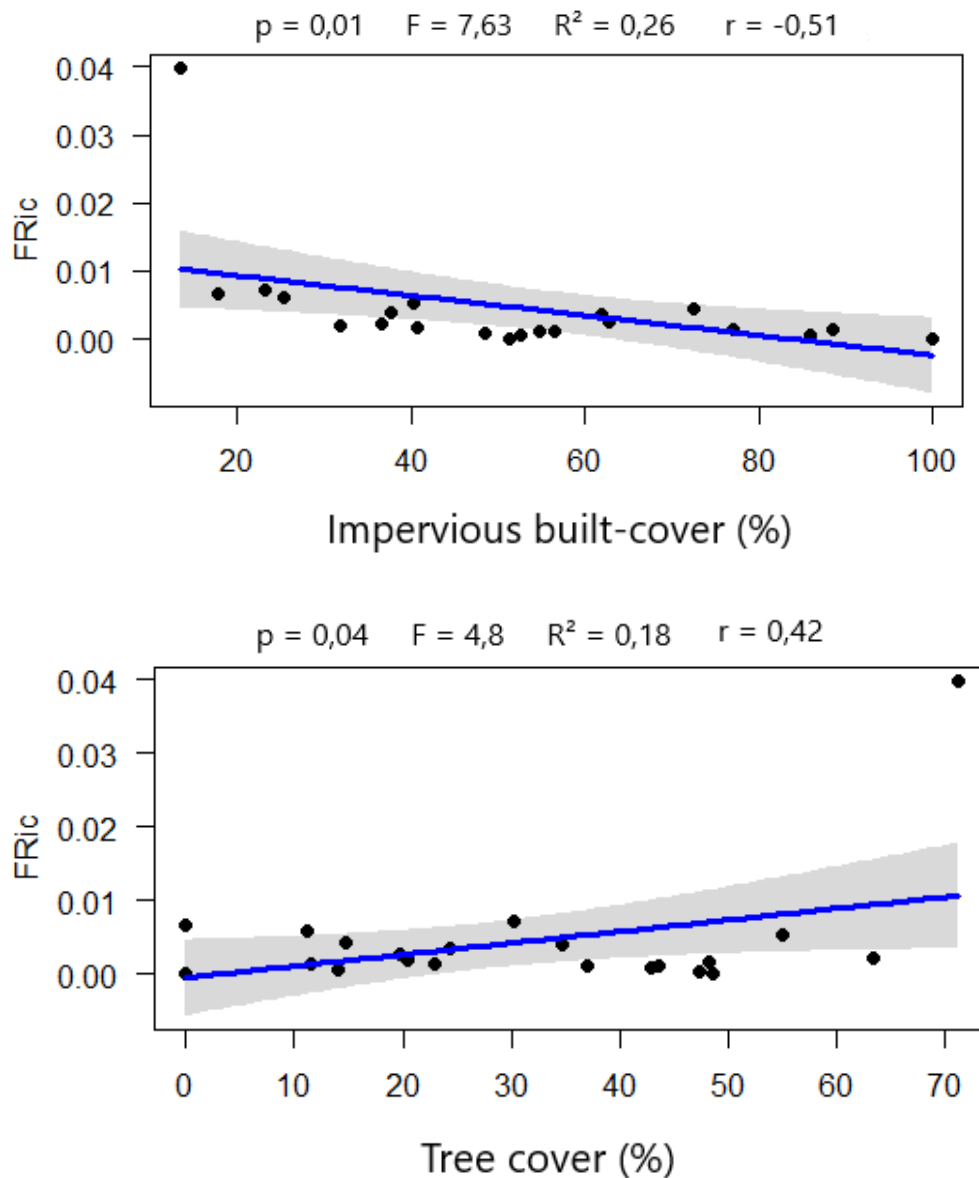


Figure 1.15: Influence of impervious built-cover and tree cover on FRic, on the streets.

In parks, vegetation patch size and connectivity are the variables that significantly influence the functional richness (FRic; Figure 1.16). The correlation values between these variables and the FRic index are similar: 64% correlation with the vegetation patch size ($r = 0.64$; $F = 6.98$; $p = 0.02$) and 63% with connectivity ($r = 0.63$; $F = 6.46$; $p = 0.03$).

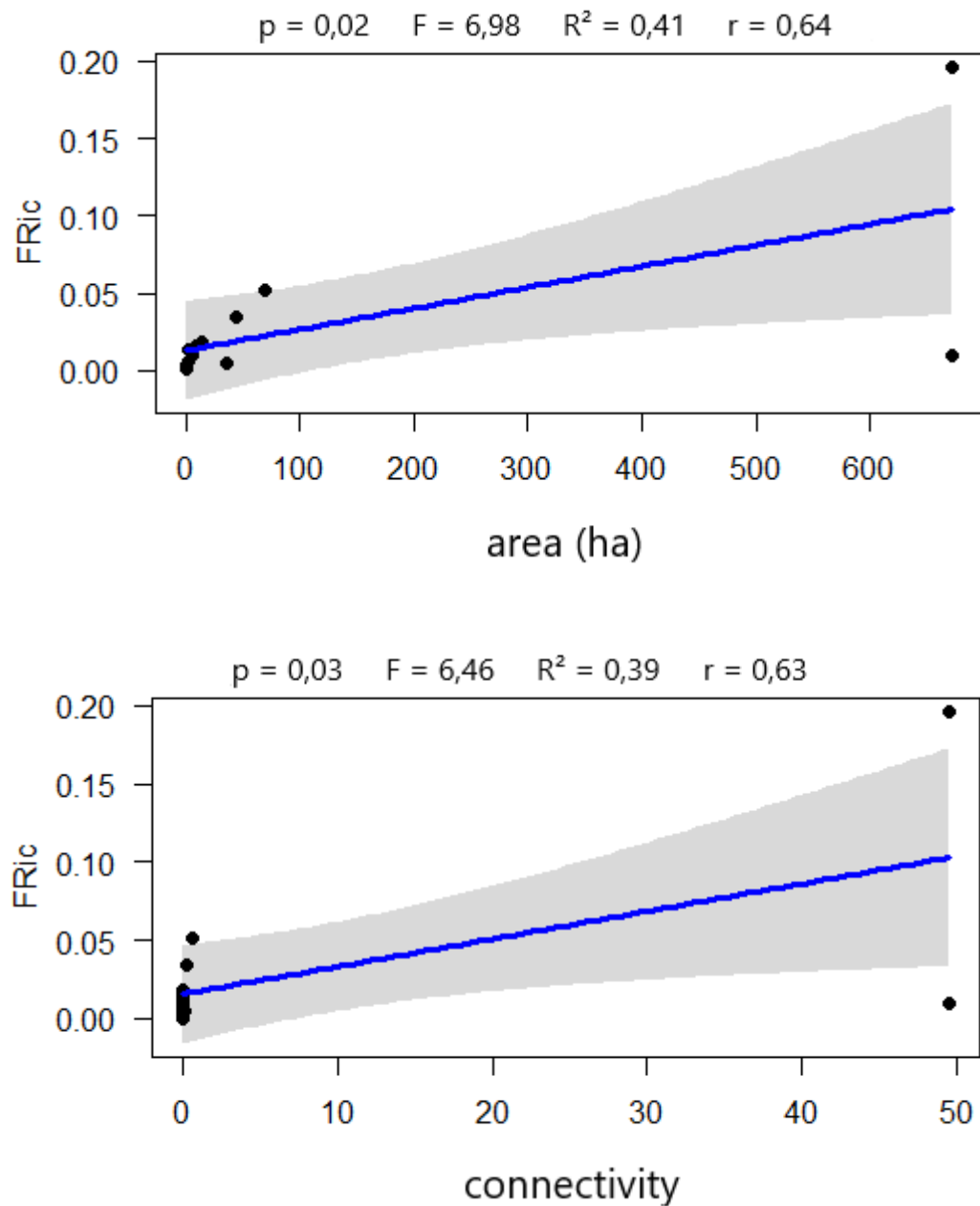
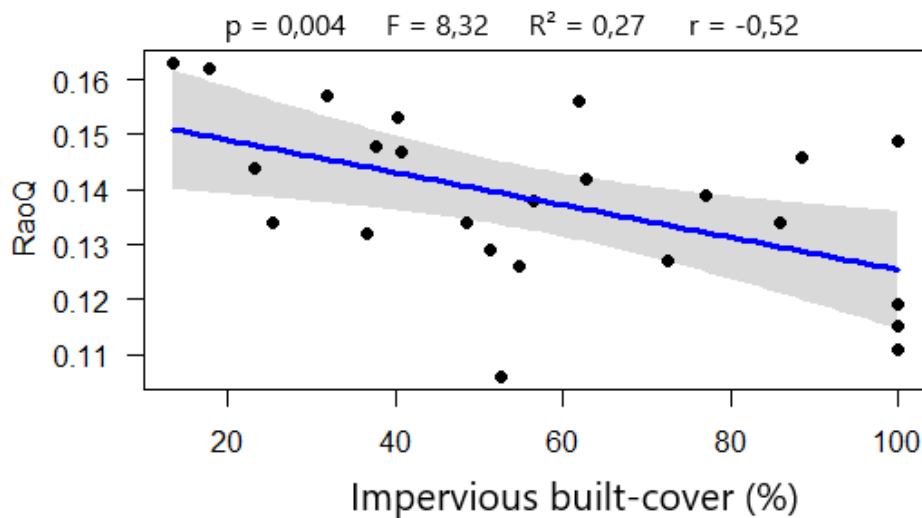


Figure 1.16: Influence of vegetation patch size and connectivity variables on FRic, in parks.

Regarding the Rao's Quadratic Entropy (RaoQ index), which incorporates relative abundances of species and functional differences in pairs between species, a significant relationship was found only with the impermeable cover variable (Figure 1.17). As a result, it was found that impervious built-cover influences RaoQ in a correlation of -52% in streets ($r = -0.52$; $F = 8.32$; $p = 0.009$) and -71% in parks ($r = -0.71$; $F = 9.98$; $p = 0.01$).

Streets



Parks

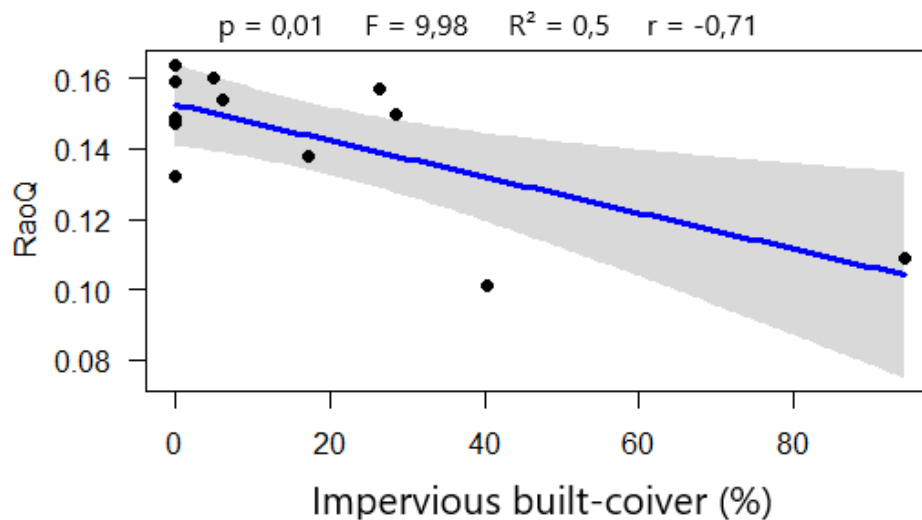


Figure 1.17: Influence of the impervious built-cover variable on RaoQ, in streets and parks.

1.5.4 Selection of correlation models between urban environmental variables, using the Akaike information criterion (AICc)

After analyzing the effect between each pair of environmental variable and response variable, we calculated the correlation analysis between the urban environmental variables. Thus, we verified which variables were highly correlated and which, therefore, overlapped their effects. Thus, we found that tree cover and impervious built-cover are -83% correlated in parks and -60% in streets, respectively,

(Figure 1.18 and 1.19). Therefore, we discard this relationship, since their effects overlap to explain the response variables.

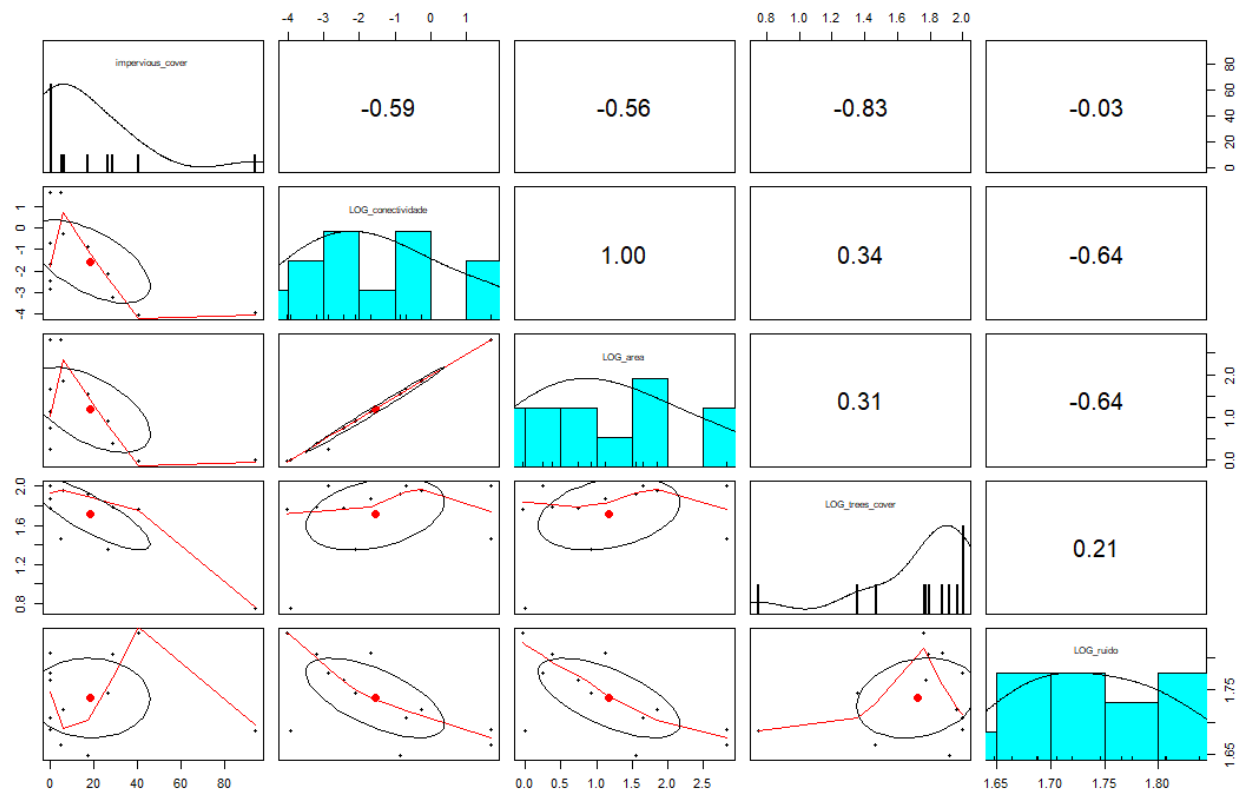


Figure 1.18: Result of correlation analysis between urban environmental variables, in parks

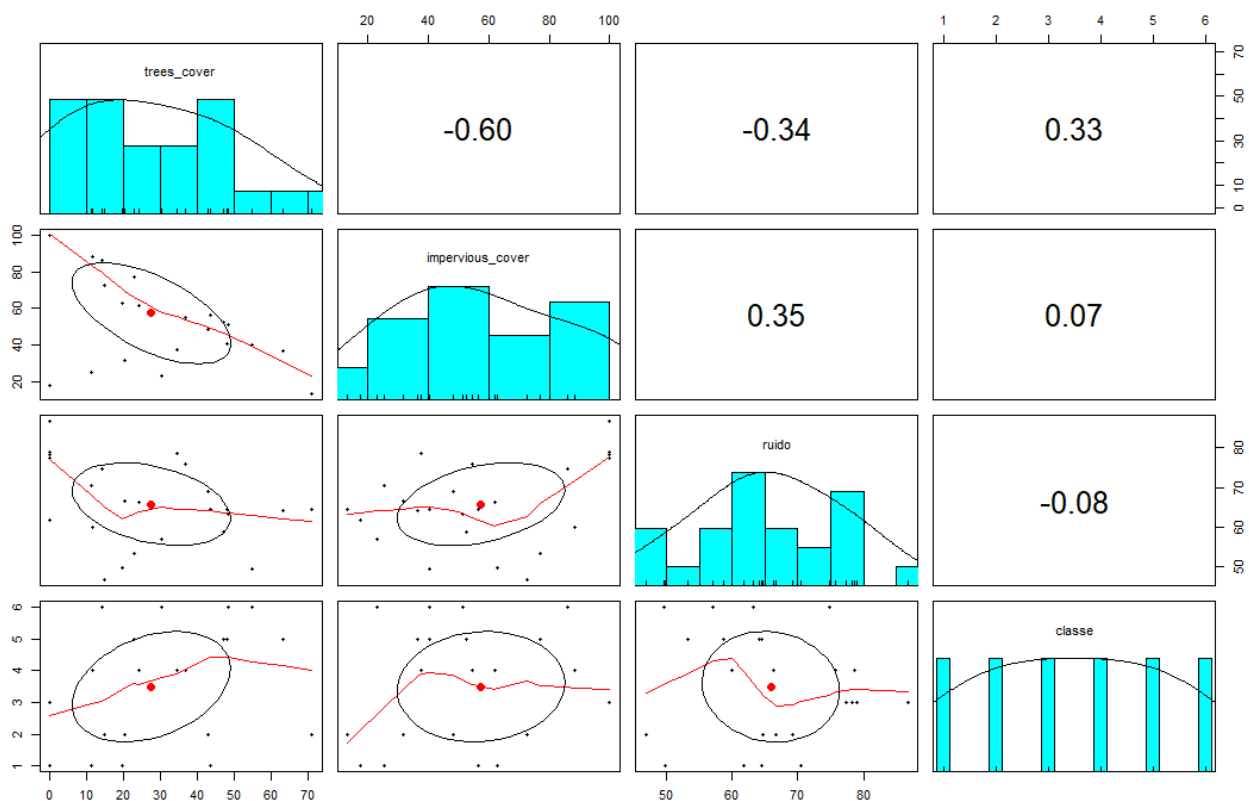


Figure 1.19: Result of the correlation analysis between urban environmental variables, in streets

Then, we used the Akaike information criterion for small samples (AICc), with $\Delta\text{AICc} < 2.0$ to assess which interaction models were significant. Considering the streets, the results validated the models confirming that: 1) The three variables: noise, tree cover and impermeable cover influence taxonomic richness and functional diversity (FD) and that 2) functional dispersion (FDis), functional richness (FRic) and Rao's Quadratic Entropy (RaoQ) have a negative relationship with impermeable cover. Analyzing the bivariate interaction models, we identified two models that were statistically significant: noise and impermeable cover, which have negative relationships with and richness ($\Delta\text{AICc} = 0$) and FD ($\Delta\text{AICc} = 1.24$; figure 1.20).

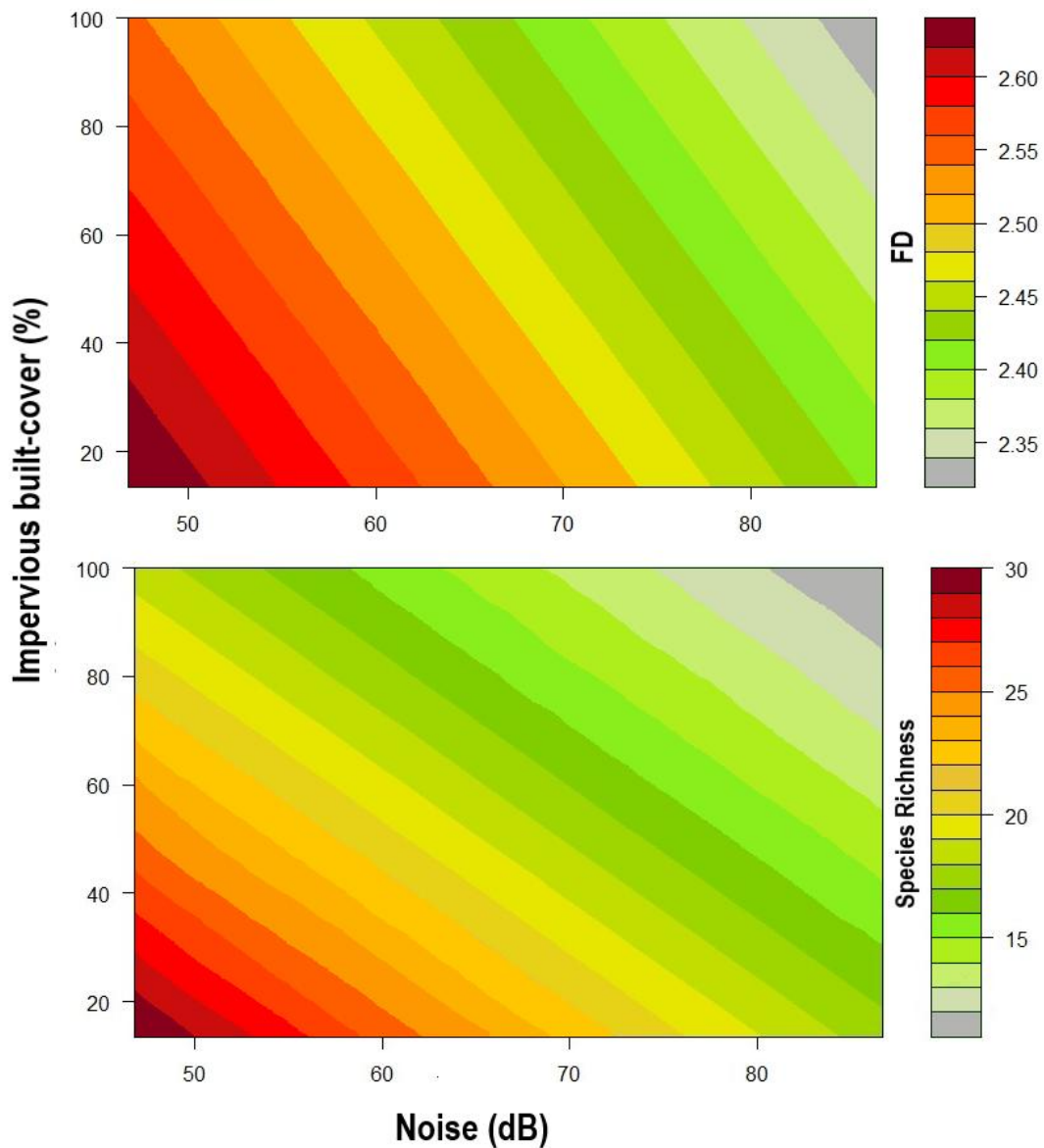


Figure 1.20: Bivariate model of the interaction between noise and impervious built-cover on richness and FD, in streets

In the parks, the results validated the models confirming that: 1) richness has a negative correlation with impervious built-cover; 2) functional dispersion (FD_{is}) has a negative correlation with impervious built-cover; 3) functional richness (FR_{ic}) has a positive correlation with connectivity and vegetation patch size and 4) Rao's Quadratic Entropy (RaoQ) has a negative correlation with impervious built-cover. Considering the bivariate models, the one that presented a significant result was 1) the interaction between connectivity (positive correlation) and tree cover (negative correlation) to explain FR_{ic} ($\Delta AIC_c = 0$).

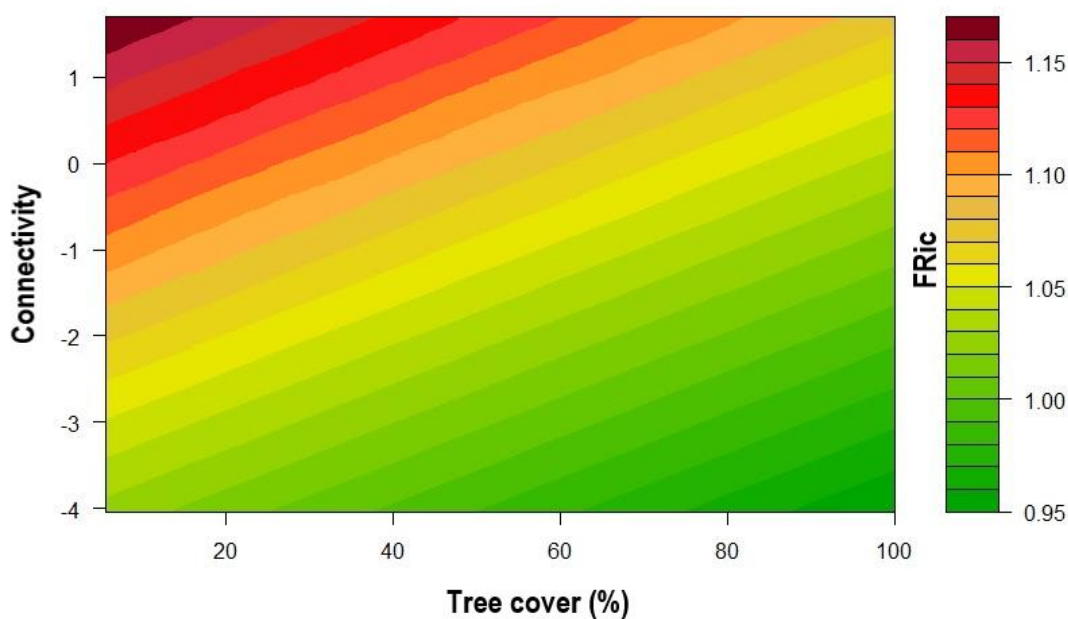


Figure 1.21: Bivariate model of the interaction between connectivity and tree cover on FRic in parks

1.5.5 LSCorridors simulations and taxonomic and functional aspects of the bird community

The analysis considering the different RSFI classes selected by the simulation showed that these classes can be statistically significant to identify possible groups of streets with similar urban environmental characteristics. As it was possible to verify, the division of the RSFI classes managed to group streets with similar environmental variables in the same class, so the functional diversity (FD) could be explained both by the urban environmental variables and by the division of the classes. Therefore, FD is explained by both impervious-built cover ($F = 13.14$; $p = 0.002$), tree cover ($F = 7.92$; $p = 0.01$) and noise ($F = 21.78$; $p = 0.0002$), and by the RSFI classes ($F = 5.39$ and $p = 0.004$; $F = 5.86$ and $p = 0.002$; $F = 3.39$ and $p = 0.02$) respectively (Figure 1.22). While the pair FD and impervious-built cover has an $r^2 = 0.23$, when adding the class variable, the effect of the sum of the two variables rises to $r^2 = 0.70$. In the case of the pair FD~tree cover + class, the $r^2 = 0.15$ for $r^2 = 0.69$; and the pair FD~noise + class, the $r^2 = 0.39$ goes up from to $r^2 = 0.69$.

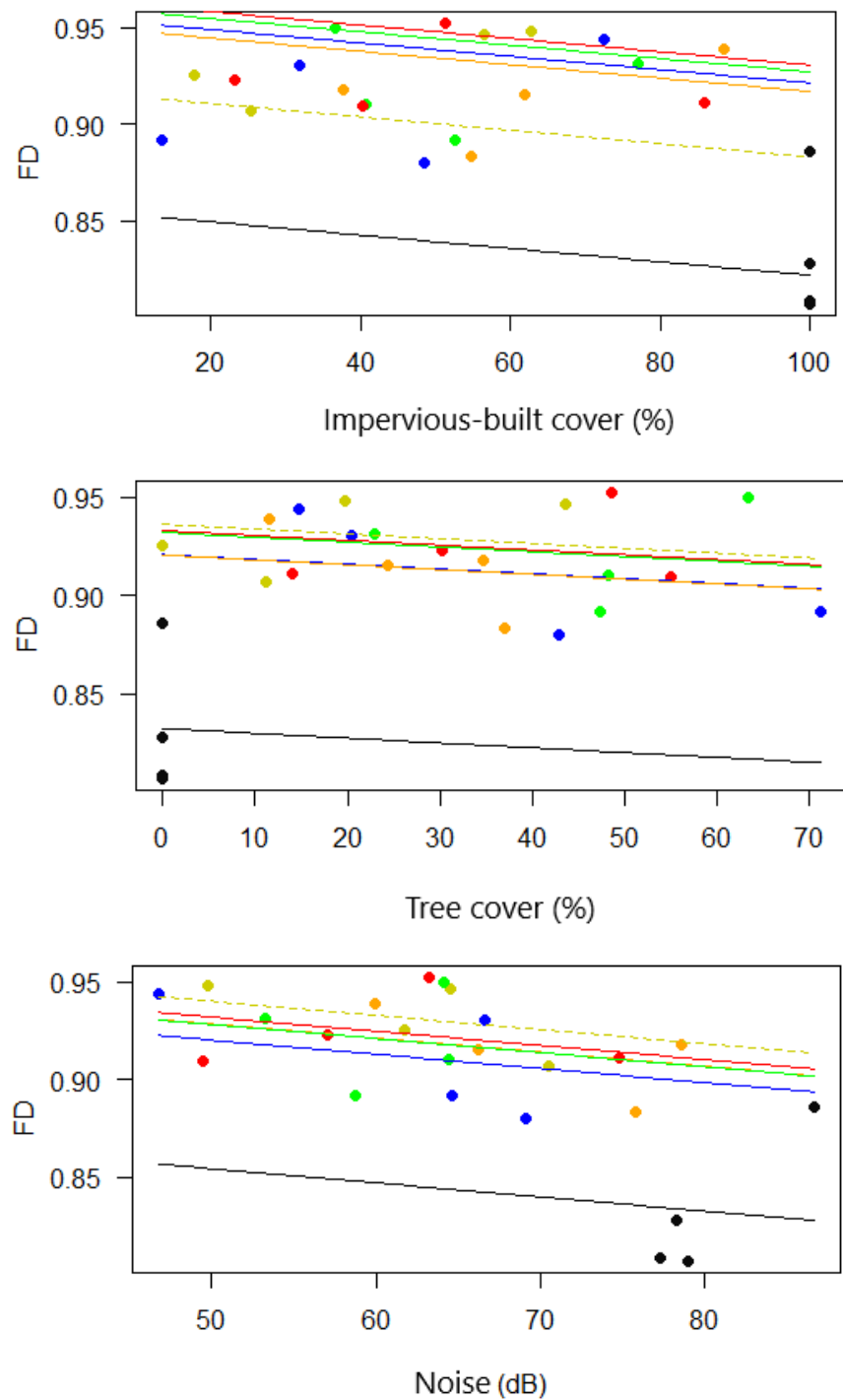


Figure 1.22: Influence of the interaction of the variables impervious-built cover, tree cover and noise and RSFI classes [class (RSFI=0); yellow class (RSFI of 900 1879); blue class (RSFI from 1880 to 2959); orange class (RSFI from 21960 to 4159); green class (RSFI from 4160 to 6049); red class (RSFI from 6050 to 8070)] in functional diversity (FD), in the streets.

Similar to the interactions of variables on functional diversity (FD), we found that the sum of the variables: impervious-built cover+class ($F = 14.48$; $p = 0.04$) and noise+class ($F = 13.42$; $p = 0.04$) have a significant effect on richness (Figure 1.23).

While the pair richness~impervious-built cover has an $r^2 = 0.42$, when adding the class variable, the effect of the sum of the two variables increases to $r^2 = 0.50$. In the case of the richness~noise pair, the $r^2 = 0.39$ rises to the $r^2 = 0.50$.

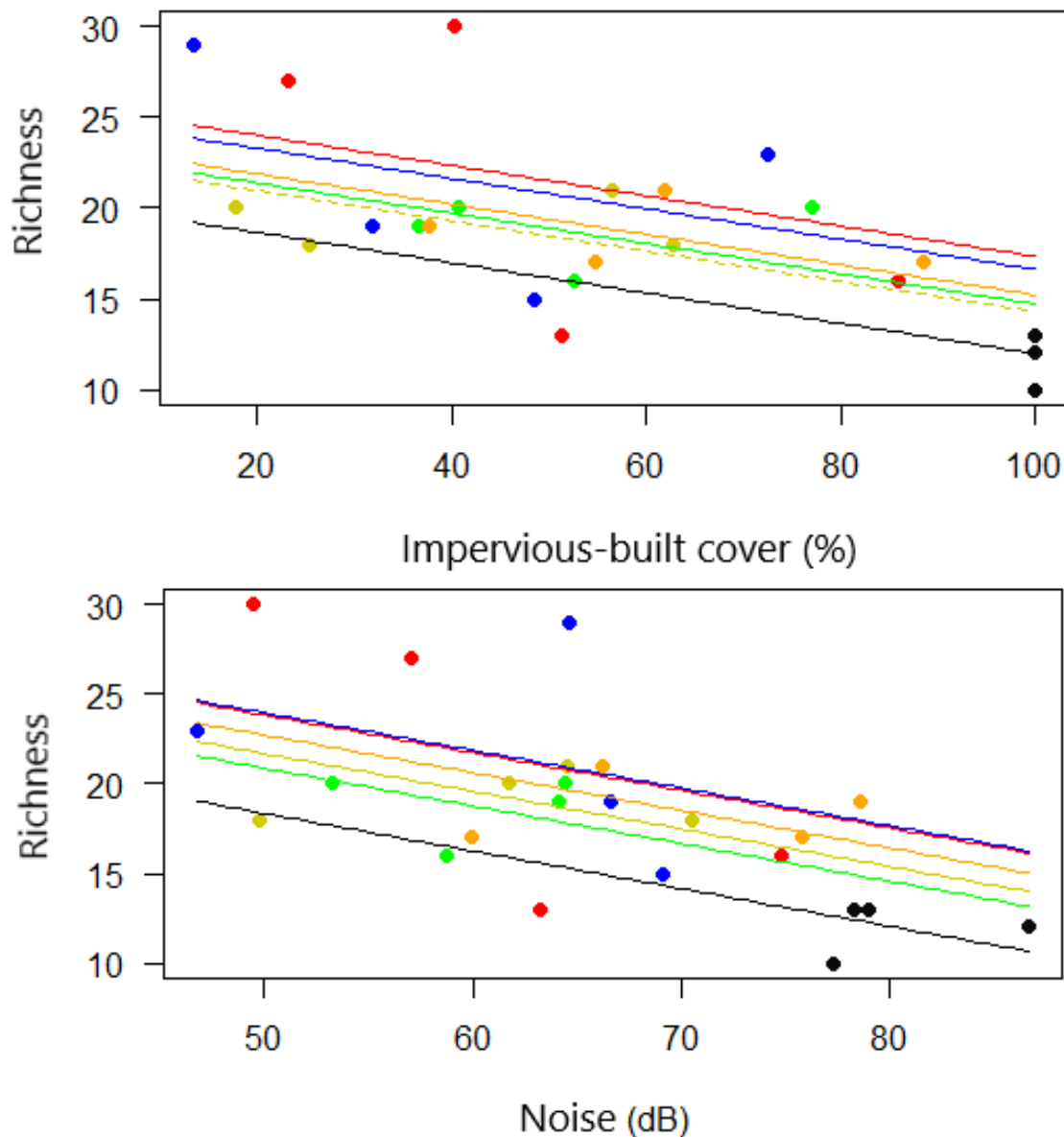


Figure 1.23: Influence of the interaction between impervious-built cover and noise variables and RSFI classes [white class (RSFI=0); yellow class (RSFI of 900 1879); blue class (RSFI from 1880 to 2959); orange class (RSFI from 21960 to 4159); green class (RSFI from 4160 to 6049); red class (RSFI from 6050 to 8070)] on taxonomic richness, in the streets.

Regarding the other indices, only the interaction between RSFI classes and tree cover proved to be significant to explain functional richness (FRic). This happened because tree cover defines the RSFI classes that in turn influences FRic

(Figure 1.24). Therefore, the interaction $\text{FRic} \sim \text{tree cover} * \text{class}$ has $F = 4.22$; $p = 0.04$ $p = 0.009$ and $r^2 = 0.76$.

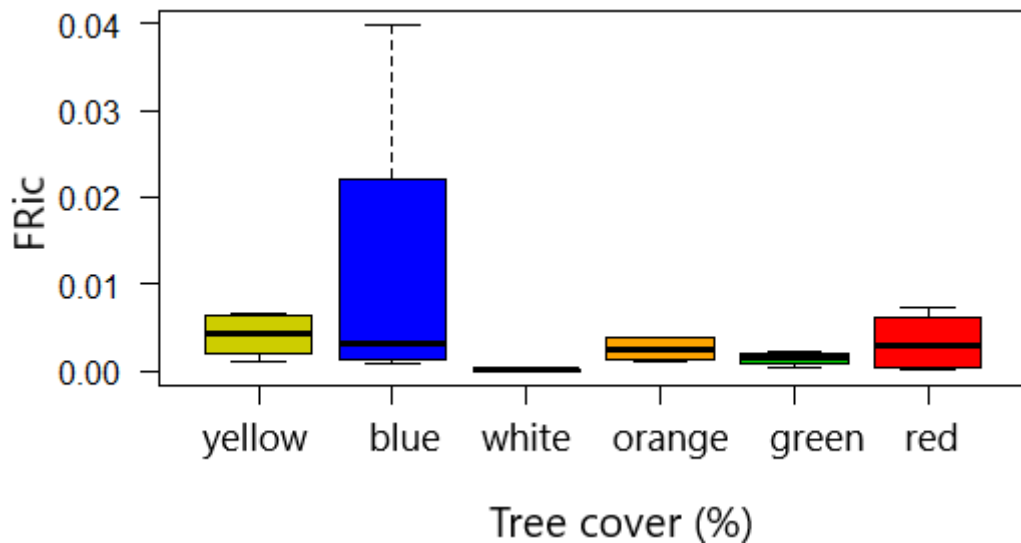


Figure 1.24: Influence of the interaction of the variables tree cover and RSFI classes [white class (RSFI=0); yellow class (RSFI of 900 1879); blue class (RSFI from 1880 to 2959); orange class (RSFI from 21960 to 4159); green class (RSFI from 4160 to 6049); red class (RSFI from 6050 to 8070)] on functional richness (FRic), in the streets

However, it is important to note that despite the division of streets into RSFI classes influences significantly functional diversity (FD), taxonomic richness and functional richness (FRic), when calculating the difference between the classes selected by LSCorridors, there was no significant difference (all classes have $p > 0.05$). The significant difference is between the effect of the white class (unselected routes - RSFI=0) in relation to the effect of colored classes [Selected routes: yellow class (RSFI of 900 1879); blue class (RSFI from 1880 to 2959); orange class (RSFI from 21960 to 4159); green class (RSFI from 4160 to 6049); red class (RSFI from 6050 to 8070)].

1.5.6 Multiscale analysis of landscape influence

The multiscale analysis of the influence of landscape on taxonomic richness and the number of bird records revealed that there is a significantly positive effect between richness and tree cover, in the streets, at scales of 50 ($F = 7.02$; $p = 0.01$; $r^2 = 0.21$), 100 ($F = 24.96$; $p < 0.001$; $r^2 = 0.51$), 250 ($F = 30.47$; $p < 0.001$; $r^2 = 0.56$), 500 ($F = 6.88$; $p = 0.02$; $r^2 = 0.20$) and 750 meters: ($F = 6.38$; $p = 0.02$; $r^2 = 0.19$; Figure 1.25).

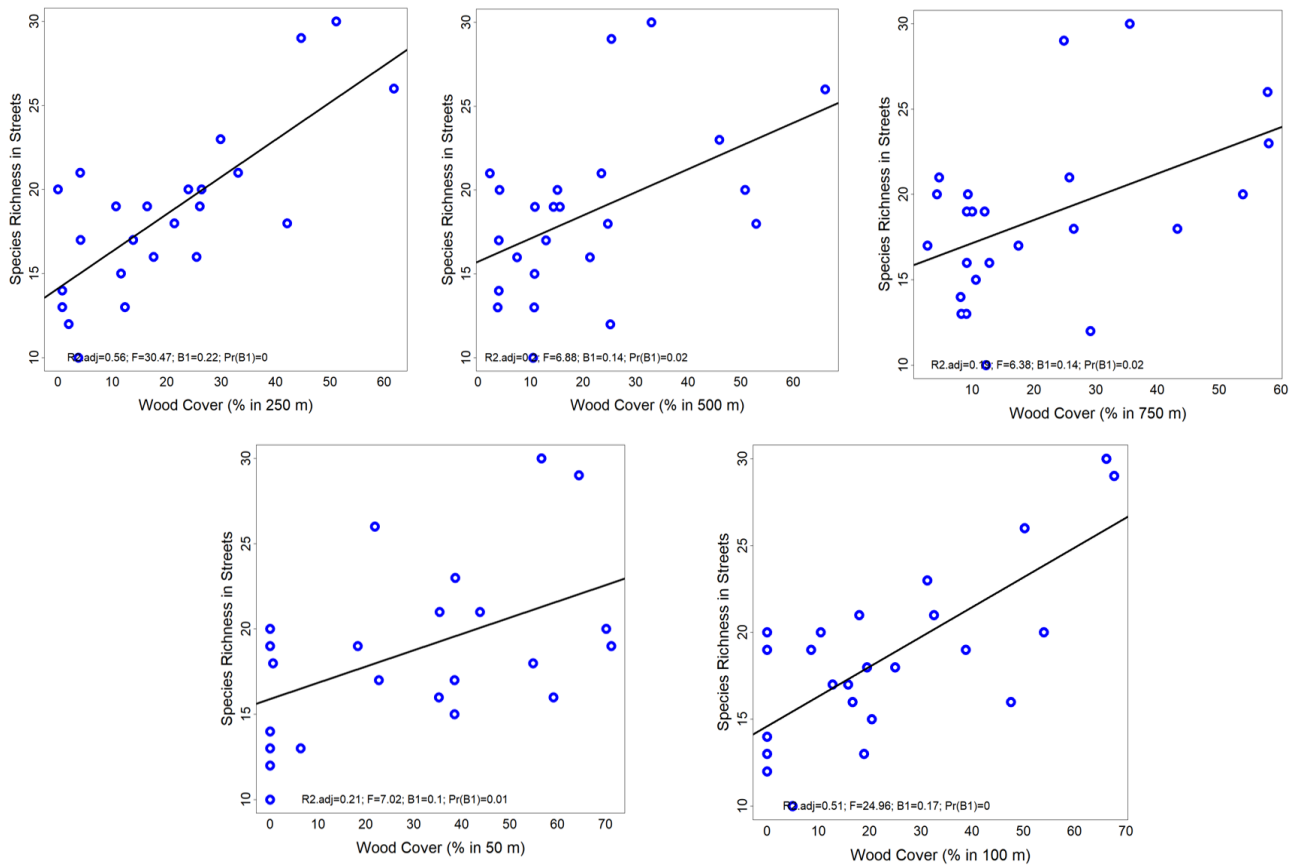
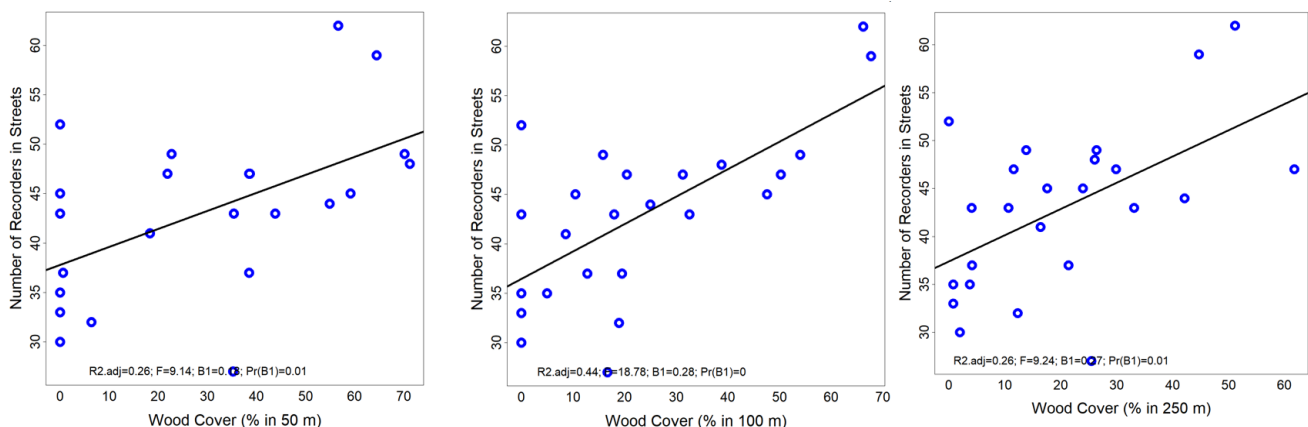


Figure 1.25: influence of tree cover on the bird richness, at scales from 50 to 750 meters in relation to the sampling point of streets.

The number of records and tree cover, in the streets, at scales of 50 ($F = 9.14$; $p = 0.01$; $r^2 = 0.26$), 100 ($F = 18.78$; $p < 0.001$; $r^2 = 0.44$) and 250 ($F = 9.24$; $p < 0.001$; $r^2 = 0.26$) also showed positively significant



relationships (Figure 26).

Figure 1.26: influence of tree cover on records of bird species, at scales of 50 to 250 meters in relation to the sampling point of streets.

A pattern similar to the number of records was registered between richness and herbaceous cover, in the streets, at the scales of 250 (F = 4.91; p = 0.04; r^2 = 0.15) and 500 (F = 5.10; p = 0.03; r^2 = 0.15) meters (Figure 1.27).

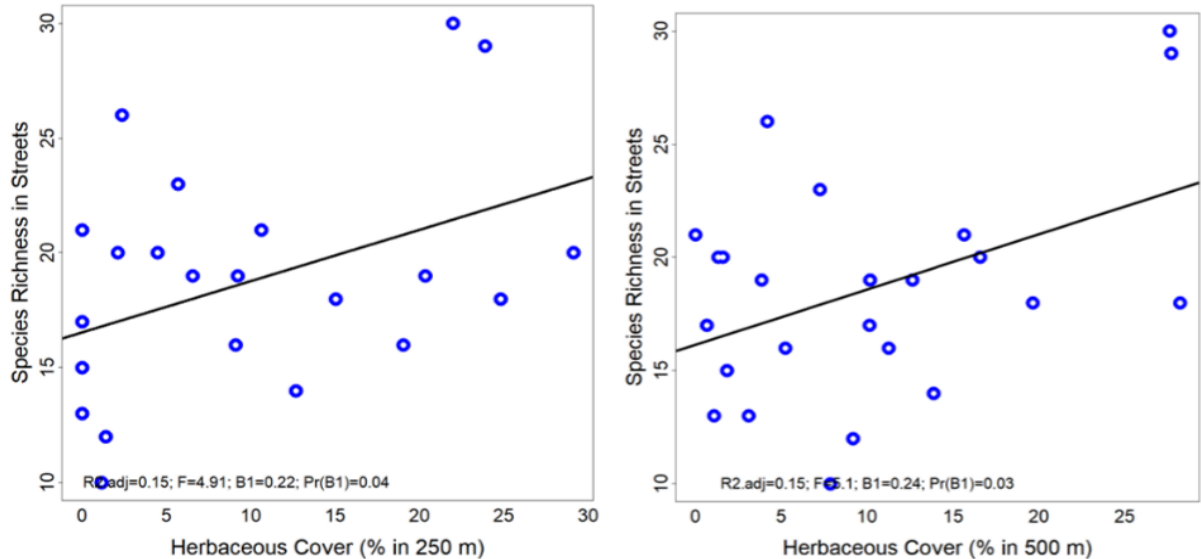


Figure 1.27: influence of herbaceous cover on the bird species richness, at scales from 250 to 500 meters in relation to the sampling point of streets

The relation between the number of records and herbaceous cover also was positively significant, in the parks, at scales of 25 (F = 5.89; p = 0.04; r^2 = 0.31), 50 (F = 6.07; p = 0.03; r^2 = 0.32) and 100 (F = 6.20; p = 0.03; r^2 = 0.32) meters (Figure 1.28).

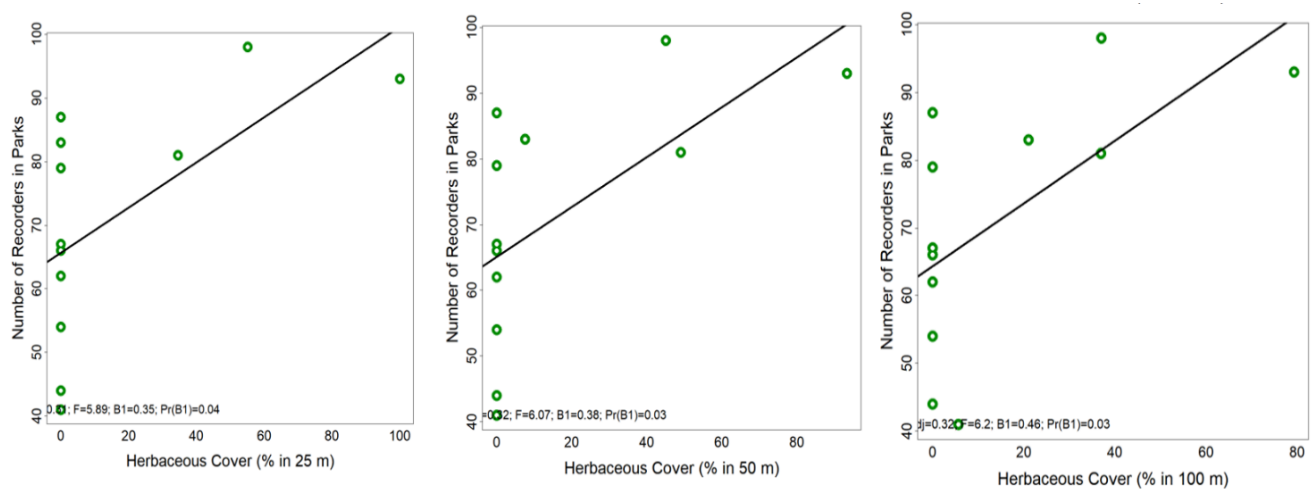


Figure 1.28: Influence of herbaceous cover on the records of bird species, at scales from 25 to 100 meters in relation to the sampling point in parks.

1.6 DISCUSSION

Our study provides evidence that impermeable-built cover is the main variable to explain the effects of landscape on taxonomic and functional richness. The proportion of impervious surface is negatively correlated with taxonomic richness and functional diversity (FD), functional dispersion (FDis), functional richness (FRic) and Rao's Quadratic Entropy (RaoQ) indices on the streets; and with the taxonomic richness, FDis and RaoQ in the parks. Thus, in all sampling points, whose buffer with a radius of 25 meters contained less the percentage of impermeable-built cover, the communities presented better taxonomic and functional characteristics.

Although impermeable-built cover is inversely correlated with the percentage of tree cover, there are other land uses/covers that must be considered such as water and herbaceous vegetation. Multiscale analysis of herbaceous vegetation revealed that it has a positive effect on taxonomic richness of streets (at a scale of 250 to 500) and on records in parks (at a scale of 25 to 100 meters). The percentage of tree cover explains taxonomic richness (at the multiscale from 50 to 750 meters), functional richness (FRic) and functional diversity (FD) only in streets, but they do not explain these variables in parks. This reveals that there are other factors that influence the taxonomic and functional characteristics of birds in parks; more important than the afforestation itself, is the existence of a diversity of uses and land cover, such as water, herbaceous vegetation and tree cover. Therefore, in parks, the presence of these three environments provide a higher richness and diversity in the functional characteristics of the species.

Herbaceous vegetation may be important in a city such as Bauru, in the transition zone between Atlantic Forest and Cerrado (SCHULZE 2015). Many species of birds need herbaceous vegetation to forage (eg *Furnarius rufus* and *Sicalis flaveola*) and to nest (eg *Vanellus chilensis* and *Athene cunicularia*) (SICK, 1997). So, having a highly wooded environment makes it difficult for species that need more open areas to live. Therefore, in cities located in Atlantic Forest and Cerrado transition environments, it's necessary to have urban green areas that mix both herbaceous and arboreal vegetation. These areas have important ecological roles in cities and provides resources and refuges for urban biodiversity (GRAVIOLA et al. 2021; ROSA, 2021; SCHÜTZ; ; SCHULZE 2015).

Also, in parks, the variables vegetation patch size and connectivity positively influence the functional richness of species (FRic), which means that such factors influence the richness of bird species from different food guilds, morphologies, substrate foraging and nesting sites. The presence of wooded streets can increase urban landscape connectivity, allowing the movement of different species between habitat patches (FERNÁNDEZ-JURICIC 2000; GRAFIUS et al. 2017; PENG et al. 2017). The interaction between tree cover and connectivity is significant to explain FRic, with connectivity having a positive correlation and tree cover a negative correlation. This may be related to the greater presence of forest species traits with the increase in tree cover, while in regions with less tree cover there are generalist and open area species, increasing the richness of traits.

Interestingly, noise did not influence any index within the parks. This shows that parks and gardens may be functioning as buffers that minimize the effect of noise within them - a result that contrasts with other studies that have seen that influence (BARBOSA et al., 2019; PENA et al., 2017). Contrary to this result, in the streets, noise is a limiting factor and is the variable that most appears in the models with statistical support AICc. In the street, the impervious-built cover is also a limiting factor, but noise appears to modulate some aspects of the community, such as the functional diversity and taxonomic richness. In parks, the amount of habitat and connectivity influence the community, while in the streets, birds are more exposed to disturbances such as noise.

Still considering the streets, our study revealed a very important aspect: if well planned, they can help to connect fragments of urban vegetation and serve as ecological corridors. Knowing that: noise negatively influences richness and functional diversity (FD); tree cover is positively related to taxonomic richness, functional richness (FRic) and FD; the Impervious-built cover has a negative influence on all indices; - it is possible to guide urban planning to create wooded streets, which also present gardens with different vegetation strata (from herbaceous to arboreal). Another point to consider is that, although noise has a negative effect on the streets, afforestation can reduce its effects.

Furthermore, the MLCC simulations showed that the LSCorridors program can be a very useful tool to identify the streets with the greatest potential to increase connectivity between the vegetation fragments in cities. Using the program, it is also

possible to identify which roads have the potential to function as multifunctional ecological corridors, allowing the circulation of bird species in urban areas (GRAVIOLA et al., 2021). As connectivity is an important factor in parks, implementing wooded streets can increase connectivity in squares and parks.

Wooded streets have a positive influence on avifauna: they increase the richness and diversity of birds (YOUNG et al., 2007), the functional aspects of the community (SCHÜTZ; SCHULZE, 2015) and the number of bird feeding associations (WHITE et al., 2005). These influences are stronger in urban areas where native trees predominate (IKIN et al. 2013). Wooded streets also improve urban mobility for birds (KENWORTHY, 2006), as they use them to move through urban landscapes (FERNÁNDEZ-JURICIC, 2000). Considering that Brazil is a tropical country, wooded streets also protect people from the sun and can improve microclimate conditions (VAILSHERY et al, 2013). Cities need to be planned in a manner that reduces negative impacts of urban landscape characteristics on the biosphere and that increases their ability to sustain biodiversity (ANGEOLETTO et al. 2019). If well planned, cities can provide good places to bird lives.

1.7 CONCLUSION

This study showed that, if well planned, cities can have an important role on bird biodiversity conservation. By connecting fragments of urban vegetation through wooded streets, we can create functional ecological corridors that contribute positively to taxonomic and functional richness and can reduce the negative effects of noise in the cities. Considering the streets, impervious-built cover is a limiting factor, but noise appears to modulate some aspects of the community, such as the functional diversity and taxonomic richness. In parks, the amount of habitat and connectivity influence the community, while in the streets, birds are more exposed to disturbances such as noise. Furthermore, considering the parks, we observed that tree cover may not necessarily leads to higher functional diversity but the herbaceous vegetation may be important in a city such as Bauru, in the transition zone between Atlantic Forest and Cerrado. More important than the afforestation itself, is the existence of different land cover/land uses, such as water, herbaceous vegetation and tree cover. Therefore, the presence of these three environments provide a higher richness and diversity in the functional characteristics of the species.

Multiscale analysis also revealed that herbaceous vegetation has a positive effect on taxonomic richness of streets and on records in parks and that tree cover (%) explains taxonomic richness at the multiscale from 50 to 750 meters. Finally, the MLCC simulations showed that LSCorridors program can be a very useful tool for urban planners if they want to simulate which roads have the potential to function as multifunctional ecological corridors. Thus, the set of such results reveal interesting guidelines to urban planning: If we want to reduce the negative impacts of urban landscape characteristics on birdlife, we must study the land use/cover, analyze the local fauna and understand how animals occupies the landscape. By doing this, we can create better environments that contribute positively the biodiversity within cities.

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CHAPTER II

Colorful cities: urban bird assemblages can be as colorful as those from nonurban systems in the Neotropics³



³ This chapter is the full version (main text and supplementary material) of the research paper: “Colorful cities: urban bird assemblages can be as colorful as those from nonurban systems in the Neotropics”, submitted to the journal *Landscape and Urban Planning*.

2.1 INTRODUCTION

Urbanization is associated with the loss of biodiversity (GRIMM et al., 2008), a pattern that is not random across phylogenetic and functional diversities (LA SORTE et al., 2018; MCKINNEY, 2006). The harsh conditions of cities (e.g., high noise and air pollution), can be considered as an environmental filter that leads to a decline in bird species color richness, while leading to an increase in the biomass of urban exploiter species (SACCO et al., 2015; ARONSON et al., 2014). Urban bird assemblages, for instance, are dominated by a subgroup of regional species pools that tend to be broad-range generalists, such as omnivorous species (SOL et al., 2017, 2020; LA SORTE et al., 2018). Since urban landscapes are generally inhabited by taxonomically and functionally impoverished bird communities, it has been hypothesized that the environmental filtering process could also lead to the reduction in bird plumage color diversity of urban bird communities (LEVEAU, 2019a).

Color are vital for finding food, attract possible mate, hide from predators, identify their own species, to attract attention when trying to distract predators and more (WITHGOTT, 2000); also colorful feathers serve lots to attract attention when courting (SIEFFERMAN; HILL, 2005; WITHGOTT, 2000) and to recognize non-mimetic parasitic eggs (ŠULC et al. 2016). Birds see more colors than humans and are enable to discriminate a broad range of colors (STODDARD et al. 2020). Avian color variation has been addressed at large-scale events outside cities, showing that environmental factors can be major drivers (DALRYMPLE et al., 2018; DELHEY, 2018). Under some conditions (e.g. when pigment production is dependent on food resources), bird color diversity and intensity may be positively associated with habitat quality (DALRYMPLE et al., 2018); thus it could be hypothesized that bird communities in cities would be less colorful than birds in more preserved ecosystems. Although there are strong negative associations between birds and the urbanization process, avian community plumage color diversity has only recently been addressed by Leveau (2019a) in three cities of the Argentinian Pampas region. In his article, Leveau (2019a) noted that highly urbanized areas in subtropical cities in Argentina were inhabited mainly by 'gray-colored' birds, while sites with higher habitat diversity were inhabited by yellow and green-colored species.

Notably, he used a method called 'color plumage patches' to describe the dominant color in birds' body parts (e.g. head, wing), concluding that the degree of

urbanization intensity played an important role in determining bird plumage color diversity, leading to color homogenization. This method has two worrisome pitfalls: (1) bird parts are being considered as study units while these may show critical changes in size and form in this taxon, and (2) Leveau considers body parts with several colors as categories differing in form from the basic colors, e.g. white-black representing a different categorical unit that is not associated with white or black.

Given that the tropics have the most colorful birds (COONEY et al. 2022;. CARBALLO et al., 2020) and highly biodiverse urban landscapes, such as many Neotropical cities, harbor highly diverse and colorful bird communities, even in highly urbanized and stressful contexts, such as streetscapes (GUIMARÃES et al., 2020; PENA et al., 2017), we were surprised to see Leveau's (2019a) findings and conclusions. As Leveau (2021) recently stated, to better understand the mechanisms that modulate bird plumage color in cities, interspecific studies that analyze bird color diversity along urbanization gradients are still needed (LEVEAU, 2021).

Thus, in this study, we tested whether Leveau's (2019a) findings were generalizable to other Neotropical urban landscapes located in the Northern and Southern Hemispheres with distinct occupational histories and different bird species pools (Bauru, Brazil; Xalapa, México). Colorful birds such as parrots, parakeets, and hummingbirds are common within many Neotropical cities (BARBOSA et al., 2020; GUIMARÃES et al., 2020; SILVA et al., 2020; PERILLO et al., 2017; PENA et al 2017), thus, we did not expect Leveau (2019a) to be applicable to conditions in Bauru and Xalapa. To do this, we explored both Leveau's (2019a) color plumage patches method and developed a different approach to assess the bird color richness and diversity ("color percentage" method) that better describe bird coloration.

2.2 MATERIAL AND METHODS

2.2.1 Study areas

We conducted our study in two Neotropical cities located in similar latitudes of the Northern and Southern Hemispheres, but with widely different occupational histories, landscape structures, and bird species pools (Bauru, Brazil, South America; Xalapa, México, North America; Figure 2.1). Bauru is a medium-sized city in the central-west region of the state of São Paulo, Brazil (22°18'55" S, 49°3'41" W). The city occupies an area of ~ 69 km² with 344 000 inhabitants (SEMMA, 2015) and is located in the transition zone between the Atlantic Forest and Cerrado (Brazilian Savanna) biodiversity hotspots. The urban landscape of Bauru is highly heterogeneous, presenting rivers surrounded by riparian forests with different conservation levels and native forest patches embedded throughout the urban matrix (SEMMA, 2015). Xalapa, the state capital of Veracruz-Llave, México (19°32'20" N, 96°54'35" W), is also a medium-sized city that occupies an area of approximately 64 km² and ~ 500,000 inhabitants (INEGI, 2010). Approximately 40% of Xalapa's landscape is comprised of green cover. In contrast to Bauru, the urban landscape of Xalapa harbors highly preserved cloud-forest patches mainly in the periurban region, while the city's downtown (oldest and most historical areas) is highly dominated by built-up structures (FALFÁN et al., 2018). For landscape analysis, used the maps already produced (Figure 2.1): for Bauru, we used the one created for chapter 1 (see details on section 1.3.2); for Xalapa, we used map available on Red de Ambiente y Sustentabilidad, Instituto de Ecología (Xalapa, Mexico).

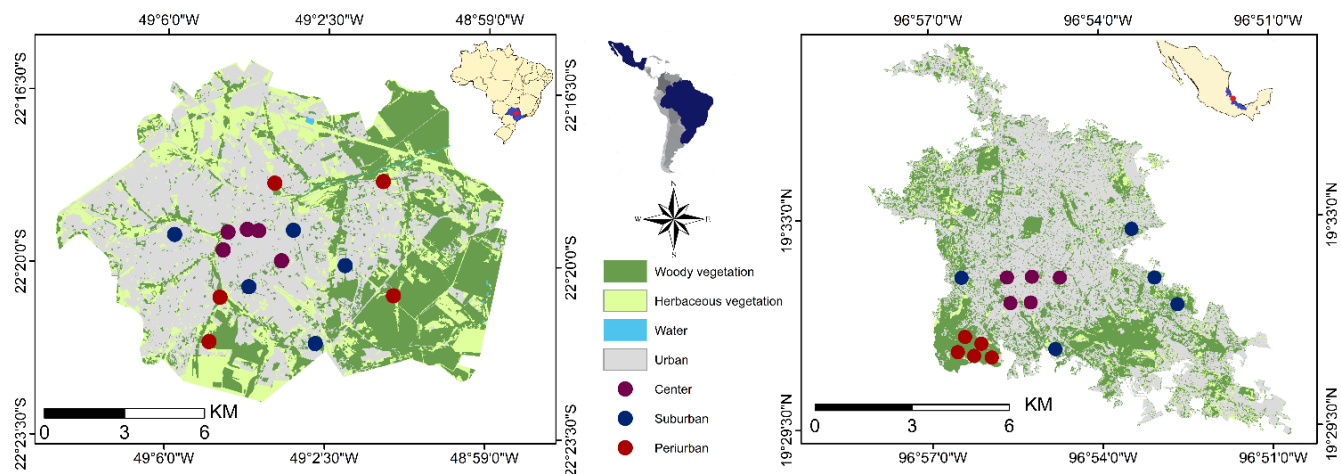


Figure 2.1: Land-cover map of Bauru (São Paulo, Brazil) and Xalapa (Veracruz, México)

2.2.2 Bird surveys and urban landscape variables

To mimic the data-gathering procedures of Leveau (2019a), we conducted bird surveys at 15 sites spread throughout three different parts of each city (Leveau, 2019b), using the point count method (LLOYD et al., 2000), during the local summer and spring seasons over 2 years in 2018 and 2019. The observations were conducted, using the point count method (LLOYD et al., 2000), often used for bird sampling in urban and forest landscapes (PENA et al., 2017; TOLEDO et al., 2012; FONTANA et al., 2011; VOLPATO et al., 2009). In this method, each point count is selected and the observer stops at predefined spots, recording all the birds seen or heard for a predetermined time (GREGORY et al., 2004), which in our study was 10 min (TOLEDO et al., 2012). Bird observations were conducted during the mornings (GREGORY et al., 2004; LLOYD et al., 2000) in the summer and spring seasons of 2018 and 2019. This period coincides with the breeding period of most species, including migratory species (SICK, 1997). The sites were visited six times, three each in summer and spring.

To select our sampling sites, we followed a similar approach to the one used by Leveau (2019b), selecting them according to their position in relation to a gradient of urbanization (center, suburban, and periurban). We preferred an urban center to the periurban zone approach [which has been heavily criticized; (MCDONNELL & HAHS, 2008); yet, we followed the method for comparability with Leveau's (2019a) study].

In each city zone, we selected five 25-m-radius circular plots in the 'urban center' (main commercial and historical districts; hereafter center), five in 'suburban zones' [following Leveau's (2019b) study, we considered suburban as neighborhoods outside the center, generally composed of houses with yards] and five in 'rural' and 'periurban' zones (some periurban zones were comprised of a mixture of crops and forest patches in Bauru; hereafter periurban). It should be highlighted that by following Leveau's (2019b) urban classification method, we represented different degrees of urbanization intensity and environmental conditions throughout the urban landscape. We found differences in the arrangement of sampling sites in Bauru and in Xalapa, mainly associated with the local landscape structure. For instance, in Bauru the center harbored many green spaces, while in Xalapa the center was

heavily urbanized. For both cities, we developed land-cover maps and calculated the habitat diversity and proportion of built-up cover (representing a measure similar to the 'impervious built-cover' used by Leveau 2019a,b) surrounding each sampling site.

We used land-cover maps for the cities of Bauru and Xalapa to proceed with the landscape analysis. For Bauru, the land-cover map was made with ArcGIS 10.4 software, using 25-km² RapidEye satellite images acquired in 2016, with 5-m spatial resolution, and five spectral bands from the online catalogue of the Brazilian Ministry of the Environment. For Xalapa, we used the map available in Falfán et al. (2018). Both maps were classified, using the Maximum-Likelihood classifier tool from ArcGIS 10.4 into classes: 1) arboreal vegetation, 2) herbaceous vegetation, 4) buildings, 5) paved roads, and 6) bodies of water (LEVEAU, 2019b). We analyzed the 25-m plots surrounding the sampling points, following the method used by Leveau (2019b), due to our interest in the diversity influence of the local habitat (Figure 2.2). The urbanization intensity gradient was represented by an impervious built-cover (%), which is the sum of building cover (%) and paved road cover (%). We calculated the landscape diversity (Shannon diversity index) of all 30 sites within the 25-m radius buffers (as done by Leveau, 2019a). The habitat diversity was calculated for each circle, using the Shannon Index.

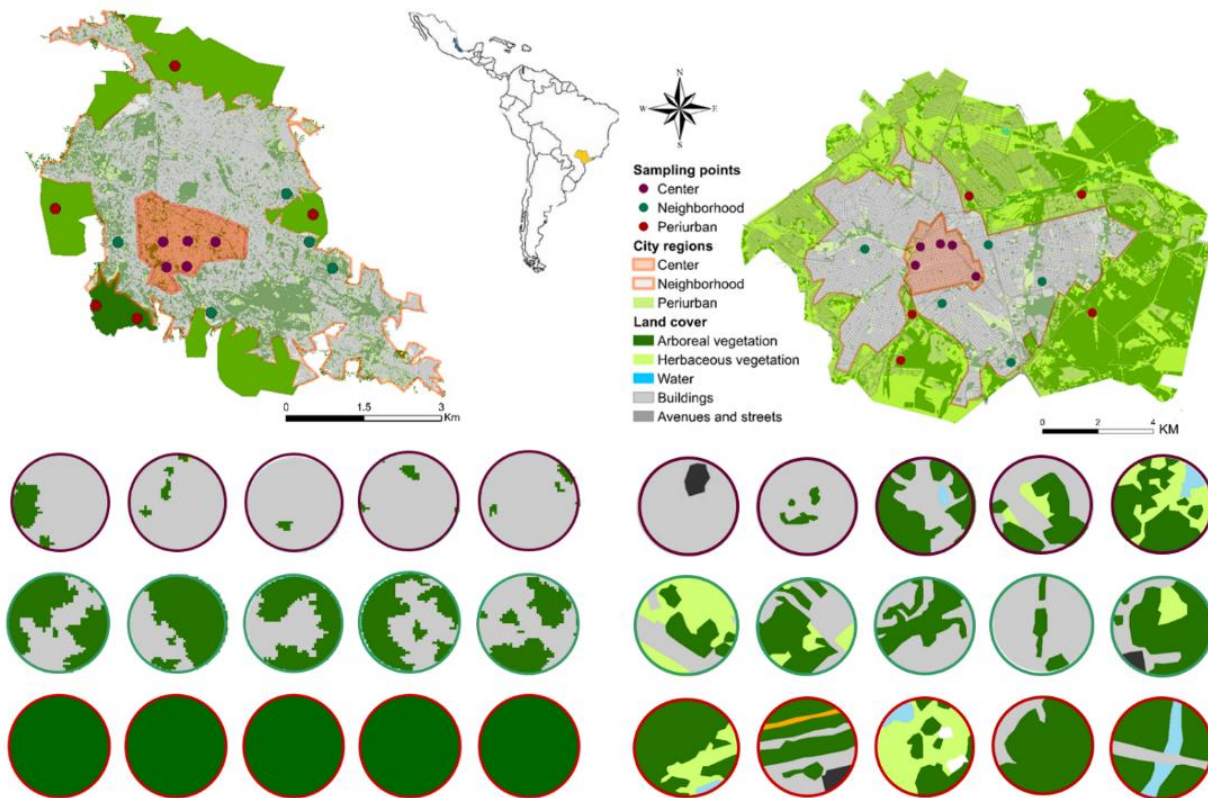


Figure 2.2: Sampling points distribution in urban landscape of Bauru (São Paulo, Brazil). The circles below represent the 25-m radius sampling points land cover.

2.2.3 Bird coloration quantification using color plumage patches method from Leveau (2019a)

This method considers only the bird's color plumage. For this study, we generated a matrix with colors using the color plumage patches method (LEVEAU, 2019a) that classifies colors according to birds' body parts (e.g. head, wing). To calculate bird coloration, we first generated a matrix with plumage colors, using the same characteristics considered by Leveau (2019a): 1) crown, 2) head, 3) cheek, 4) mantle, 5) primaries, 6) wing coverts, 7) back, 8) rump, 9) tail, 10) belly, 11) breast, and 12) throat. We also considered four bird characteristics: 1) dimorphism, 2) polymorphism, 3) plumage iridescence, and 4) body size. To describe species coloration, we used male-only photos, which were taken from Handbook of Birds of the World online (<https://www.hbw.com>). We also created binary categories for body patches that had two colors, in which the first color was the dominant (LEVEAU, 2019a).

We created a matrix of color characteristics (Appendix B and C) to calculate a dissimilarity distance between species, using the Gower distance with the *gowdis* function of the FD package (LALIBERTÉ et al., 2015) in R (R CORE TEAM, 2020).

With the dissimilarity values, we calculated two diversity indices originally proposed for functional diversity (FD) itself, based on the presence/absence of species data (Petchey & Gaston, 2002), and functional dispersion (FDis; LALIBERT; LEGENDRE, 2010), which considers the relative abundances of species. It should be emphasized that we used color instead of species attributes to calculate FD and FDis. We used the *hclust* function of the *stats* package (R CORE TEAM 2020) and the *treedive* function of the *vegan* package (OKSANEN et al., 2020) to calculate the hierarchical clustering and FD for each sampling point. Therefore, we simulated null distributions (SWENSON, 2014) by reshuffling species 999 times, using the richness method for FD and the independent swap method for FDis in the R *picante* package (Kembel et al., 2010). Finally, the observed and expected diversity values were compared by calculating a standardized effect size index (SES):

$$SES = D_o - \bar{X}_{Dnull} / SD_{Dnull}$$

where D_o represents the observed diversity values $\bar{X}_{Dnull}$ the mean null diversity values, and SD_{Dnull} the standard deviation of null diversity values. Subsequently, we built a species matrix and the number of individuals for each color type to calculate the Bray-Curtis dissimilarity indices among transects. Non-metric multidimensional scaling (NMDS) was performed, using the *metaMDS* function in the *vegan* package. Finally, the NMDS axes were associated with the impervious built-cover percentage and habitat diversity, using the *envfit* function in *vegan* to identify the plumage traits associated with the various environmental variables.

2.2.4 Bird coloration quantification using a new method: color body percentage

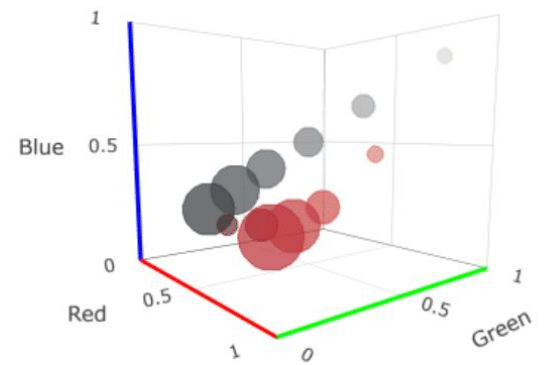
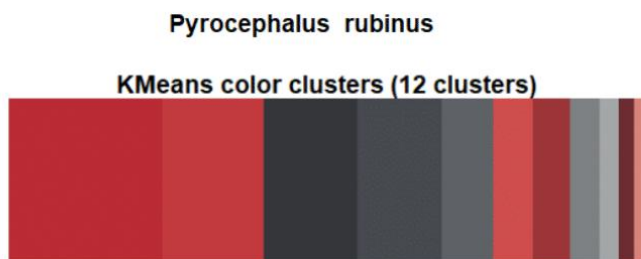
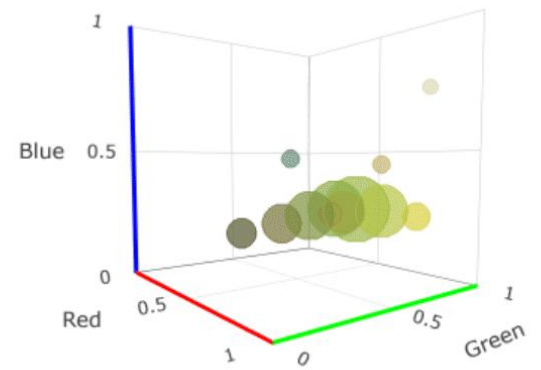
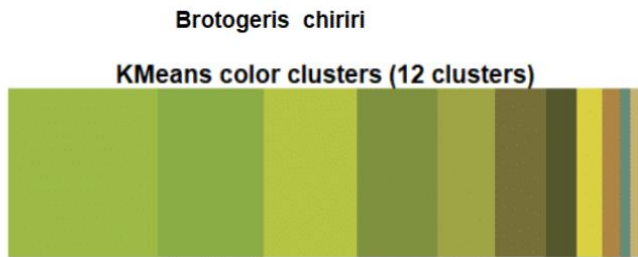
Since we aimed at assessing avian body color more accurately and avoiding some of the pitfalls of the color plumage patches method, we developed the color percentage method. For this, we used professional bird drawings from the *Handbook of Birds of the World Online*; (<https://www.hbw.com>) to quantify the colors, using the *countcolors* package (WELLER, 2019) in R (R Core Team, 2020).

We chose drawings instead of photos, because photos are often taken at different angles and can have variable lighting, depending on the camera, habitat, time of the day, and weather in which the photo was taken. Since we used the

professional drawings of each male of all species found in the cities, from the Handbook of Birds of the World Online. These drawings were already standardized, which would have made it easier to calculate the colors, starting from the same viewing angle. Then we calculated the color percentages using the `countcolors` package in R (WELLER, 2019). This package counts colors within color ranges in images and provides a masked version of the image with targeted pixels changed to a different color (WELLER, 2019). This classification generated an automatic output table file with the pixel interval proportions of each red/green/blue (RGB) color (Figure 2.3).

However, we should recognize that our method also has limitations: it is only a two-dimensional representation of birds that are affected by drawing techniques. For example, in drawing it is common to add some colors just to give light and shadow effect. For this reason, the pixel intervals were adjusted and summed through a hand-held bird-by-bird conference, to check if the results obtained were equivalent to the photographs and the description of the birds.

a) Bauru, São Paulo, Brazil



b) Xalapa, Veracruz, México.

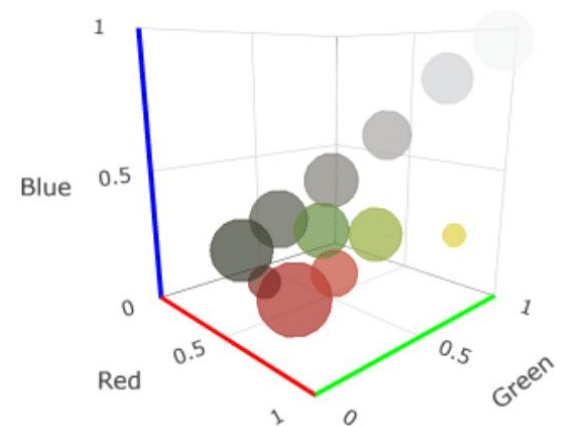
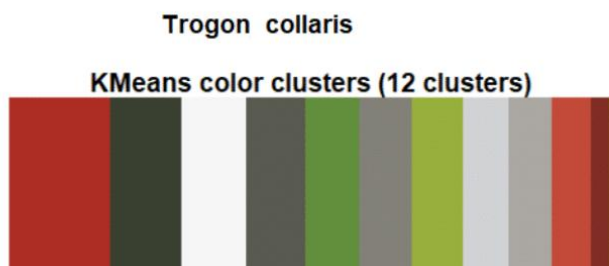
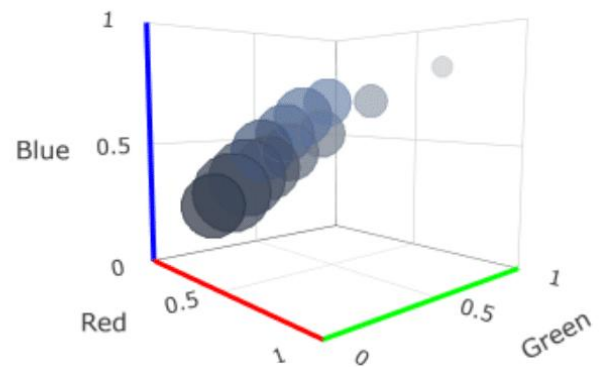
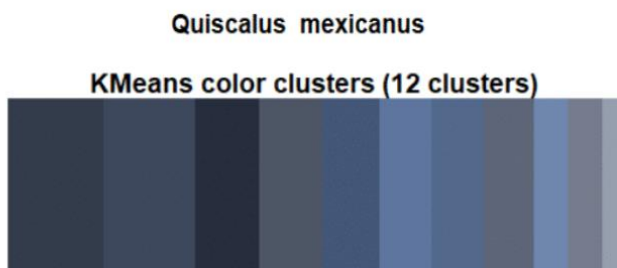


Figure 2.3: examples of pictures and graphics generated by the analysis, using the countcolor package. They represent the proportions of color extracts based on k-means clustering and the proportion of RGB colors. We have two examples of 133 species from both cities: a) Bauru, São Paulo, Brazil and b) Xalapa, Veracruz, México.

Thus, based on this automatic classification, to access all colors from the entire community, we used a figure containing the drawings of all male from the species to identify all colors present in the pixels of all images. One of the outputs of this procedure is a matrix with the percentage of colors of each pixel's value color intervals. However, some intervals represented only shades of the same color, caused by the drawing technique. Thus, to minimize the effect of this issue on our results, we grouped color shades by taking into account our 30-color palette and consulting photographs of the addressed species and color description available in the *Handbook of Birds of the World Online*; the colors that contain 'iris' are iridescent (Figure 2.4).

a) The first row represents all the bird colors found in all the cities, the second row, the colors chosen to be part of the 30-color palette



b) Colors in the 30-color palette



Figure 2.4: all bird colors found in all cities and the 30-color palette used in the color percentage method

From the pixel proportions of each RGB color, we obtained the color percentages for each species (Appendix D and E). We considered all bird patches, including legs and beaks, since these body parts can comprise considerable proportions of some species. For example, the Snowy Egret (*Egretta thula*) has long yellow and black legs and the Toco Toucan (*Ramphastos toco*) has a very large orange beak (SICK, 1997). Thus, this color percentage method classified colors as numerical variables, based on a color palette defined by pixel intervals and produced a continuous description of bird color.

2.2.5 Calculating bird color richness and diversity

2.2.5.1 Color richness and diversity based on color plumage patches method from Leveau (2019a)

Using the plumage color matrix generated, based on the color plumage patches method (Table S1), we performed the same procedures that were followed by Leveau (2019a). Thus, we calculated the dissimilarity distances between species, using the Gower distance with the *gowdis* function of the functional diversity (FD) package (LALIBERTÉ et al., 2015) in R (R Core Team, 2020). With the dissimilarity values, we calculated two diversity indices originally proposed for FD: FD itself, based on the presence/absence of species data (PETCHEY & GASTON, 2002), and functional dispersion (FDis; (LALIBERTÉ & LEGENDRE, 2010), which considers the relative abundances of species.

2.2.5.2 Color richness and diversity based on the color percentage method

Here, we did not repeat the same procedure as in Leveau (2019a) to analyze color richness and diversity using the color percentage method. Here, we used other metrics that describe bird color in Bauru and in Xalapa differently. Some of the indices used by Leveau (2019a) take into account species abundances, which may be a biased approach due to the predominance of some bird colors of superabundant gregarious birds common in Neotropical cities, such as native pigeon and dove (Columbidae) species (SILVA et al., 2020). Therefore, at each sampling point in both cities, we calculated the average color richness per bird species, total color richness (total number of colors found in the community), and the color diversity (color Shannon diversity index).

Then we calculated the frequency of each color in the city zones (center, suburban, and periurban), using the rule of three. To visualize the color distribution in the zones, we created pictures based on the frequency and percentage of colors, using the *countcolor* package (WELLER, 2019). The pictures were created using Excel. The cells of the spreadsheet were standardized with the same sizes so that each cell could represent a pixel of the image. To add the colors, we used the RGB values from the 30-color palette, generated in the previous analyses. Twelve images

were created, based on the color proportions found in each zone (Figure 2.5). Finally, using the countcolor package, we extracted the color proportions, based on k-means clustering, to determine the centers of each color observed in each zone of each city.

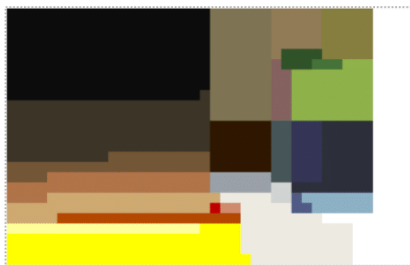
1) Bauru



Colors frequency in center

Colors frequency in suburban

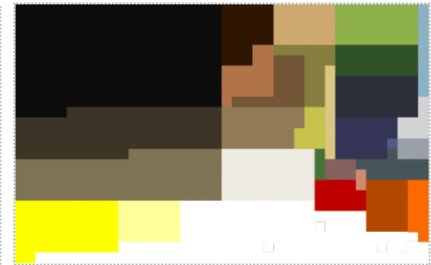
Colors frequency in peri-urban



Colors percentage in center

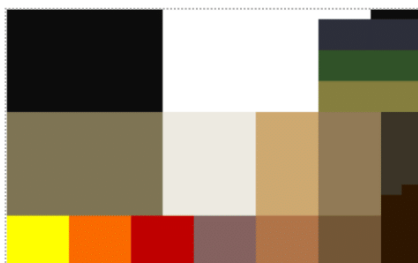


Colors percentage in suburban



Colors percentage in peri-urban

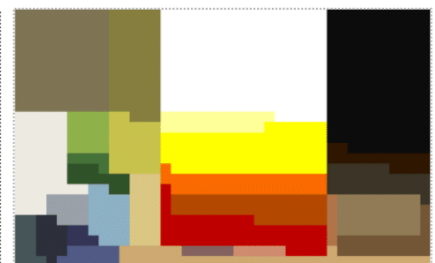
2) Xalapa



Colors frequency in center



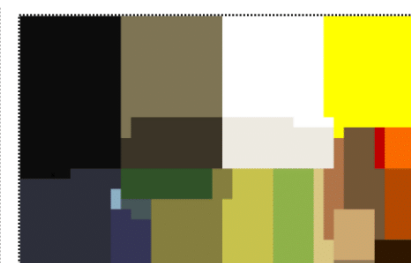
Colors frequency in suburban



Colors frequency in peri-urban



Colors percentage in center



Colors percentage in suburban



Colors percentage in peri-urban

Figure 2.5: Pictures created in Excel Spreadsheet, based on the frequency and percentage of colors found in each zone of each city: 1) Bauru (São Paulo, Brazil) and 2) Xalapa (Veracruz, México). The colors are those from the 30-color palette (Figure 2.4).

2.2.6. Statistical analysis

2.2.6.1 Repeating statistical analysis from Leveau (2019a) to color plumage patches method

We applied the same statistical analysis performed by Leveau, (2019a) on the data gathered through both bird color approaches. For the color plumage patches method (LEVEAU 2019a), we used Generalized Linear Models (GLMs) with Gaussian distribution of errors to analyze the association between the environmental variables (built-up cover (%) and habitat diversity) and the functional diversity (FD) and functional dispersion (FDis) indices. Pseudo-R² values were calculated (i.e. $\text{pseudo-R}^2 = 1 - (\text{residual deviance} / \text{null deviance})$; MCFADDEN, 1973)]. The models were plotted, using the *visreg* package (BREHENY & BURCHETT, 2017).

2.2.6.2 Repeating statistical analysis from Leveau (2019a) to color percentage method

For the color percentage method, we repeated the same procedure, performing GLMs with Gaussian distribution of errors to analyze the associations between the environmental variables (built-up cover % and habitat diversity), color diversity and color richness. We also built a matrix with the color percentage of each species for each color type. Using this matrix, we calculated nonmetric multidimensional scaling (NMDS), as in Leveau (2019a) with the function *metaMDS* in the *vegan* package (OKSANEN et al., 2020) in R.

2.2.6.3 Additional statistical analysis

For the additional analyses, we used only data from the color percentage method. We applied GLMs with Gaussian distribution of errors to analyze the associations between the built-up cover (%) and habitat diversity with the average color richness per bird species at each sampling point, in Bauru and in Xalapa (Figure 2.1). Then, we conducted a pairwise comparison between both color description methods (color percentage and color plumage patches), using Pearson's Correlation. We calculated the Pearson Correlation, using the *cor* function of the

stats package for all pairs of variables of the data obtained from both color count methods (R CORE TEAM, 2020).

Subsequently, we analyzed the data generated by the color percentage method, using the *vegan* and *vioplot* packages in R (ADLER et al., 2021; OKSANEN et al., 2020). We used the GLM analysis with Gaussian error to compare the color diversity/color richness by point in each city zone: center, suburban, and periurban. We plotted this comparison in a violin graphic, using the *vioplot* package.

Then, we calculated the similarity between the three city zones by controlling the number of species per site and subtracting the Bray-Curtis dissimilarity distance (similarity = 1 – Bray-Curtis). To obtain the Bray-Curtis values, we used the *vegdist* function of the *vegan* package (OKSANEN et al., 2020; R CORE TEAM, 2020). Bray-Curtis index is an abundance-based index, which, in this case, it is associated with the number of color percentages recorded in each bird species. To verify the null hypothesis, we applied chi-square tests and calculated the parameter estimates.

We also calculated the cumulative color richness curves from each city zone to compare the values at the end of the curves, when adding new colors to the community. For this analysis, we calculated the parameter estimates, using 84% intervals of confidence instead of the 95% standard, given that it is suitable for mimicking 0.05 statistical tests for both symmetric and asymmetric intervals of confidence (MACGREGOR-FORS & PAYTON, 2013).

Finally, based on images of the percentage of colors, we extracted color proportions and frequencies based on k-means clustering to determine the distribution of each color observed in each zone at both cities, using the *countcolor* package (WELLER, 2019) in R.

2.2.7. Applying the color percentage method in the Argentinian urban bird communities

To test whether the results observed by Leveau (2019a) would change after applying the color percentage method to the urban bird communities in Argentina, we assessed the data provided by Leveau (2019b) (although we did not have access to

the landscape variables and the bird data at each sampling site) and repeated the same procedure of color identification for each species.

We downloaded the professional drawings of each male of all species from the *Handbook of Birds of the World Online* and used the *countcolors* package (WELLER, 2019) to identify all the colors and obtained a new 30-color pallet (Figure 2.6). In this new pallet, the colors light blue gray and light blue were not found, and two new colors were identified: turquoise and iridescent red (Figure 2.6). We repeated the same procedure of color identification (*countcolors* package; WELLER, 2019) for each species.

Light gray	White	Light yellow	Yellow	Orange	Rufous
Red	Rose	Brown	Light brown	Dark brown	Wood brown
Brown olive	Dark olive	Iridescent	Dark green	Green	Green olive
Olive	Turquoise	Blue	Iridescent blue	Iris dark blue	Dark blue gray
Blue gray	Iridescent red	Violet gray	Gray	Brown gray	Black

Figure 2.6: New 30-color pallet from application of the color percentage method in data from the Argentinian cities

Then, we calculated the average color richness per bird species and the color frequency in each city zone (center, suburban and periurban). We also summed all the color percentages and calculated the proportion of each color in each one of the three city zones (Table 2.1). To assess the color distribution between the urban zones, we created six pictures: three based on the color frequency and three on the color percentage at each urban zone (Figure 2.7).

Table 2.1: Percentage of bird colors by city zone in Argentinian cities.

Colors	Peri-urban	Suburban	Center
Black	14.9	12.4	11.7
Blue gray	0.7	0	0.4
Blue	0	1.3	0
Brown gray	13.1	10.2	12.2
Brown olive	0.8	1.4	0.0
Brown	3.5	4.4	7.4
Light brown	6.9	6.8	7.3
Wood brown	4.2	1.9	0.0
Dark blue gray	1.2	2.3	0.7
Dark brown	2.9	2.1	2.0
Dark green	0.3	0.3	0.0
Dark olive	2.4	3.7	2.0
Green	1.1	1.4	0
Green olive	1.6	1.6	0.7
Light gray	8.6	9.8	13.1
gray	8.0	7.9	7.1
Iridescent blue	2.3	2.9	4.9
Iris dark blue	3.2	3.8	10.1
iridescent gree	1.1	2.8	2.3
Iridescent red	0.8	0.0	0
Olive	1.3	1.6	1.2
Orange	1.1	1.0	1.4
Red	0.6	0.1	0.1
Rose	0.6	0.4	0.3
Rufous	2.1	2.0	2.1
Turquoise	0.2	0.2	0
Violet gray	1.0	1.4	1.6
White	9.3	8.3	6.8
Yellow	6.0	7.2	4.6
Light yellow	0.6	0.7	0.1

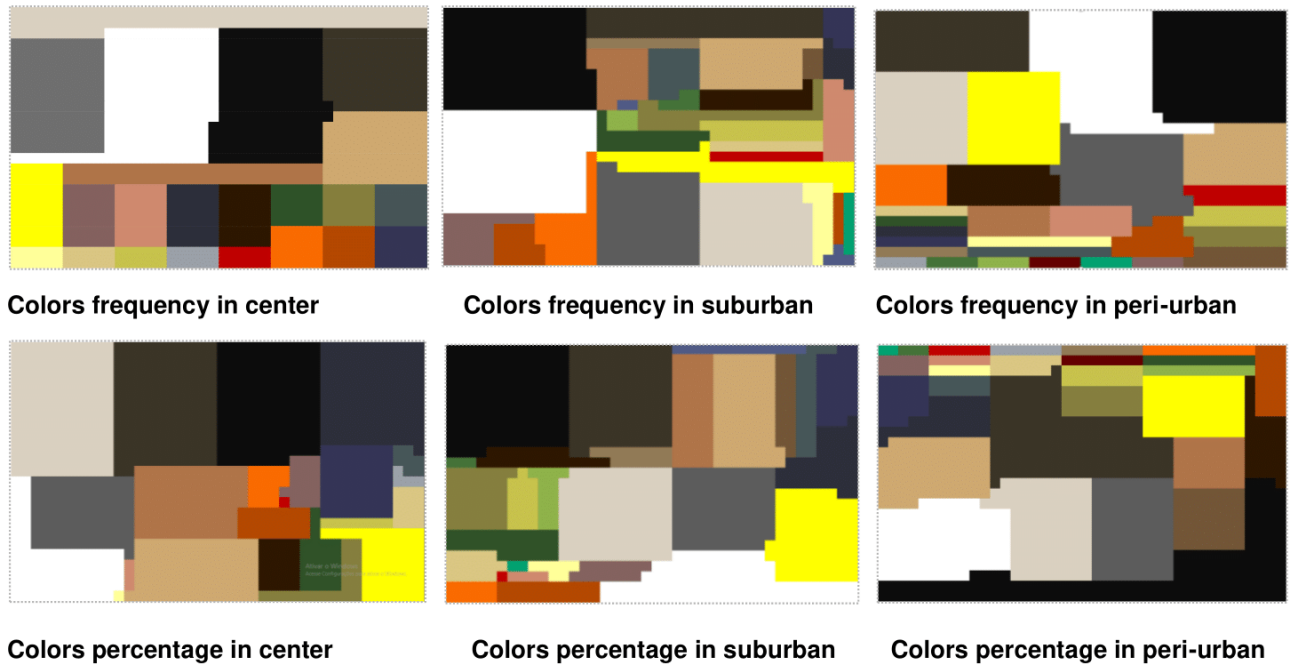


Figure 2.7: Pictures created in Excel Spreadsheet, based on the frequency and percentage of colors found in each zone of cities in Buenos Aires province. The colors are those from the 30-color palette (Figure 2.6).

We again created a color dissimilarity matrix for each site and each urban zone, using the Bray-Curtis index. We extracted the color proportions and frequencies, based on k-means clustering, to determine the distribution of each color observed in each zone (Figure 2.15). We also calculated NMDS (as in LEVEAU, 2019a) with the function *metaMDS* in the *vegan* package (OKSANEN et al., 2020) in R (Figure 2.16). Finally, because we could not repeat the GLM analysis, we calculated the color diversity in each zone, using the Shannon index.

2.3 RESULTS

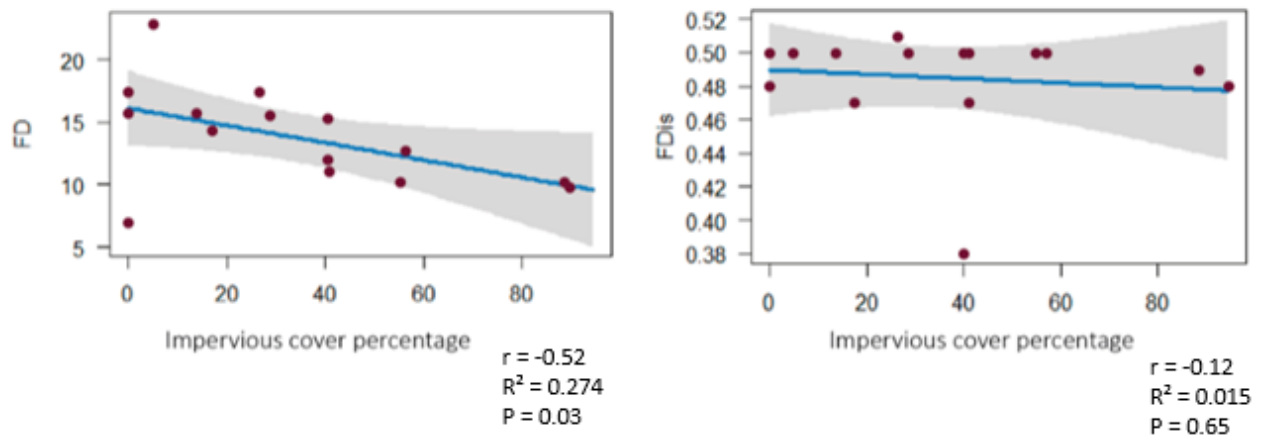
Our surveys recorded a total of 84 and 53 bird species (326 and 202 bird records) in Bauru and Xalapa, respectively. The most abundant species in Bauru were the Rock Dove (*Columba livia* JF Gmelin, 12.6% of individuals), White-eyed Parakeet (*Psittacara leucophthalmus* (Statius Müller), 12.2%), Blue-and-white Swallow (formerly *Pygochelidon cyanoleuca* (Vieillot), now *Notiochelidon cyanoleuca* (Vieillot), 12.2%), House Sparrow (*Passer domesticus* (L.), 8.2%), Yellow-chevroned Parakeet (*Brotogeris chiriri* (Vieillot), 8%), and Great Kiskadee (*Pitangus sulphuratus* (L.), 6%). In Xalapa, the most abundant species were the Great-tailed Grackle (*Quiscalus mexicanus* (JF Gmelin), 14.8%), Common Bush-tanager (*Chlorospingus flavopectus* (Lafresnaye), 7%), Rock Dove (*Columba livia*, 6%), White-fronted Amazon (*Amazona albifrons* (Sparrman), 5.5%), and Social Flycatcher (*Myiozetetes similis* (von Spix), 5.5%).

2.3.1 Results applying statistical analysis from Leveau (2019a) to color plumage patches method

The analysis, based on the 'color patches' method (LEVEAU, 2019a) showed that in Bauru, functional diversity (FD) was negatively associated with built-up cover ($r = -0.52$, $P = 0.03$) (Figure 2.8A) and functional dispersion (FDis) was positively associated with habitat diversity ($r = 0.54$, $P = 0.02$) (Figure 2.8A). In Xalapa, both FD and FDis were negatively associated with built-up cover (FD: $r = -0.44$, $P = 0.07$; FDis: $r = -0.52$, $P = 0.03$) (Figure 2.8B), but were unassociated with habitat diversity (FD: $r = -0.03$ and $P = 0.90$; FDis: $r = 0.34$ and $P = 0.20$) (Figure 2.8B).

Color plumage patches method

A) Bauru (Brazil)



B) Xalapa, (México)

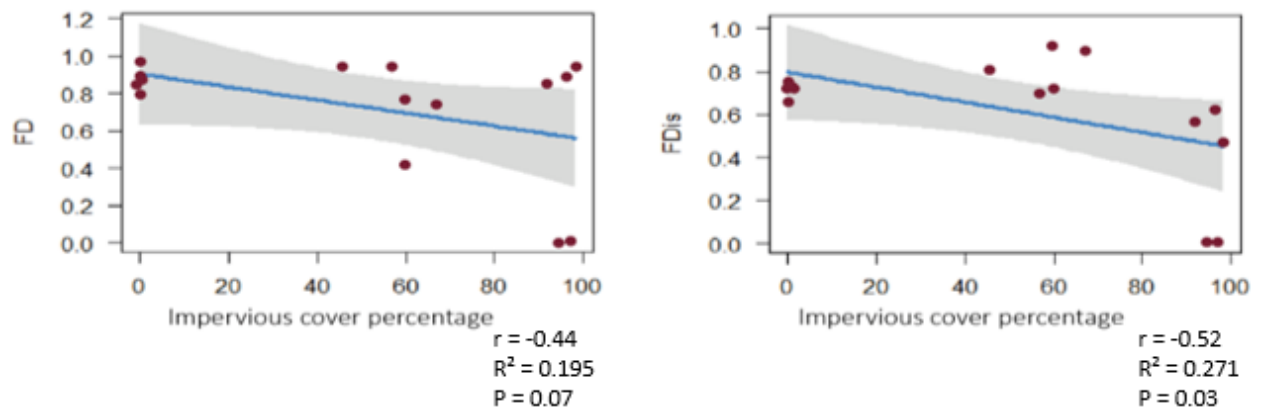


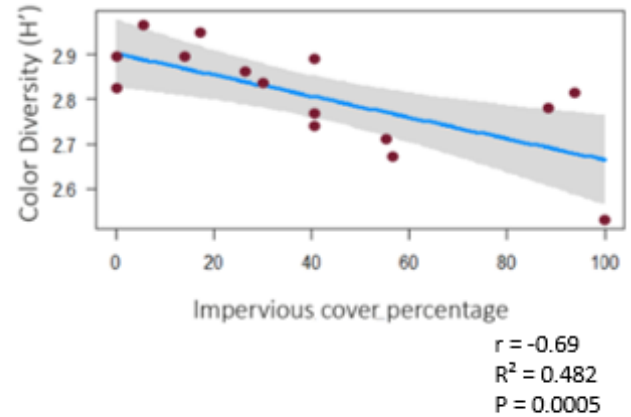
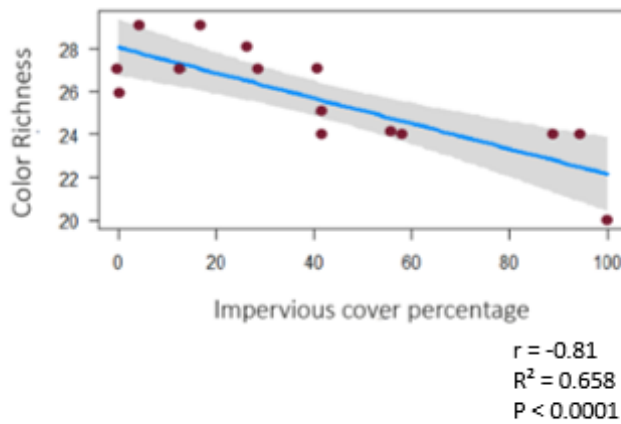
Figure 2.8: Plumage color diversity (FD) and functional dispersion (FDis), regarding its associations with habitat diversity, and the percentage of impervious built-up cover in A) Bauru, São Paulo, Brazil and B) Xalapa, Veracruz, México.

2.3.2 Results applying statistical analysis from Leveau (2019a) to the color percentage method

In considering the color percentage method, we observed that the proportion of built-up cover was negatively associated with color richness and diversity in Xalapa (color richness: $r = -0.68$, $P < 0.001$; color diversity: $r = -0.74$, $P < 0.001$) (Figure 2.9A) and in Bauru (color richness: $r = -0.81$, $P < 0.001$; color diversity: $r = -0.69$, $P = 0.05$) (Figure 2.9B). However, we observed no associations between habitat diversity and color richness and color diversity in both cities (Figures 2.9A and 2.9B).

Color percentage method

A) Bauru (Brazil)



B) Xalapa, (México)

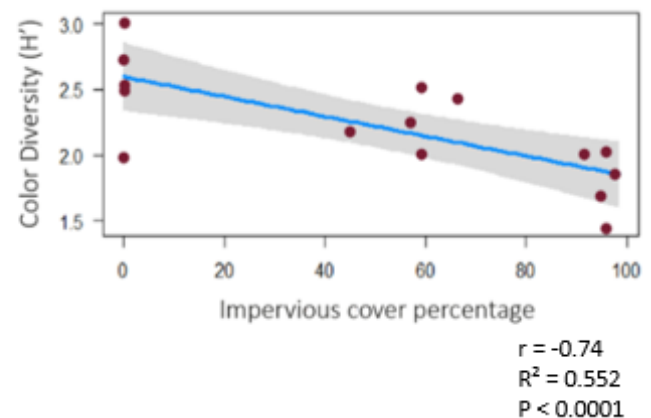
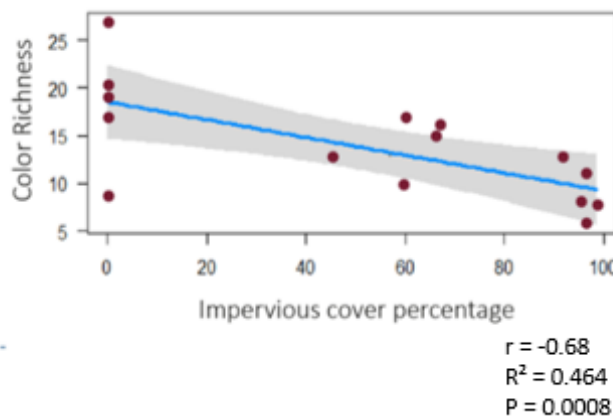


Figure 2.9: Plumage color richness and color diversity association with habitat diversity and the percentage of impervious built-up cover in A) Bauru, São Paulo, Brazil and B) Xalapa, Veracruz, México.

The NMDS analysis in Bauru showed that the olive color was only observed in the periurban zone, leading to the lowest similarity observed with the center and the suburban zones (Figure 2.10). With the exception of olive and orange (present only in the suburban and periurban zones), all other 28 colors were present throughout the city. Some colors were more common in periurban than in the suburban and center zones, such as green olive, brown olive, orange, red, and light yellow (Figure 2.10). In Xalapa, the lowest similarity was associated with the reduced color richness observed in the center, while the periurban zone registered five unique colors (i.e. light blue-gray, blue, dark green, pink, and light yellow). The NMDS analysis also showed that conditions at the center of Xalapa forced the concentration of black, white, iridescent blue colors, and shades of gray and brown (Figure 2.10).

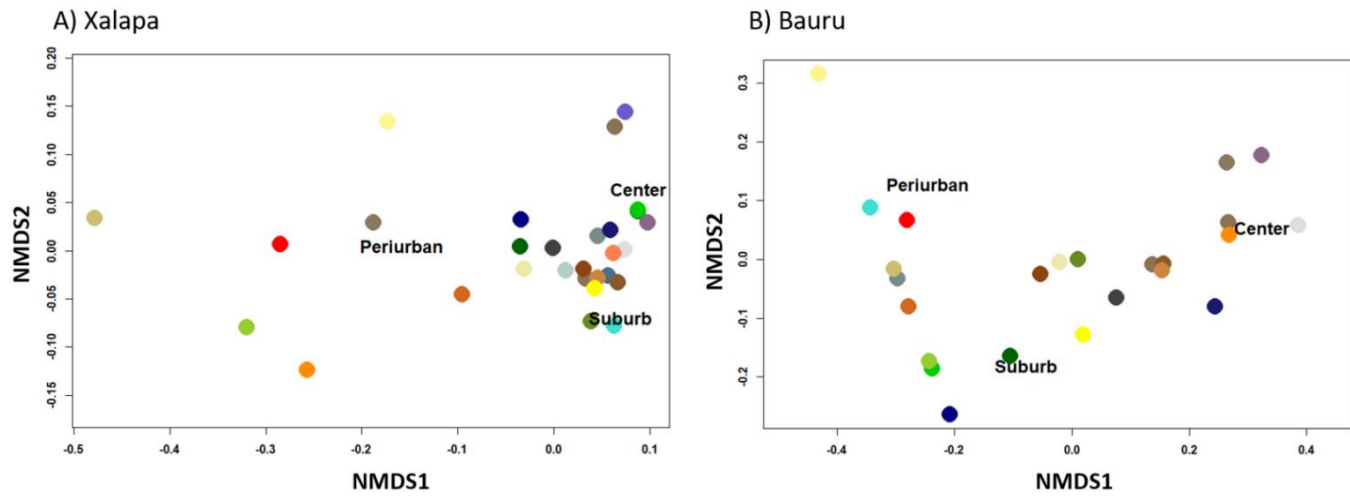


Figure 2.10: Nonmetric Multidimensional Scaling (NMDS) analysis of color variations according to city zones in A) Bauru, São Paulo, Brazil and B) Xalapa, Veracruz, México. Each point represents where each color is located spatially between the cities

2.3.3 Results of the additional analysis

The results of the GLM between built-up cover and average color richness per bird showed different results in both cities. In Bauru, higher urbanized areas present a higher average color richness per bird ($r = 0.67$; $P < 0.001$). In Xalapa, we found no associations between these variables ($r = 0.04$; $P = 0.86$).

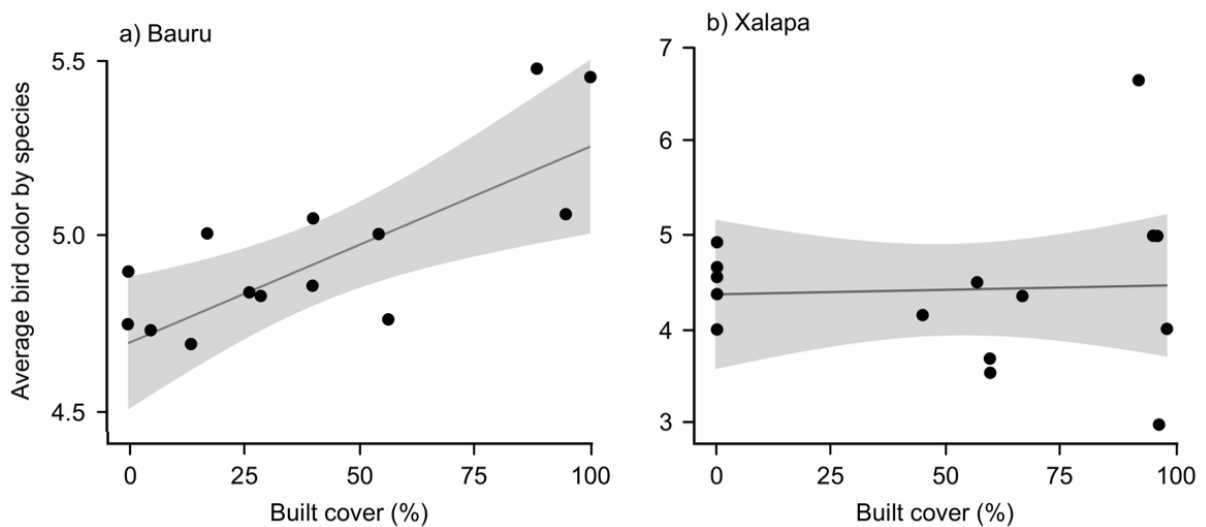


Figure 2.11: Associations between the average color richness per bird species and built-up cover in A) Bauru (São Paulo, Brazil) and B) Xalapa (Veracruz, México)

The cumulative color richness curves showed that the addition of species leads to a higher probability of adding new colors to the community. We compared the values at the end of the curves, since the sample size was identical; there were no differences between zones in any of the cities. Moreover, the number of colors in Bauru was similar in the three zones, indicating that the zones are unassociated with color richness (Figure 2.12).

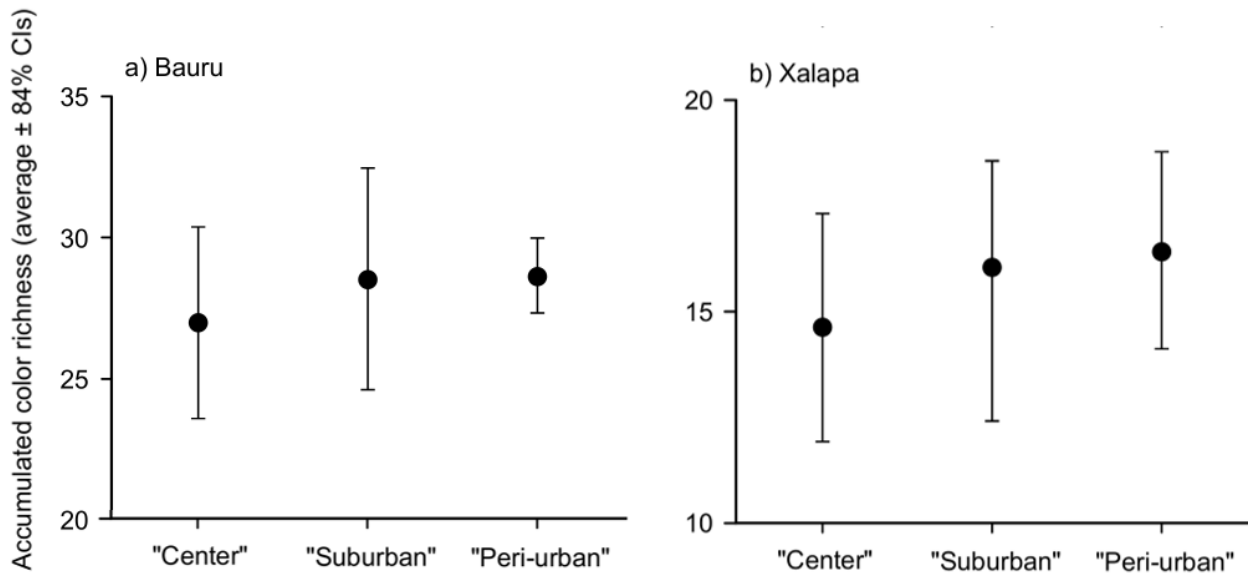


Figure 2.12: Accumulated richness of bird colors between urban zones in A) Bauru (São Paulo, Brazil) and B) Xalapa (Veracruz, México)

In considering the Bray-Curtis analysis, which is based on a “per species” approach, we found no significant differences between city zones in both cities (Figure 2.13). In Bauru, the lowest similarity was observed between the periurban and the center and between the periurban and the suburban zones (84%). There was 91% similarity between the suburban zone and the center of Bauru. In Xalapa, the lowest similarity was 59% between the center and periurban zones, while the suburban-periurban zones presented 75% similarity, and the center-suburban zones 62% similarity.

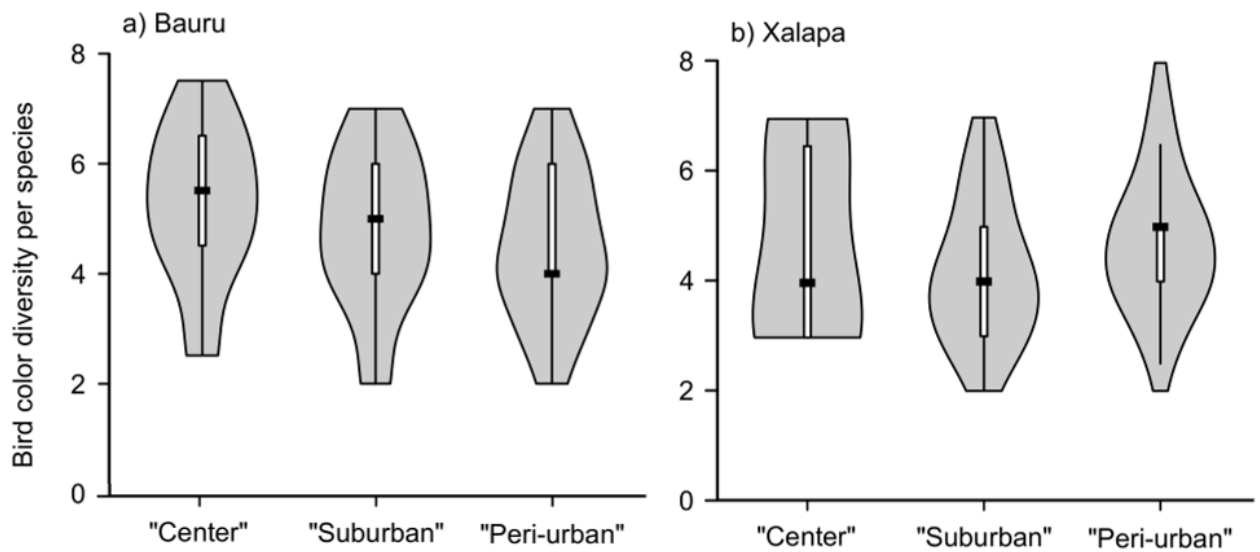


Figure 2.13: Bird color richness and color diversity between city zones in A) Bauru (São Paulo, Brazil) and B) Xalapa (Veracruz, México)

We recorded no color differences between the zones in both cities. We recorded 39 species in the center of Bauru, 43 in its suburban area, and 72 in the periurban zone, and similar numbers of colors in all three zones (center: 28 colors; suburban: 29; periurban: 30). On the other hand, we recorded 7 species in the center of Xalapa, 21 in its suburban area, and 40 in the periurban zone, leading to a reduced number of colors in the center (center: 17; suburban: 23; periurban: 29). The proportions of colors based on k-means clustering (Figure 2.14) confirmed the similarity of color distributions between the three zones in Bauru; in Xalapa, however, it is possible to observe that the suburban and periurban zones present colors not observed in the center (e.g. red, orange, yellow).

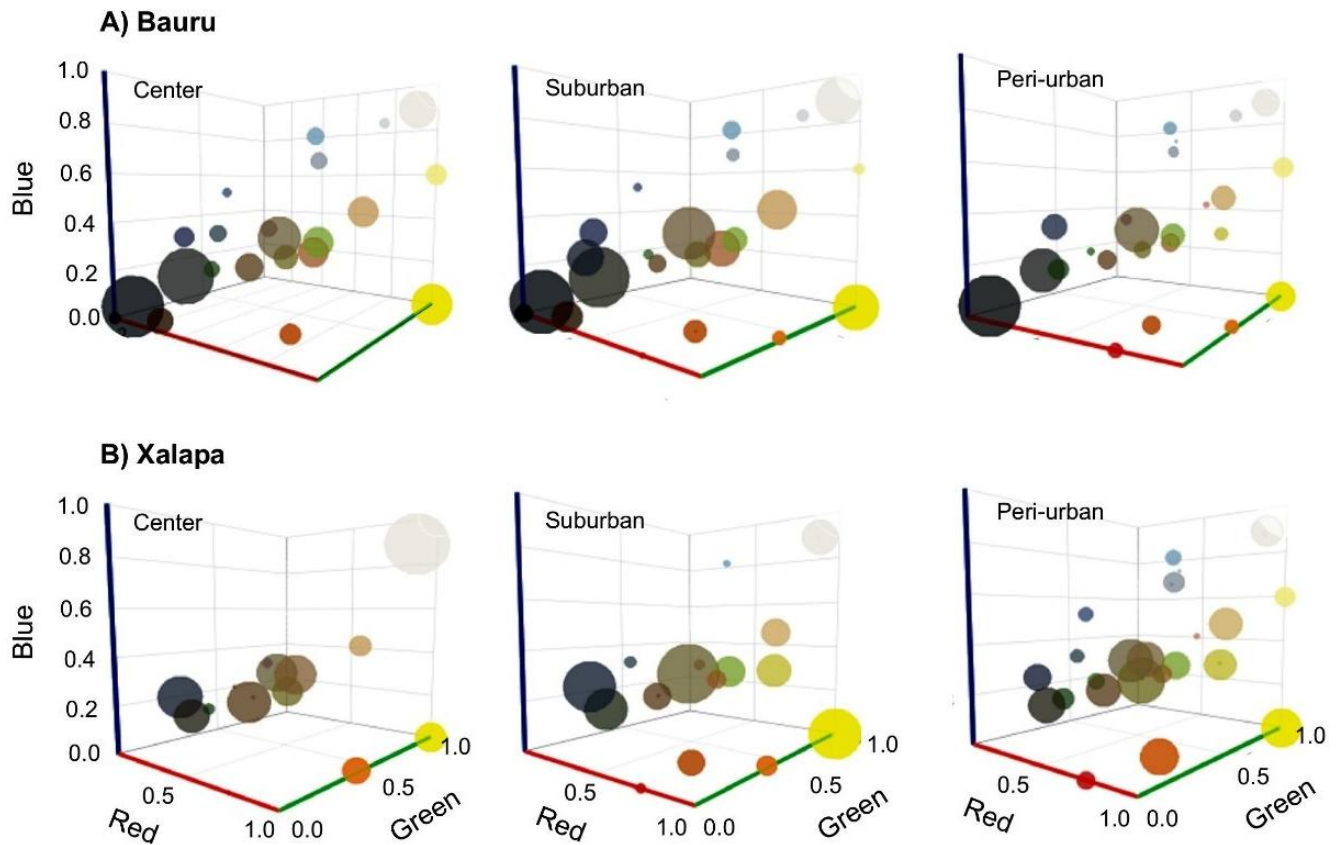


Figure 2.14: Proportions of color extracts based on k-means clustering to determine the centers of each color found in the 3 zones in Bauru, São Paulo, Brazil (27, 29, and 30 colors in the center, suburban, and periurban zones, respectively) and Xalapa, Veracruz, México (17, 23, and 29 colors, respectively).

2.3.4 Results of the color percentage method applied in the Argentinian urban bird communities

We found no significant differences in bird coloration between the zones, using the data produced by the color percentage method, from that of birds of the Argentinian cities (LEVEAU, 2019a). The dataset is comprised of 20 species and 23 colors in the center, 34 species and 28 colors in the suburban, and 43 species and 30 colors in the periurban zones. Regarding the average color richness per bird species levels, we found that the three zones are statistically similar (center: 5.0 colors; suburban: 5.1; periurban: 4.9) and present similar Shannon diversity indices (center: 2.67; suburban: 2.92; periurban: 2.86). In the Argentinian cities, the lowest similarity was 78% between the center and periurban zones, while the suburban-periurban zones presented 88% and the center-suburban zones 80% similarity. The proportions and frequencies of colors based on k-means clustering (Figure 2.15) and

NMDS analysis (Figure 2.16) also confirmed the similarity of color distributions among the three city zones.

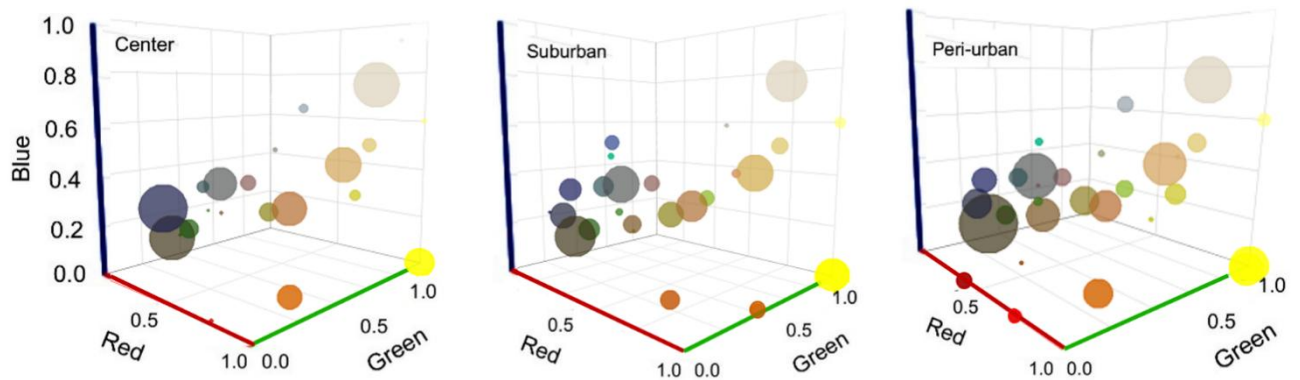


Figure 2.15: Proportions of color extracts based on k-means clustering to determine the centers of each color found in the 3 zones in Buenos Aires Province (center: 23 colors; suburban: 28 colors; periurban: 30 colors).

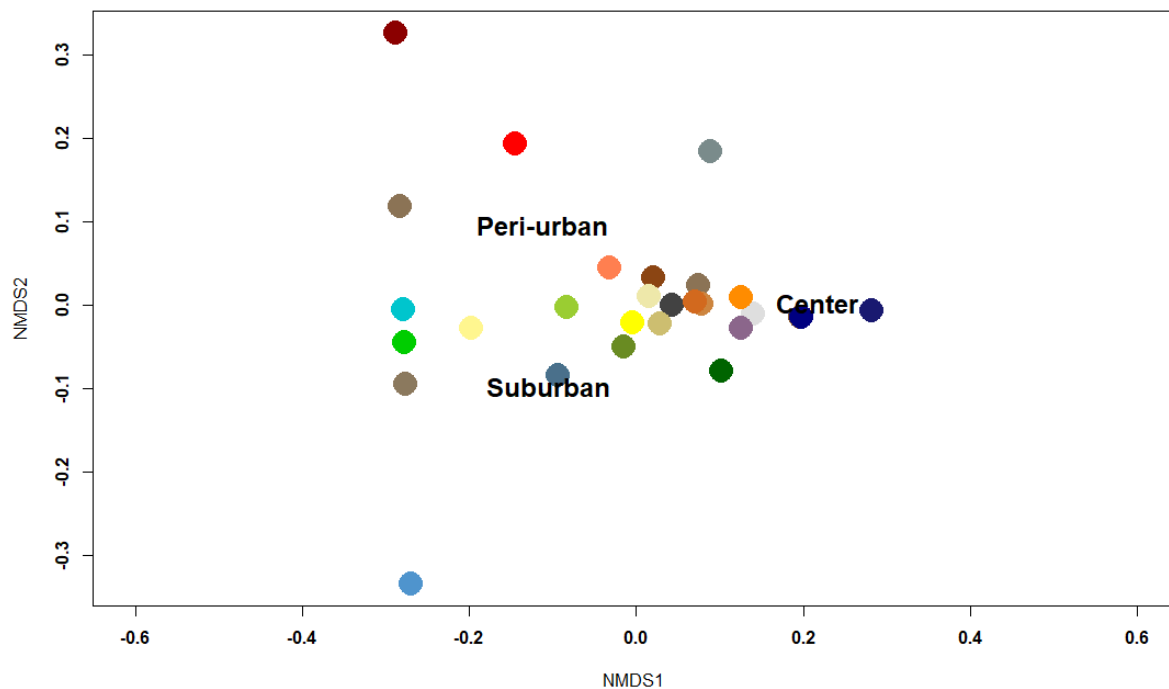


Figure 2.16: Nonmetric Multidimensional Scaling (NMDS) analysis of color variations according to city zones in the Argentinian urban bird communities. Each point represents where each color is located spatially between the cities

2.4 DISCUSSION

Our results clearly show that there is no evidence for stating that urbanization induces bird color homogenization, not even with the set of birds analyzed by Leveau (2019a). We show here the importance of the adopted approach for estimating bird plumage color and its selected response variables. The diversity and richness of colors in urban bird communities may not be negatively associated with the degree of urbanization intensity. For example, habitat diversity only modulated functional dispersion (FDis) in Xalapa when applying the color plumage patches method. Furthermore, although the proportion of built-up cover presented negative associations with diversity and color richness in both cities, the diversity and color richness can be high in the center. Considering the NMDS and Bray-Curtis analyses, we observed no significant differences among the city zones in both cities. For instance, in Bauru we observed 20 different colors (such as red, rose, yellow, green, and shades of blue), even at sites without green cover nearby high-traffic avenues.

Regarding bird color evaluation, the previously mentioned color plumage patches method presents several methodological drawbacks. Birds' body parts represent different proportions, according to each species. Additionally, bird plumage is not the only colorful aspect of birds; some species commonly observed in Neotropical cities present other colorful body parts, such as the Snowy Egret (*Egretta thula* – Molina) which has long yellow and black legs, and the Toco Toucan (*Ramphastos toco* – Statius Müller) which has a very large and orange beak (SICK, 1997). Therefore, the color plumage patches method may result in over or underestimation of the diversity of colors in the community. Furthermore, this method considers colors as categorical variables (LEVEAU, 2019a). Consequently, if a bird species presents a black and white head, the color plumage patches method would create a new color category "black-white" (LEVEAU, 2019a). Thus, this new category would not "add" to the white or the black of the species, but to a new categorical color combination.

We suggest that the color percentage method proposed here represents a better alternative for describing bird coloration, because it considers the bird's body as a continuum based on a color pallet defined by pixel intervals, reducing the bias associated with the various proportions occupied by each bird body part that is present in the color patches method (LEVEAU, 2019a). However, it should be recognized that our method also has limitations. For instance, it is only a two-dimensional representation of birds that are affected by drawing techniques. Maybe because vision is a fundamental part of human lives, it is difficult to imagine another vertebrate perceiving the world in a different way, but birds' sensitivity to UV light was first demonstrated in the 1970s, with pigeons and hummingbirds (WITHGOTT, 2000). Birds can also detect colors in the ultraviolet (UV) spectrum, which would add to their perceived coloration. While humans have three types of color or cone receptors that are sensitive to red, blue, and green spectra, birds have a fourth receptor, allowing the perception of UV wavelengths (TEDORE; NILSSON, 2019; CRONIN; BOK, 2016; LIND et al., 2013). Thus, it would be important new further studies on the role of UV color vision in analysis would greatly increase our understanding of how urbanization gradients affect bird colors.

Regarding the additional analysis, the results of the GLM analysis between built-up cover and the average of color richness per bird species showed that in Bauru, this variable was significantly and directly proportional to built-up cover. This suggests that higher urbanized areas are home to more colorful birds (higher average of color richness per bird species). The latter is mentioned because there are periurban areas in Bauru that have several large-bodied species with few colors (e.g. Western Great Egret – *Ardea alba* L., Green Ibis–*Mesembrinibis cayennensis* (JF Gmelin), and the Snowy Egret – *Egretta thula*). Consequently, the presence of these species leads to a decrease in the average of color richness per bird species in the periurban zones. On the other hand, we found pigeons, parakeets, and sparrows in the center of Bauru that have up to seven different colors per species, leading to an increase in the average of color richness per bird value. In Xalapa, we observed no differences between the average of color richness per bird species and the city zones.

Our findings also demonstrate that the accumulated number of bird colors is very similar, showing no statistical differences among zones in both cities examined. The proportions of colors based on k-means clustering also indicate that the zones may not necessarily be associated with bird color diversity, but rather with types of species diversity that are modulated by local biotic (e.g. species pool, functional traits composition; SOL et al., 2020; SOL et al., 2014) and abiotic (e.g. amount of vegetation, tree species compositions, bodies of water) aspects of cities (IKIN et al., 2013; MEFFERT & DZIOCK, 2012; MORENO-MATEOS et al., 2011).

Bird coloration is a trait crucial to the reproductive success of birds, especially when it serves as camouflage to avoid detection by predators (PATANKAR et al., 2021). Also colorful feathers serve lots to attract attention when courting (SIEFFERMAN; HILL, 2005; WITHGOTT, 2000). Leveau (2019a) found that environmental and landscape changes in cities may favor species with black and gray plumage colors that would be more adapted to the artificial surfaces that dominate cities. However, it is difficult to generalize results, because cities are heterogeneous ecosystems formed by a variety of habitats that are locally modulated by biotic (e.g. local species pool; SOL et al., 2020; SOL et al., 2014; CROCI et al 2008) and abiotic (e.g. occupational history, climate) characteristics (RAMALHO; HOBBS, 2012; KOWARIK, 2011; GRIMM et al., 2008). Furthermore, the tropics have the most colorful bird species (CARBALLO et al., 2020) and highly biodiverse urban landscapes (BARBOSA et al., 2020; GUIMARÃES et al., 2020; Silva et al., 2020; PENA et al., 2017). Therefore, bird color richness and diversity may be more associated with the diversity of bird species locally observed than with environmental and landscape conditions (DALRYMPLE et al., 2018), such as habitat diversity and the proportion of built-up surfaces.

Local landscape structure and occupational histories may be crucial drivers of bird color diversity. Depending on the urbanization process, a city center zone may be able to harbor more or as much habitat as the periurban zones. The opposite also holds; there are cities where the periurban zones do not harbor high numbers of habitats for bird species. Urban landscapes are heterogeneous places (RAMALHO; HOBBS, 2012). Although there are global patterns of the association between urbanization and birds, their effects are also associated with the local pool of original species (SOL et al., 2014).

Considering this study, both cities have different urban landscapes and historical aspects. Xalapa was founded in 1519 (FALFÁN et al., 2018) and Bauru in 1816 (GHIRARDELLO, 2020). The urban landscape of Bauru expanded with the maintenance of several green spaces and a wooded train railway network that crosses the entire city (GHIRARDELLO, 2020), while Xalapa has a historical center dominated by built-up surfaces. At the same time while Bauru is surrounded by sugar-cane plantations, pastures, and small fragments of native vegetation (SEMMA, 2015), Xalapa is surrounded by large, well-preserve cloud-forest patches, providing shelter for a high diversity of bird species in the periurban zone (FALFÁN et al., 2018).

Thus, in Bauru, bird species may be required to exploit the urban landscape, while in Xalapa they may be concentrated in the periurban habitat patches. Therefore, when cities are compared, urban zones may not represent similar degrees of urbanization intensity and, consequently, may not have the same influences on bird communities. In the assessed here, Neotropical cities bird communities inhabiting the center were as colorful as, or even more so, than birds inhabiting periurban vegetation patches. In Bauru, this result is even more evident: color frequencies in the community are similar in all urban zones.

Regarding the outcome obtained using data from Argentina, our results show that when the color percentage method was used, the three urban zones showed similar bird plumage color diversities. Despite colors such as iridescent red, which only appeared in periurban areas in the species White-faced Ibis (*Plegadis chihi* (Vieillot)) and suburban and periurban zones that presented colors not observed in the center (such as green, turquoise, and some shades of blue and brown), bird coloration did not vary significantly along urbanization gradients. Colors such as shades of gray that could be more associated with highly urbanized areas were also observed in suburban and periurban zones (20.2% of the total number of colors in the center, 17.7% in suburban, and 16.6% in the periurban zones). Therefore, we found no evidence that bird coloration varied along the urbanization gradient. Thus, our results suggest that the methodological issues of the procedure used in Leveau (2019a) may have driven the findings reported.

2.5 CONCLUSION

Using a different method to describe bird color, our study indicates that urbanization leading to bird color homogenization does not follow a generalized pattern and that color richness did not vary among urban regions. By describing the color of whole bird bodies as continuous variables, we can reduce the bias of the color plumage patches method of over or underestimating the presence of colors in the community due to the different proportions occupied by each bird body part. The associations between urbanization and bird communities are highly complex, modulated by patterns of urban growth and by phylogenetic, taxonomic, and evolutionary forces (SOL et al., 2020; LA SORTE et al., 2018; SOL et al., 2014). The colors richness and diversity in urban bird communities are influenced by environmental conditions, but may be more associated with the diversity of bird species in the community (DALRYMPLE et al., 2018; DELHEY, 2018). Since previous studies suggest that highly urbanized areas can be inhabited by a high diversity of bird species (MACGREGOR-FORS et al., 2014), even streetscapes (GUIMARÃES et al., 2020; PENA et al., 2017), these urban areas can also be inhabited by colorful bird communities. Therefore, the influences of urbanization on bird color may be more associated with local characteristics of cities rather than a worldwide pattern of color homogenization.

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CHAPTER III

Using UV wavelengths: a suggestion for future research on bird color in cities



3.1. INTRODUCTION

Urbanization process can be considered an environmental filter, reducing phylogenetic diversity, as well as reducing the diversity of functional characteristics of birds in cities (SOL et al., 2020; LA SORTE et al., 2018). Since urbanization can act as an environmental filter, Leveau (2021, 2019) concluded that urbanization leads to homogenization in the colors of bird plumage. However, tropical birds are much more colorful than their temperate peers (COONEY, 2022) and Neotropical cities are home to highly diverse and colorful bird species, even in highly urbanized contexts, such as streets and avenues (GUIMARÃES et al., 2020; PENA et al., 2017). Several species of colored birds (such as parrots and parakeets) are common in Neotropical cities (BARBOSA et al., 2020; GUIMARÃES et al., 2020; SILVA et al., 2020; PERILLO et al., 2017), demonstrating the difficulty of generalize the relationships between urbanization and color diversity in urban bird communities.

Vision is the most highly developed and acute bird sense (WITHGOTT, 2000). They see more colors than humans and are enable to discriminate a broad range of colors, including many non-spectral colors (STODDARD et al. 2020). While humans have three types of color receptors or cones – which are sensitive to the red, blue, and green spectral wavelengths – birds have a different fourth receptor, allowing the perception of the UV wavelength (TEDORE; NILSSON, 2019; CRONIN; BOK, 2016; LIND et al., 2013). Some bird groups, however, present a different vision perception because they are most active during dawn and dusk, or at night, such as some owls (Strigiformes: Strigidae and Tytonidae; MARTIN, 1990, MARTIN, 2008). For example, despite owls don't have UV/V cones as other birds' species, they can detect UV light, by seeing the UV-reflecting feathers as brighter signals at night (HÖGLUND et al. 2019).

Color are vital for finding food, attract mates, hide from predators, identify their own species, attract the attention when trying to distract predators and more (Cornell Lab of Ornithology, 2016). Also, colorful feathers are important to attract attention when courting. Some bird females choose as partner best ornamented and brighter-feathered males, once these characteristics would be correlated with a better health (WITHGOTT, 2000). Therefore, we consider that it is important to consider UV spectrum when studying the influences of the environment on bird color. For

instance, some species' sexes — which look virtually identical to the human eye — appeared different when UV reflectance is measured (WITHGOTT, 2000). Several examples of sexual dichromatism not detectable with human visual capabilities suggest that our categorizations of plumages as sexually mono- or dichromatic might often be incorrect (EATON, 2005). Natural variation in UV reflectance is important in avian mate assessment: for example, under UV- conditions, zebra finches females (*Taeniopygia guttata*) ranked males in a different and nonrandom order, but plumage reflectance in the human visible spectrum did not predict choice (BENNETT, 1997).

Moreover, under UV light, some bird species can recognize non-mimetic parasitic eggs, despite having similar visible colors and marks (according to human's view), this gives the ability of differentiate when an egg is not their own and then to reject the foreign egg (ŠULC et al. 2016). Regarding feeding, some fruits have waxy coatings that reflect UV light, making them stand out vibrantly against green foliage so that birds can easily identify the fruit clearer than humans (WITHGOTT, 2000). Therefore, studying how birds see color is a crucial first step toward understanding its behavior, which is essential for creating better strategies to preserve them. Taking this into account, this chapter aimed to propose a new perspective to analyze the influences of urban environmental characteristics of urban landscapes on the color of birds. For this, we present a more robust method that is based on the spectral characteristics of the colors of birds (considering the ultraviolet spectrum), carried out with spectrophotometric analysis of taxidermized specimens in Brazilian museums.

The need for a more robust analysis based on the bird's view became evident after the end of the analyzes of chapter 2, since in addition to the visible spectrum, birds also perceive the ultraviolet wavelengths. In this way, by incorporating UV into the analysis, we would be able to better understand how the urbanization process is related with the richness and diversity of bird coloration in Neotropical cities. However, due to limitations regarding the use of the necessary equipment for analyzing the museum specimens (mostly the access to a spectrometer), it was not possible to complete this part of the research during the thesis's timeline. Nevertheless, we decided to describe the approaches we developed as a suggestion for future research on bird colors in cities.

3.2. QUESTIONS, HYPOTHESES AND PREDICTIONS

Considering the colors of the ultraviolet spectrum, what is the influence of the urban landscape of different Neotropical cities on the colors of bird communities?

We hypothesises that urbanization does not act as an environmental filter on the colors of bird communities, even considering the ultraviolet color spectrum (Figure 3.1).

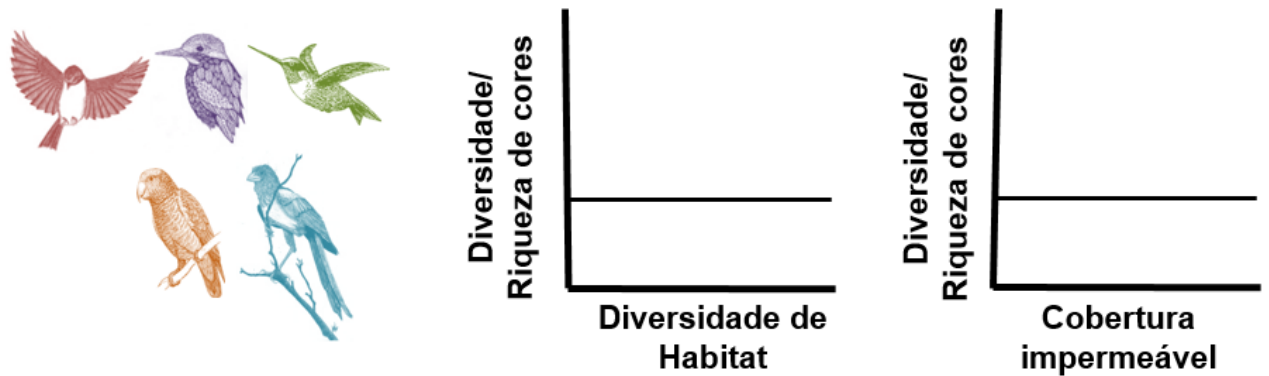


Figure 3.1: Expected influences of urbanization (percentage of impervious built-cover and habitat diversity) on the diversity and richness of bird's coloration, considering the ultraviolet spectrum.

3.3 MATERIAL AND METHODS

The first idea was to analyze data from three neotropical cities in Brazil: Bauru, described in chapter 1, Belo Horizonte and São Paulo. Belo Horizonte (W 19° 55' 37", S 43° 56' 34") is one of the first well planned cities in Brazil and is the capital of the state of Minas Gerais, situated in the transition between the Brazilian Savanna and Atlantic Forest biomes. São Paulo (S 23° 32' 51"; W 46° 38' 10') is one of the most populous cities in the world, with more than 12 million people and occupies an area of 1521 km² (IBGE, 2017). As data on bird species composition, for Bauru we would use data collected between 2018 and 2019 (Chapter 1). Regarding Belo Horizonte and São Paulo, we would use the data already collected in the cities in different studies (BARBOSA et al., 2020; PENA et al., 2017; PERILLO et al., 2017).

In these cities, we would consider birds species datas found in 15 sampling sites distributed in different regions of each city: a) city center, b) suburban and c) peri-urban. To calculate landscape diversity and impermeable cover, we would analyze each city's land cover/use maps (as described in Chapter 2), which were already available from the collaborators.

3.3.1 *Measuring the color of birds: from the visible to ultraviolet spectrum*

From December 11th to 16th, a pilot study was carried out at the Ornithology Laboratory of Museum of Zoology (Figure 3.2), from University of São Paulo (USP) to analyze the taxidermized specimens. The visit was made under the supervision of Prof. Dr. Luis Fabio Silveira, the curator of the museum.



Figure 3.2: Photos of Museum of Zoology, from University of São Paulo (USP). Own authorship, 2021

During this pilot study, we checked the species available in the museum's collection and collect measurements of the main body parts of each species. Measurements were performed using the caliper of at least 10 specimens of each species of interest (Figure 3.3). From the measurement of these 10 specimens, we extracted the mean values of birds' body parts for each species (Figure 3.4). This procedure was adopted to help us to decide how to measure the coloration of the body parts of different species.

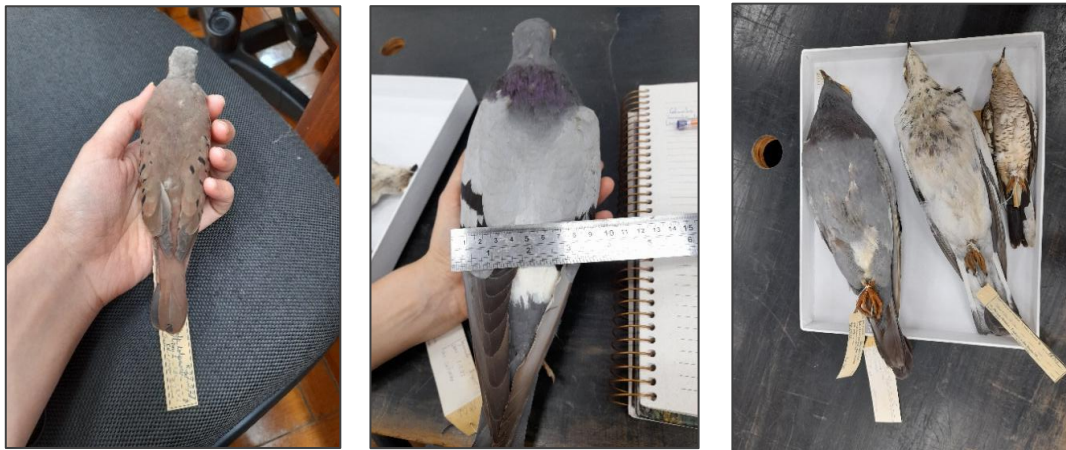


Figure 3.3: Measurement of specimens with a caliper at the Zoology Laboratory. Own authorship, 2020.

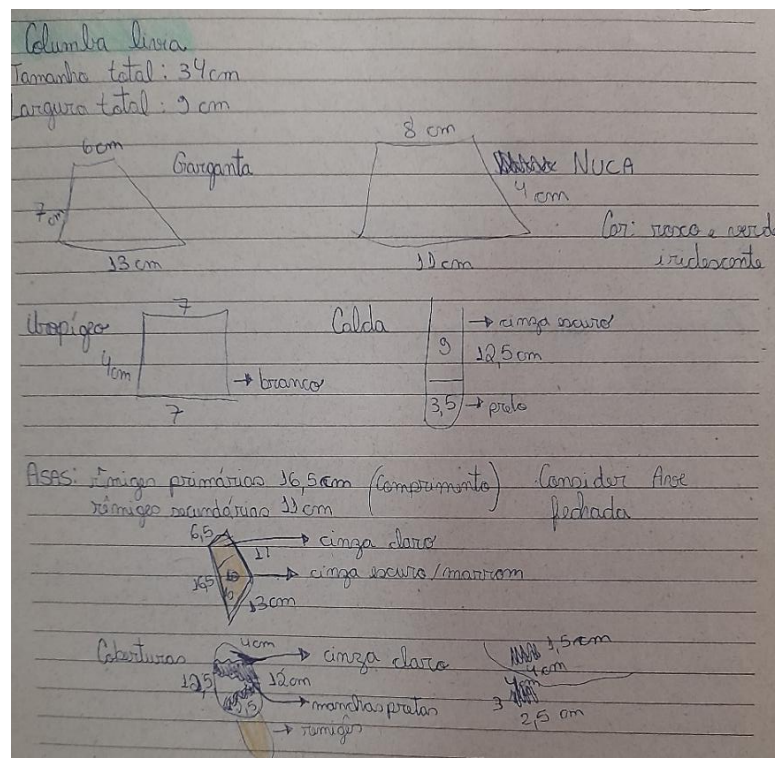


Figure 3.4: notes of species measurements. Source: own authorship, 2020

The most commonly used instrument for the measurement of the optical performance for UV, VIS, and NIR is a spectrometer. To measure the coloration of birds from the visible to ultraviolet spectrum, we expected to use and borrow the spectrometer available at the Federal University of Itajubá (UNIFEI; Figure 3.5).



Figure 3.5: UNIFEI entrance. Source: own authorship

From March 21th to 28th, I went to UNIFEI in order to learn how to use the spectrometer and how to measure color wavelengths with professors and researchers: Dr. Roberto Shigueru Nobuyasu Junior, Dr. Thiago Vernaschi Costa and Dra. Karlla Vanessa de Camargo Barbosa, who are collaborators and partners of LEEC (Laboratory of Space Ecology and Conservation), at São Paulo State University (UNESP) Campus Rio Claro (Figure 3.6).



Figure 3.6: on the left, there are Dr. Thiago Vernaschi Costa and Dr. Roberto Shigueru Nobuyasu Junior (computer); on the right, there are me, Dr. Vernaschi, Dra. Karlla Vanessa de Camargo Barbosa and Dr. Nobuyasu. Source: own authorship, 2022

We used a StellarNet fiber optic spectrometer (Figure 3.7) coupled to a reflectance probe, transmission fixture and fiber optic light source; fiber optic cables provide an easy way to transmit light without need for system alignment or attenuation of signal (STELLARNET, 2022). The spectrometer measures the percentage of transmission, absorbance, and reflectance of any optical element. Reflectance is the amount of color wavelengths reflected by a surface, normalized by the amount of color wavelengths incident on it; transmittance is the amount of color wavelengths transmitted by a surface, normalized by the amount of color wavelengths incident on it; any color wavelengths not reflected or transmitted is absorbed (FEST, 2013).

We used the SL4 High Power UV-VIS Light Source, which is a light source that covers the 190-2500 nm range and the white reflectance standard (Figure 3.8), which is used to take reference measurements using the reflectance probe from spectrometer. This white standard will reflect >97% of the light and because white contains all colors, we used this equipment to get a standard reference of measurement for all color values.



Figure 3.7: StellarNet fiber optic spectrometer coupled to UV-VIS Light Source. Source: own authorship



Figure 3.8: StellarNet white reflectance standard. Source: own authorship

Once obtained the reference measurement, we proceeded to measure the wavelength of the colors present in the available bird specimens. Wavelength is

usually expressed in nanometers ($1 \text{ nm} = 10^{-9} \text{ m}$). The UV range normally extends from 100 to 400 nm, with the visible range from approximately 400 to 800 nm. Because there was only three specimens of taxideimized birds available at UNIFEI, we used bird feathers and took color measurements on at least 10 feathers of each available bird species. The light was emitted through fiber optic cables which was placed on bird feather. The same procedure was repeated for different feather's colors and parts. The spectrometer was connected to a computer (Figure 3.9) and then linked to the *OriginPro 9* software (Figure 3.10), that is used for data analysis and graphing.



Figure 3.9: The spectrometer is connected to a computer. Source: own authorship

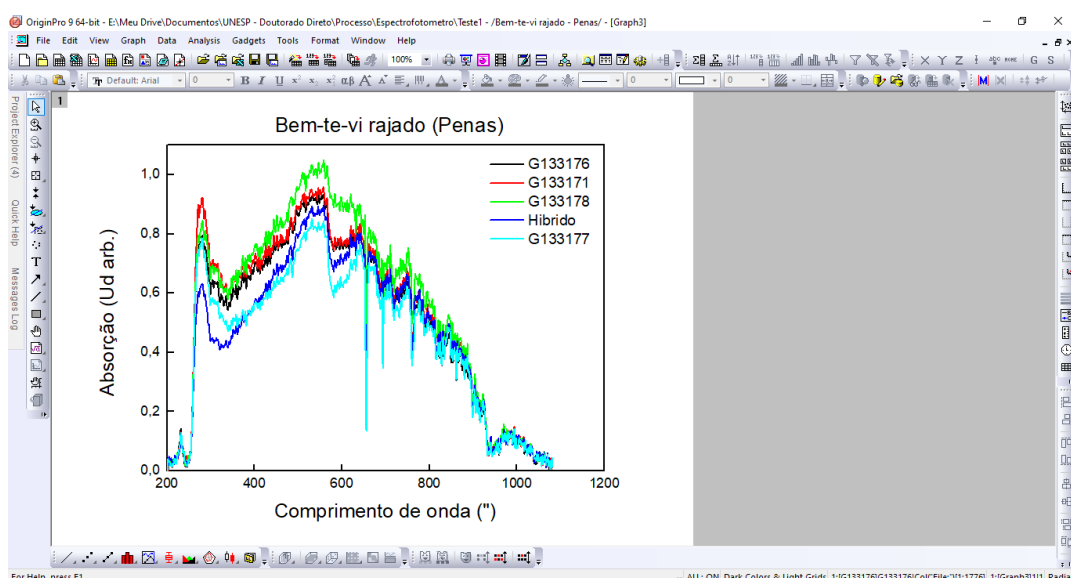


Figure 3.10: Screen of *OriginPro 9* software

3.4 PRELIMINARY RESULTS

Our pilot testing of the color measurement on feathers using the spectrometer method was a success. We were able to measure the wavelengths of colors (UV range from 100 to 400 nm and visible range from approximately 400 to 800 nm). The greater the absorption of light UV, the less UV colors it reflects. An optical spectrometer records the wavelengths at which absorption occurs, together with the degree of absorption at each wavelength. We repeated the measurement on several bird feathers in order to extract the mean of wavelength values and then, to get the color measurements of each species. The following figures show the wavelength graphs of feathers (Figure 3.11) and plumes (Figure 3.12) of the Streaked Flycatcher (*Myiodynastes maculatus*).

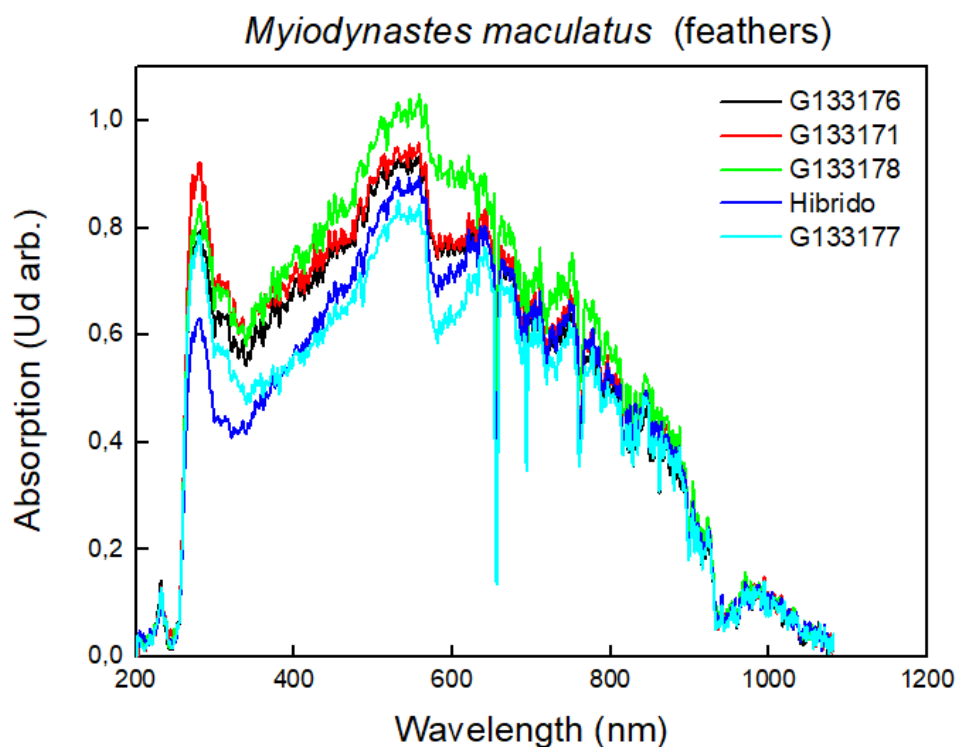


Figure 3.11: Wavelengths of the color of the feathers of *Myiodynastes maculatus*. Each line represent a different feather. In the legend, the name is a code that identify the five sampled feathers.

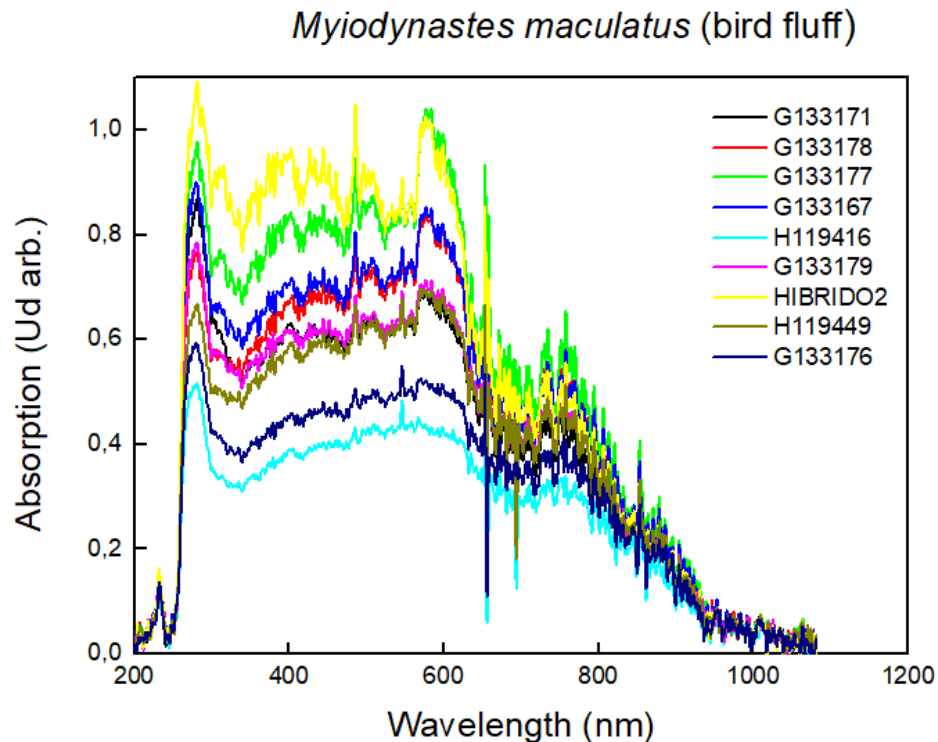


Figure 3.12: Wavelengths of the colors of the plumes of *Myiodynastes maculatus*. Each line represent a different feather. In the legend, the name is a code that identify the nine plume samples.

In Figure 3.13, there is an example of a graph with all colors present on a peacock feather. We extracted the mean of colors and put the wavelengths together on the same graph for a visualization of how color spectrum of a peacock feather looks like.

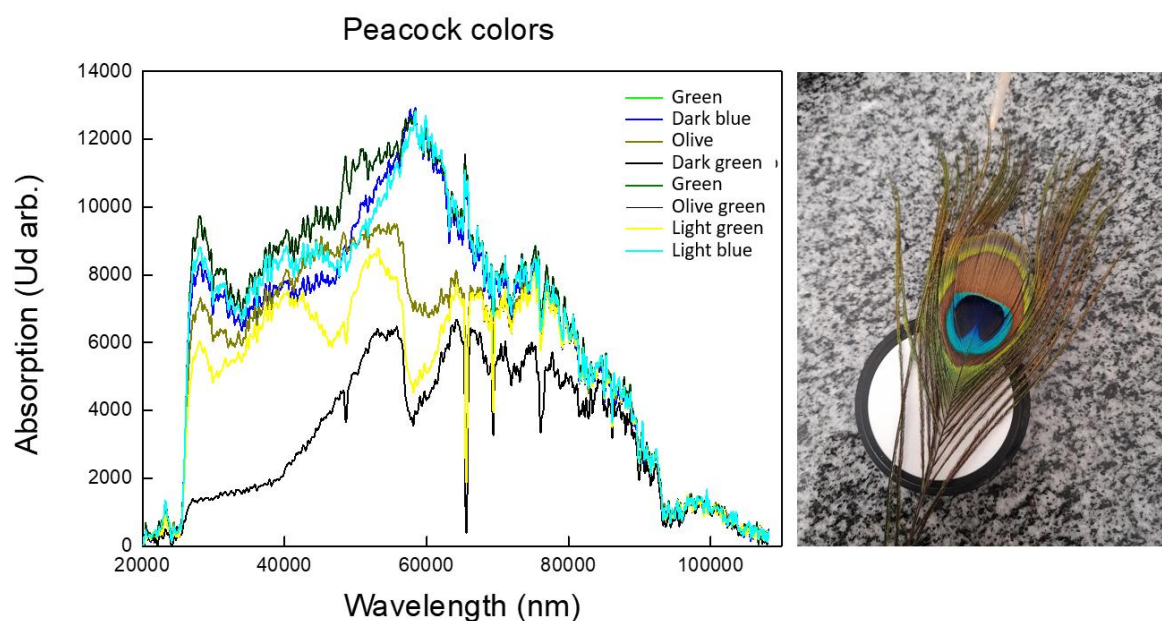


Figure 3.13: graph of wavelength and photo of peacock feather's colors

3.5 NEXT STAGES AND DATA ANALYSIS: WHAT WE WERE PLANNING TO DO

With the use of the spectrometer, four color variables would be measured: (1) brightness, (2) hue and the values of (3) visible chroma and (4) UV chroma - being chroma, the degree of difference in stimulation between the cones (color receptors) (VAQUERO-ALBA et al., 2016). Chroma UV would be calculated as the reflectance ratio of the UV range of the spectrum (300-400 nm) in relation to the total reflectance spectrum (R300-700; VAQUERO-ALBA et al., 2016; SIEFFERMAN et al., 2005). Regarding the variable hue (hue), it depends on which cones are stimulated and, in birds, tonality is defined by 2 angles, analogous to latitude and longitude (ENDLER; MIELKE, 2005). Finally, the brightness would be calculated as the average reflectance summed over the entire spectral range (R300–700; GALVÁN; MØLLER, 2009).

The measurement would be carried out on the entire body of the animal, including beaks and legs, as these parts of the body can represent considerable proportions of some species, such as the white heron (*Egretta thula*) which has long yellow and black legs and the toco toucan (*Ramphastos toco*) that has a very large orange beak (SICK, 1997). After the color description of the birds, color richness and diversity would be calculated using the Shannon index at each sampling point of all cities.

Data analysis would be done in a similar way to that developed in Chapter 2 (described in section 4.2). Generalized Linear Models (GLM) with Gaussian distribution would be used to analyze the relationships between the proportion of impermeable cover and habitat diversity and the four color variables (brightness, hue and visible chroma and UV chroma) and then the Pearson correlation for all pairs of variables. To compare the diversity and richness of colors between the regions of the city, all the brightness, tonality and chromas intervals of all species found in each of the 15 sampling sites in each city would be summed and the GLM analysis with Poisson error would be used to compare the color diversity and richness of each location in each region of the city: "center", "suburban" and "periurban". The similarity between the three regions would also be calculated, applying the chi-square tests, to investigate whether there is a specific color pattern according to the city region and

landscape metrics. Finally, the non-metric Multidimensional scaling (NMDS) would be performed, to identify the colors traits associated with the environmental variables.

3.6 FINAL CONSIDERATIONS

Despite training at UNIFEI and authorization to access the ornithological collection of the Museum of Zoology, the director responsible for borrowing the spectrometer did not authorize the equipment to leave the unit, at the last moment. Therefore, it was not possible to continue this research. Nevertheless, it is important to highlight that this is an interesting area to continue studying. Ultraviolet vision has been well-studied in insects, particularly bees and butterflies (WITHGOTT, 2000), including a recent award-winning Brazilian thesis (STELLARNET, 2022). But considering birds, even though their vision is highly developed and an important sense, there is a gap of ecological studies relating bird colors and landscape and environmental patterns. Studying how birds see color is a crucial first step toward understanding its behavior, which is essential for creating better strategies to preserve them.

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CHAPTER IV

Academic community perception of birds in Neotropical cities



4.1. INTRODUCTION

Most humans live in urban regions, which makes cities the prime place where humans can experience nature in their day-to-day life (SWEET et al, 2021). There are many studies that shows evidences that nature into urban spaces provides ecosystem services such as water protection, landslide prevention, reduction of heat island effect, floods, noises, and air pollution (SCHWARZ et al. 2017; VAILSHERY et al. 2013) and has positive effects on human well-being and health (DERR et al. 2017; SANDIFER et al., 2015; HARTIG et al., 2014; LOUV 2005). However, while there is a general consensus that nature into urban spaces should be increased, the way how people perceive the animals that live within cities varies greatly.

Animals are not all equally liked: in general, birds, mammals and amphibians/reptiles are liked most, while the attitude towards arthropods and other invertebrates are less positive (SWEET et al, 2021). However, there are some exceptions: while mammals like rats were the least like (BJERKE; ØSTDAHL, 2004), insects such as butterflies were liked by people (HOSAKA et al. 2017). Increasing familiarity increased the range of attitudes towards animal species, so that attitudes on average became more extreme, either positive or negative (SWEET et al, 2021).

Perception is linked to sensations, while attitude is a cultural posture formed by a long succession of perceptions (TUAN, 1983). There are five senses that allow humans to perceive and experience the world: a) sight, b) smell, c) taste, d) hearing and e) touch; the way we interpret and apprehend the information transmitted by our senses and sensations in the world we live in is perception (MERLEAU-PONTY, 1996). Our perception is based on our experience: there is no interior perception without exterior perception: “all external perception is immediately synonymous with a certain perception of my body, just as all perception of my body is made explicit in the language of external perception” (MERLEAU-PONTY, 1996, p.277). The perception of the urban landscape is multisensory and involves many actors (PALLASMAA, 2011), including the animals that inhabit cities, like the birds, a group of vital importance for ecological balance, seed dispersal and pollination (PEJCHAR et al. 2008; SICK, 1997; WENNY et al. 2016; WHELAN et al. 2015).

Even though birds are essential to ecological balance, how people perceive them? There are very few studies analyzing the people's perception for urban species, and the list of animals investigated is still very limited (e.g. SWEET et al. 2021; HOSAKA et al., 2017; BJERKE; ØSTDAHL, 2004). Thus, in this chapter, we aim to identify how humans perceive birds in two Neotropical cities: in Bauru (São Paulo State, Brazil) and Belo Horizonte (Minas Gerais, Brazil). However, it is important to emphasize that our study had a limited scope. Initially, the idea was to apply questionnaires according to the socioeconomic data of each city, but due to the pandemic, it was not possible to applying questionnaires in the streets and talked to people of different social classes, ages and genders (ROSA, 2020; FOLONI, 2018). So, our scope was reduced to people that, in general, have undergraduate degree.

Anyway, this research brought interesting results about what the academic community perceives the bird community. Understanding how humans perceive animals go some way in understanding current human-nature relationship, and such knowledge is essential for planning environments where humans and animals interact (SWEET et al, 2021). Several studies report that contact with nature can increase peoples' tolerance towards nature and the willingness to protect it (HOSAKA et al., 2017; UNTERWEGER et al., 2017).

4.2. MATERIAL AND METHODS

4.2.1 Study areas

This study was carried out in Bauru (São Paulo State, Brazil) and Belo Horizonte (Minas Gerais, Brazil). Bauru is a medium-sized city in the central-west region of the state of São Paulo (22°18'55" S, 49°3'41" W) with about 371 thousand inhabitants; its landscape presents high heterogeneity, with streams, rivers, forest fragments and important urban parks (SEMMA, 2015). Belo Horizonte (W 19° 55' 37", S 43° 56' 34") is the capital of the state of Minas Gerais and is one of the first planned cities in Brazil. Its landscape is occupied by woody and herbaceous vegetation distributed mainly in gardens, parks and in the streets (PENA et al., 2016). Both cities are located in the transition zone between the Atlantic Forest and Brazilian Savanna, two biodiversity hotspots (PENA et al., 2016; SEMMA, 2015)

4.2.2 Assessing human perception on urban birds

First, we used the bird data sampled during chapter 1 to get an overview on bird community composition in Bauru (described in section 1.4.5). For Belo Horizonte, we used bird data previously published in the literature (PENA et al., 2017). Pena et al. (2017) carried out a bird survey in 60 sample locations, distributed in streets through the southern region of Belo Horizonte. Site selection aimed to represent the variation of the influences of the streets and arboreal and herbaceous vegetation within the study; the point samples were at least 200 meters away from each other (PENA et al., 2017). They conducted the fieldwork during the first three hours of daylight on days with favorable weather conditions (sunny and non-windy days), only on working days – to avoid great variation in people and vehicles in circulation – between September 2014 and January 2015, period that coincides with birds' breeding season (PENA et al., 2017). The bird survey conducted in chapter 1 was based on the Pena et al (2017) approach.

We extracted information on bird species composition at each city: the total bird species richness of the municipality (including forest, rural and urban areas), the richness of birds within urban areas and the frequency in which each species was observed. From these data, we created the questionnaire (F) to analyze how the human population relates to the avifauna. To understand how people perceive birds in cities, we carried out an opinion survey with the use of an online questionnaire

created by Google Forms tool (as SWEET et al, 2021). Questionnaires were prepared with open and closed questions: open-ended responses are those in which respondent answers in own words, while closed questions are structured in the form of choice of yes/no (SANTOS, 2017). Questionnaires are considered to be an appropriate method, because it limits the range of answers a participant can give and allow for a standardization of results (SWEET et al, 2021). We sent them by e-mail, and through Facebook and WhatsApp groups from Bauru and Belo Horizonte residents.

The answers to the questionnaires were anonymous, but the first part of the questionnaire asked sociodemographic information regarding gender, age, education and family income. These data are important to understand the social context that was achieved. In the second part, we addressed the following open-ended and choice structured questions:

Open-ended questions

- (1) Describe in one word how you feel about urban birds
- (2) What do you believe is a benefit of birds in cities?
- (3) Do you believe that there is a harm caused by birds in cities?

Choice structured questions:

- (1) 371 bird species have already been recorded within the entire territory of Belo Horizonte (which includes forested, rural and urban areas)/ 276 bird species have already been recorded within the entire territory of Bauru (which includes forested, rural and urban areas). How many do you believe are capable of living in the urban area?

Also we used a Likert scale (SWEET et al, 2021; FARINHA et al. 2021; MOTA et al., 2019; REGIS, 2016), one of the most popular methods for conducting opinion surveys, in which, from a self-descriptive statement, the respondent chooses as a response option a scale of points with verbal descriptions that include extremes – such as “strongly agree” and “strongly disagree” (FRANKENTHAL, 2017). Statements were created regarding the contribution of birds in ecological processes such as dispersal, pollination and pest control. Thus, the respondents should express

their degree of agreement with each sentence. We used 5 points of scale from “strongly agree” and “strongly disagree”. We addressed the following statements:

- (1) Birds contribute to seed dispersal
- (2) Birds contribute to plant pollination
- (3) Birds contribute to the control of pests, insects and other animals.
- (4) Birds contribute to the prevention of the incidence of diseases

Finally, images of 20 birds were presented (the 15 most frequent and the 5 most rare) and songs of the six most frequent species were placed so that the respondents should mark which species they had seen and which sounds they had heard in the cities.

4.2.3 Questionnaire responses analysis

Regarding toward the questionnaires, first we analyzed the sociodemographic information and created a table with the main characteristics of the respondents participating in research (Table 1). Data obtained from closed and Likert scale questions were analyzed by simple counts and percentages (BORYSIK; STEPNIIEWSKA, 2022). In the case of questions in an open format, we carried out two different approaches: to analyze the answers for question “describe in one word how you feel about urban birds”, the words were placed in the Free Word Cloud Generator website (<https://www.freewordcloudgenerator.com/>), which is a tool that creates a “cloud” of words, highlighting those that appear most frequently. This website also points how many times each word was mentioned in each city. To analyze open-ended questions 2 and 3, we grouped answers according to harm or benefit mentioned and carried out simple counts and percentages to find out the main kinds of harm or benefit that were pointed by respondents.

4.2.4 Limitations of our study

It is worth noting that the scope of the questionnaires was limited. Ideally, the number of questionnaires should have a sample size that represents the population, as performed in works such as Rosa (2020, 2019) and Foloni (2018). In general, the required value of questionnaires is based on the size of the universe (total number of people in each city), percentage margin of error (statistical pattern = 5%), confidence

level (statistical pattern = 95%) and heterogeneity; for this last item, the value is generally 50%, a universal standard of probability regarding to sexual gender (ROSA, 2020). Furthermore, the choice of interviewees must be random, but based on the age and sex proportion of the original population, according to the logic of Systematic Design (HURLBERT, 1984).

However, the responses collected did not represent the population of these cities because these questionnaires only reached the group of people who were willing to respond online. To better represent the population of cities, the thesis mentioned (ROSA, 2020; FOLONI, 2018) applied questionnaires in the streets and talked to people of different social classes, ages and genders, following the same proportionality of the population data of each municipality. On the other hand, the present research was carried out during the pandemic, which resulted a difficult to access different social groups. Because we largely depended on social media, we ended up selecting a specific group according to the affinities and algorithms of each user.

4.3. RESULTS

In Bauru, a total of 112 responses were obtained, with 63.4% self-reported that they were female and 36.6% reported that they were male. Regarding to education, 97.3% of respondents had undergraduate degree, in which 41.0% of them also had a postgraduate degree. Regarding to income, 32.1% of respondents have low income, 25.9% have medium income, 22.3% have upper-middle income and 14.3% have high income. In Belo Horizonte, a total of 123 responses were obtained, with 53.7% self-reported that they were female, 44.7% reported that they were male and 1.6% declared their selves as non-binary gender. Regarding to education, 93.6% of respondents had undergraduate degree, in which 51.0% of them also had a postgraduate degree. Regarding to income, 14.6% of respondents have low income, 16.3% have medium income, 25.2% have upper-middle income and 38.2% have high income (Table 1).

Table 1. Characteristics of the respondents participating in research

Variable	Cities	
	Bauru	Belo Horizonte
Gender		
Male	41 (36.6%)	55 (44.7%)
Female	71 (63.4%)	66 (53.7%)
Other	0 (0%)	2 (1.6%)
Age		
Until 25 years	33 (29.5%)	16 (13.0%)
26 to 35 years	36 (32.1%)	44 (35.8%)
36 to 45 years	12 (10.7%)	32 (26%)
46 to 60 years	22 (19.6%)	17 (13.8%)
61 to 74 years	8 (7.1%)	14 (11.4%)
More than 75 years	1 (0.9%)	0 (0%)
Education		
Elementary and middle school	2 (1.8%)	0 (0%)
High school	9 (8.0%)	4 (3.3%)
Bachelor study incomplete	29 (25.9%)	12 (9.8%)
Bachelor study complete	24 (21.4%)	36 (29.3%)
Master and doctorate degree	47 (42.0%)	71 (57.6%)
Post-doctoral degree	1 (0.9%)	0 (0%)
Family Income		
Until 1000 reais	2 (1.8%)	1 (0.8%)
1001 to 3000 reais	36 (32.1%)	18 (14.6%)
3001 to 5000 reais	29 (25.9%)	20 (16.3%)
5001 to 10000 reais	25 (22.3%)	31 (25.2%)
More than 10000 reais	16 (14.3%)	47 (38.2%)
No answer	4 (3.6%)	6 (4.9%)

Regarding the statements, in Bauru, 91.1% of respondents strongly agree that birds have a fundamental role on seed dispersion, 77.7% % that birds contribute to plant pollination, and 83% that birds contribute to the control of pests, insects and other animals. In Belo Horizonte, 94.3% of respondents strongly agree that birds have a fundamental role on seed dispersion, 86.2% that birds contribute to plant pollination, and 86.2% that birds contribute to the control of pests, insects and other animals. The results showed that most people understand the importance of birds for ecological balance (Figure 4.1).

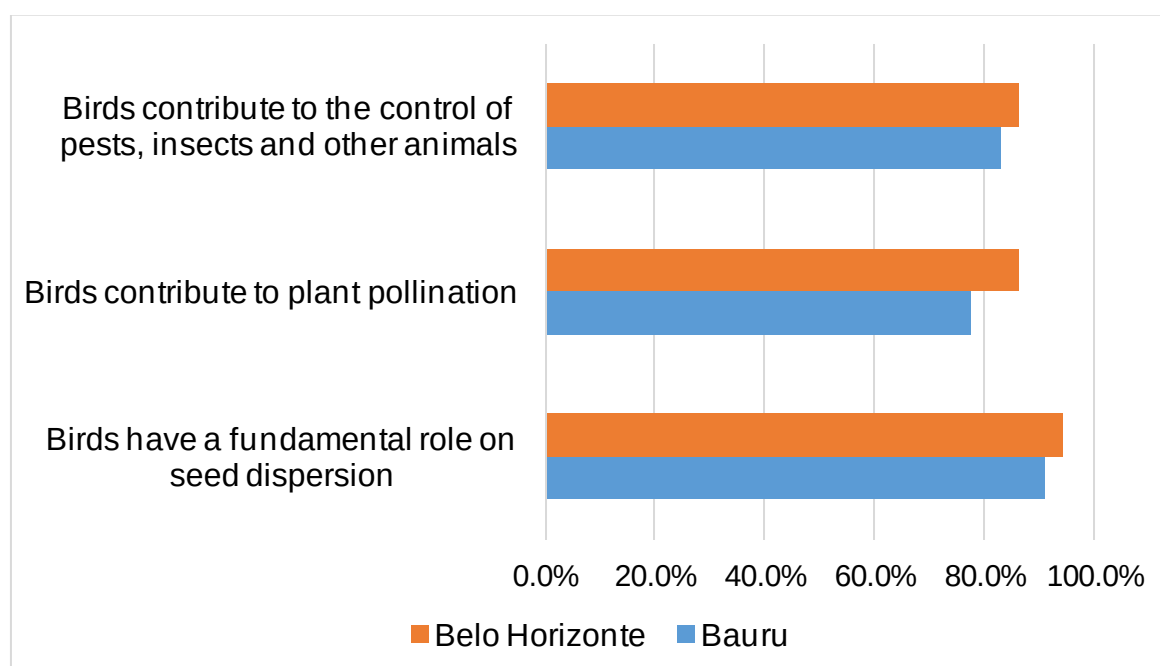


Figure 4.1: percentage of strongly agreement with the questionnaires' statements

In the case of questions in an open format, when people were asked which benefits they attribute to birds in cities, most respondents mentioned seed dispersal (Bauru: 36; Belo Horizonte: 29), biological control and life (Bauru: 24; Belo Horizonte: 35), joy and well-being (Bauru: 24; Belo Horizonte: 26). In Figure 4.2, there are all benefits that birds bring to cities according to people responses. The number means how many times each benefit was mentioned and not how many people said it; this because many people cited more than one benefit. The category "other" represent all different benefits that were mentioned only a few times such as: hope (1), environmental indicators (2), environmental education (2), spiritual connection (3), biodiversity (5). Figure 4.2 present the benefits of birds in cities mentioned by people.

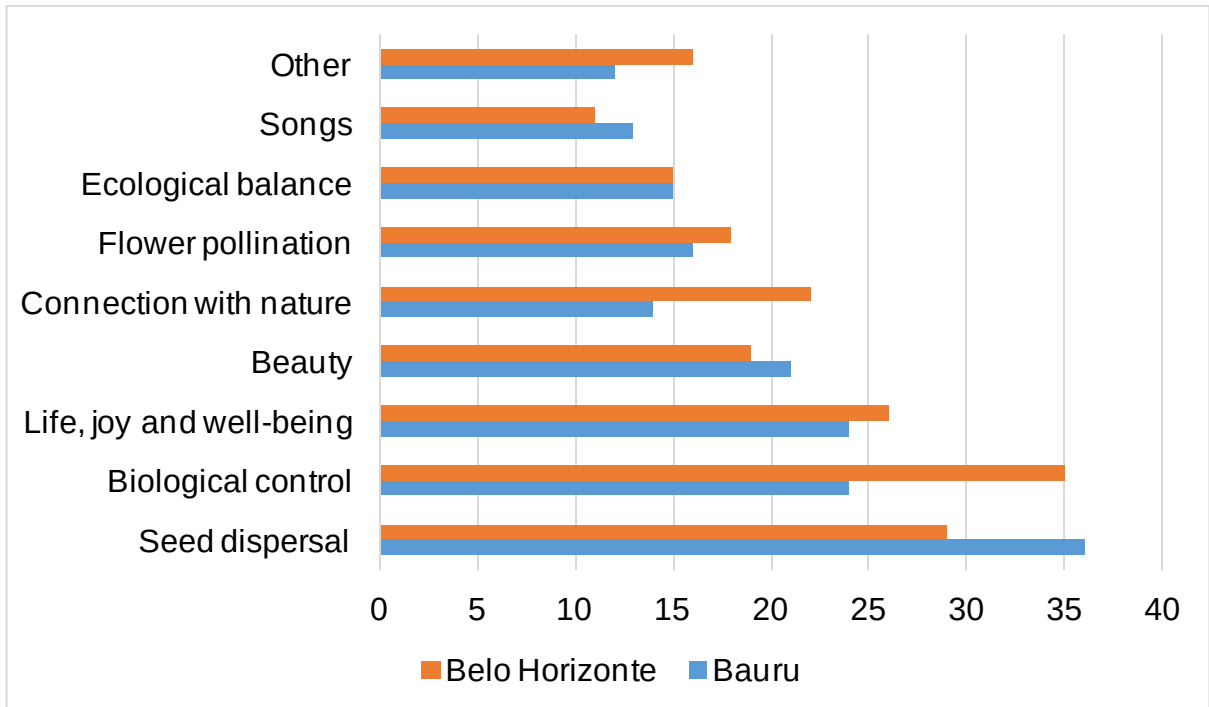


Figure 4.2: benefits of birds in cities mentioned by people. The numbers represent the how many times each benefit was mentioned.

However, people when asked if they believed there were damages caused by birds in cities, most said yes (Bauru: 66% and Belo Horizonte: 70%). When asked which damages, the majority of people mainly cited disgust and worry for the diseases that Domestic pigeons can transmit. Other problems/discomfort cited were electrical wiring damages, noise, dirt and worry concern about the ecological imbalance, in a situation of uncontrolled population of pigeons and the presence of other exotic birds (Figure 4.3).

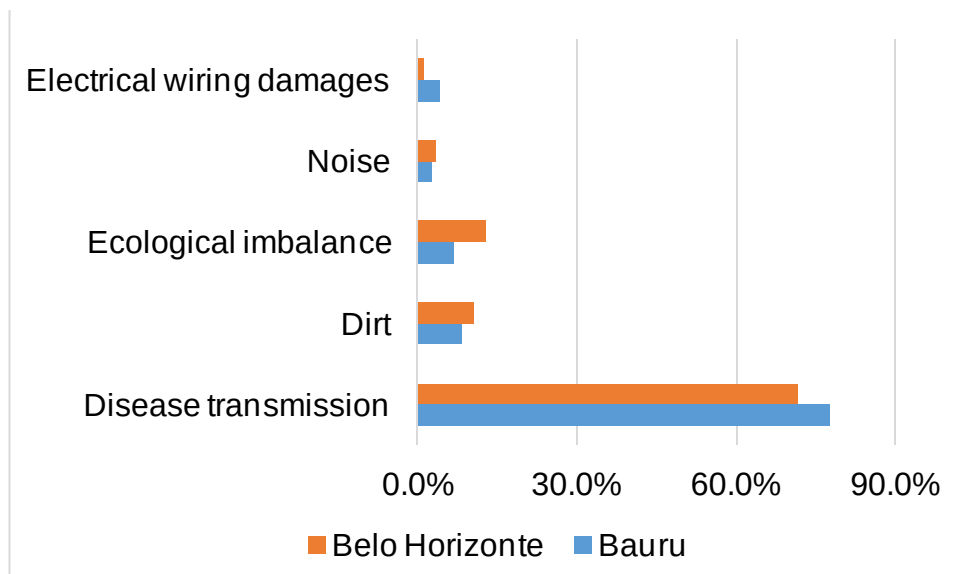


Figure 4.3: mainly damages caused by birds according to people

In Bauru, the birds most seen were Eared Dove (*Zenaida auriculata*), Domestic pigeon (*Columba livia*), Great Kiskadee (*Pitangus sulphuratus*), House Sparrow (*Passer domesticus*) and White-eyed Parakeet (*Psittacara leucophthalmus*). Four of those species are also the ones most frequently observed (*Pitangus sulphuratus*, 149 records; *Zenaida auriculata*, 141; *Psittacara leucophthalmus*, 139; *Passer domesticus*, 136; Figure 4.4). In Belo Horizonte, the birds most seen by people were Domestic pigeon (*Columba livia*), Great Kiskadee (*Pitangus sulphuratus*), Ruddy Ground-Dove (*Columbina talpacoti*), Picazuro Pigeon (*Patagioenas picazuro*) and House Sparrow (*Passer domesticus*). These species are exactly the most frequent in Belo Horizonte according with the published literature (PENA et al, 2017: *Columbina talpacoti*, 594 records; *Columba livia*, 490; *Patagioenas picazuro*, 386; *Passer domesticus*, 350; *Pitangus sulphuratus*, 345; Figure 4.5).

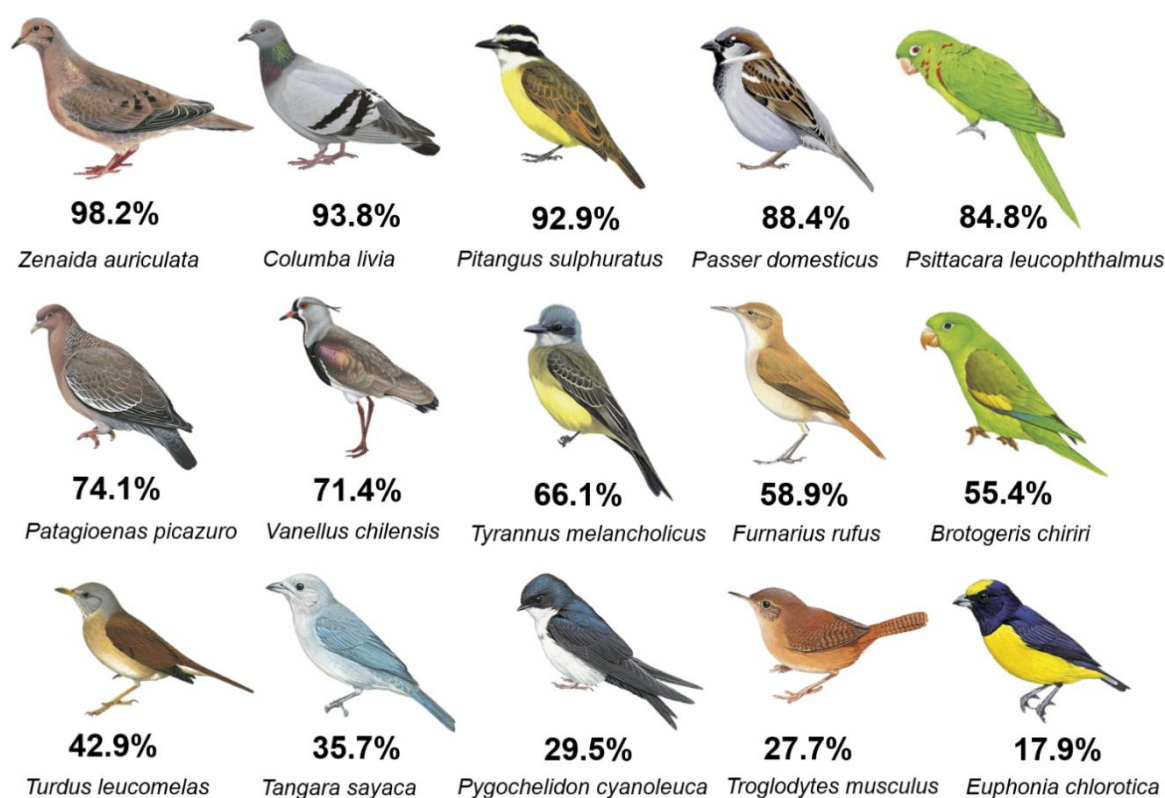


Figure 4.4: Percentage of people who often see these 15 most frequent bird species in Bauru (São Paulo), Brazil.

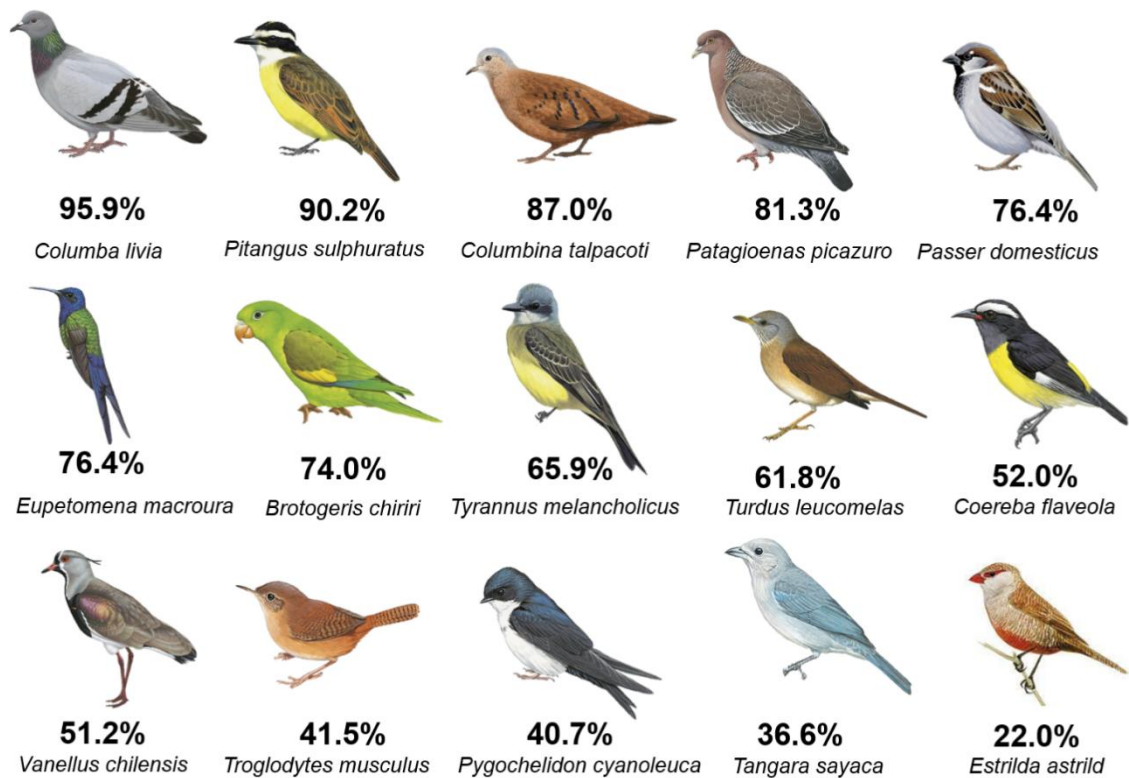


Figure 4.5: Percentage of people who often see these 15 most frequent bird species in Belo Horizonte (Minas Gerais), Brazil.

The results also confirmed that the rarest species to appear in cities are also the ones that people see the least, in both cities: Bauru (Figure 4.6) and Belo Horizonte (Figure 4.7).

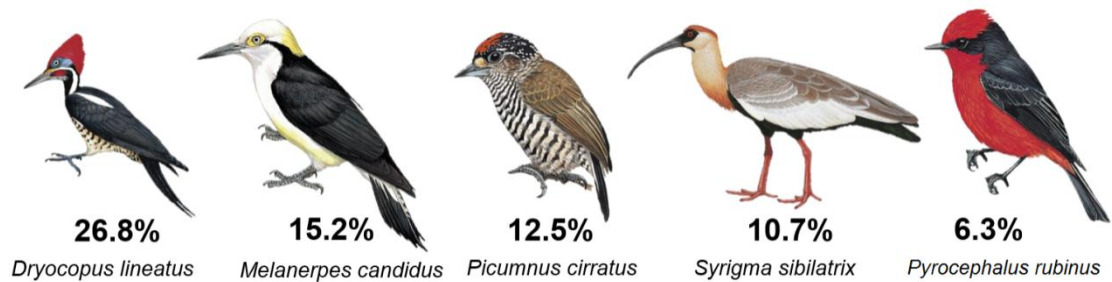


Figure 4.6: Percentage of people who have seen these 5 least frequent bird species in Bauru (São Paulo), Brazil.

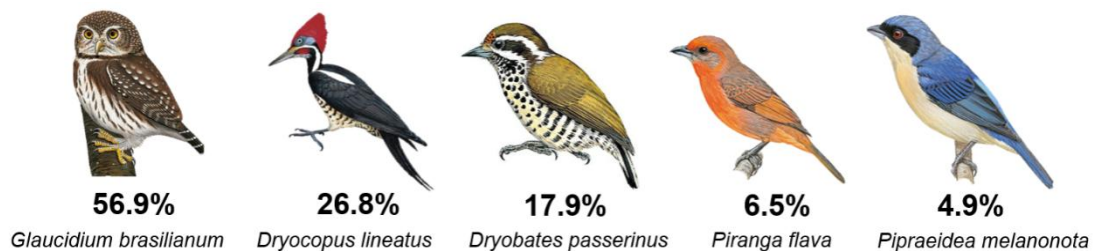


Figure 4.7: Percentage of people who have seen these 5 least frequent bird species in Belo Horizonte (Minas Gerais), Brazil.

Considering bird songs, most respondents had already heard at least some of the most frequent bird songs, which were presented (Bauru: 88.4%; Belo Horizonte: 91.9%). Only few people have declared that they did not hear any singing (Bauru: 11.6% and Belo Horizonte: 8.1%). In both cities, Great Kiskadee (*Pitangus sulphuratus*) was the most heard and one of the most seen bird species. Picazuro Pigeon (*Patagioenas picazuro*) and House Sparrow (*Passer domesticus*) appear at second or third place of bird species most heard, depending on the city (Figures 4.8 and 4.9).

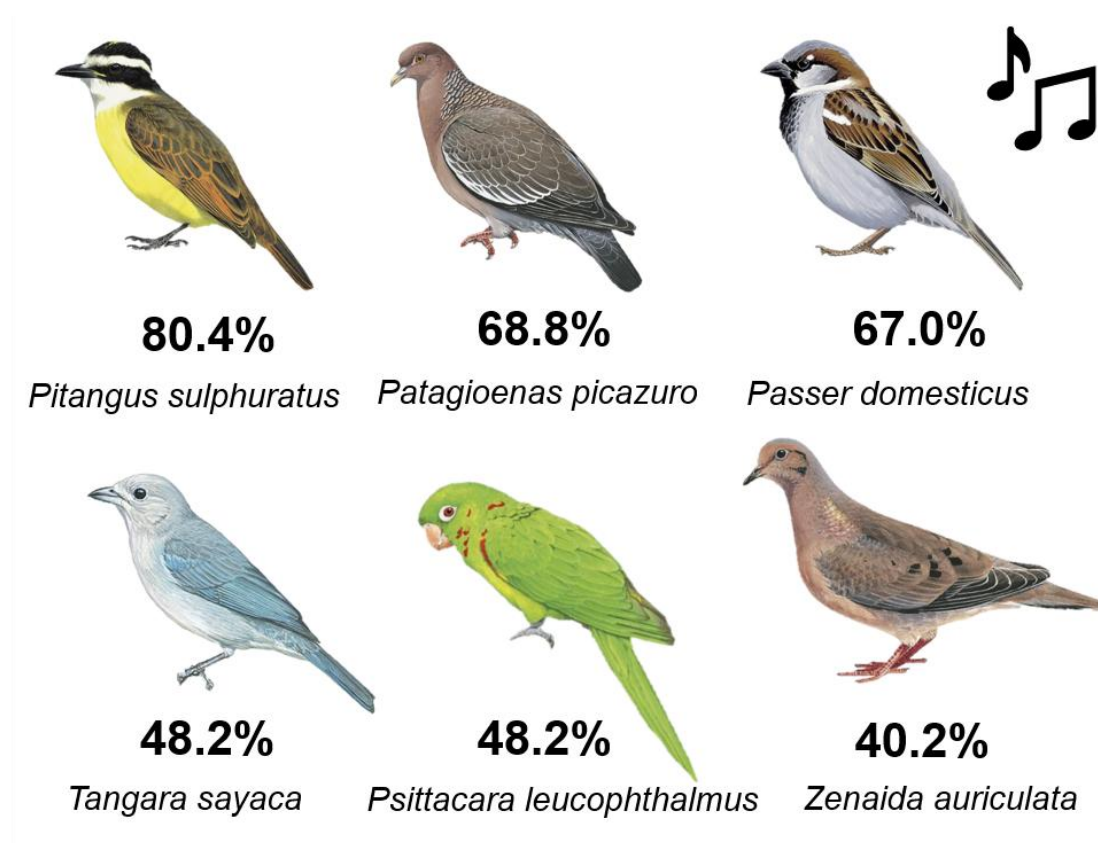


Figure 4.8: Percentage of people who have heard these bird species in Bauru (São Paulo), Brazil.

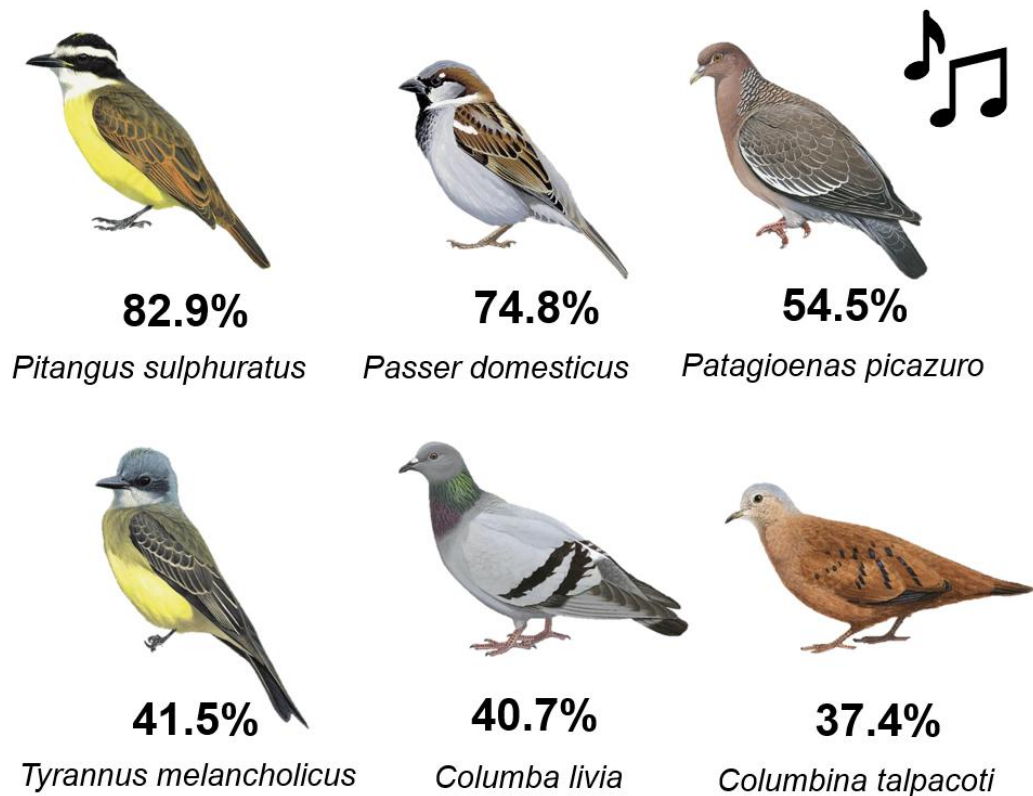


Figure 4.9: Percentage of people who have heard these bird species in Belo Horizonte (Minas Gerais), Brazil.

Regarding birds that live in urban areas, most respondents (68.7% in Bauru and 49.6% in Belo Horizonte) believed that only less than 35% of species are able to live in urban areas. However, this percentage is higher: in Bauru 36% of bird species live within cities, while in Belo Horizonte we found the percentage of 41.24%. This result showed that people have a low perception of the quantity of bird species in situ: only 16.1% of respondents in Bauru and 19.5% in Belo Horizonte got the correct percentage.

Finally, the word cloud analysis showed use the main feelings that respondents associate about urban birds. In Bauru, the most frequent words were: admiration (7), happiness (7), beauty (5), life (5), wonderful (4), depends (3), peace (3), freedom (3), tranquility (3), worry (3; Figure 4.10). In Belo Horizonte they were: admiration (13), happiness (10), beauty (8), love (4), important (4) and peace (3; Figure 4.11). The interesting thing to note is that the first three most cited words were the same in both cities. Another point that we noticed is the feelings towards birds are mostly positive feelings. Only a few people also mentioned feeling disgust, worry, illness.

4.4. DISCUSSION

Our study provides evidence that people perceive and are able to recognize the bird species most frequent in cities. Most of the species presented in our questionnaire are common in urban environments and people were familiar with a high number of the species most frequent. In Bauru, four out five birds most seen were also the ones most frequently observed. In Belo Horizonte, the birds most seen by people were exactly the most frequent in cities. This is an interesting result because Pena et al. (2017) was developed also in the streets, thus people probably have more contact with these species in their daily lives, which may explain the greater coincidence with the results.

We also found that people had a generally positive attitude towards the majority of the bird species, however, bird species were clearly not all equally liked. While the majority of people associates most bird species to positive words – such as admiration, happiness and beauty – they also dislike exotic species such as Domestic Pigeons and House Sparrows. These species are associated to disease, dirt, disgust and ecological imbalance, according to people. This result is similar with other conducted by Sweet et al. (2021), in which they found that pests such as cockroaches, rats, crane flies, mosquitoes, aphids and wasps were not liked by people.

There is a clear difference about human attitude and perception according to species. There are particular species, that are more liked (e.g. squirrels) than others (e.g. mosquitoes and cockroaches; SWEET et al, 2021). In general, birds and mammals are liked most, while arthropods and other invertebrates (mainly mosquitoes and cockroaches) are most disliked (SWEET et al, 2021), with some exceptions, rats which are the mammal least like (BJERKE; ØSTDAHL. 2004), and insects such as butterflies that are very liked by people (HOSAKA et al. 2017). There is a positive relationship between individual participants' familiarity with the species and the attitude towards them (SWEET et al. 2021).

Overall, our study confirmed that most respondents are aware about the importance of birds to ecological balance. When people were asked which benefits they attribute to birds in cities, most respondents mentioned seed dispersal and biological control in both cities. Birds play vital roles as seed dispersers in human-

altered landscapes, helping to maintain and restore plant communities (PEJCHAR et al. 2008; WENNY et al. 2016; WHELAN et al. 2015). Flower pollination and ecological balance were also two benefits very mentioned by people, confirming that most people understand the importance of birds.

In addition, we observed that people know the diversity of bird species that live within cities, but underestimates the number of birds that can live in urban areas. The song of birds is still a sense less explored and perceived by people. Probably, this could happen because of noise pollution (mainly traffic noise) and the highly dynamic urban life make it difficult for some people to hear or notice bird songs within cities. Despite most respondents were able to recognize them, this sense is less explored by people, comparing to vision. This shows the need to expand environmental education initiatives. Environmental education in early childhood provides many opportunities to sensitize children to interact with nature, promoting new generations to be environmentally aware of the importance of nature (DERR et al. 2017). Moreover, it is necessary reconcile birds and people relationship, through other initiatives that englobes adults and ancient people such as birdwatching events.

Considering social aspects, we saw that birds within cities provides to humans connection with nature, life, joy, beauty and well-being. Many people in Bauru and Belo Horizonte mentioned these as the main benefits provided by birds. Research in the fields of environmental psychology has shown that people's exposure to natural systems positively affects human well-being and health (LOUV 2005; LOVASI et al. 2008; ADAMS et al. 2017). Thus, birds are part of the urban landscape and stimulate the human senses that perceive them also in a subjective way: they bring good sensations and feelings, increasing the connection of humans with nature in urban environments. A highly 'imaginable' city would invite our eyes and ears to have an active participation in the city, so that the sensory domain would be expanded and deepened (LYNCH, 1960).

Understanding how humans perceive animals is very important for creating a conservation agenda and planning environments where humans and animals interact (SWEET et al, 2021; PETT et al. 2016). Designing green spaces and improving human-biodiversity relationships in cities is also of utmost importance to consider reaching some of the seventeen Sustainable Development Goals (SDG) for 2016-

2030 (UNITED NATIONS, 2015), e.g. the 3rd SDG (good health and well-being), the 13th SDG (climate action) and 15th SDG (life on land) (GRAVIOLA et al. 2021). Cities are ecological and socioeconomic spaces for living and non-living things (MADDOX et al. 2017) and understanding how human and ecological processes coexist can help cities become more sustainable places (MARZLUFF; et al 2018).

4.5. CONCLUSION

In our study we showed that most people can recognize the most frequent bird species and are aware of the ecological importance of birds for the balance of ecosystems. It also showed that most people associate the majority of bird species with positive sensations and feelings such as beauty, joy, well-being and peace. In other hand, species such as the domestic pigeon are considered pests and generate negative sensations. The concept of environmental perception seeks to cover aspects that influence the natural, physical and humanized environment through attitudes, values and worldview (TUAN, 1983). Thus, understanding these human–biodiversity relationships is to be aligned successfully with that of public health by policymakers and practitioners (PETT et al. 2016). The city exists through bodily experience, which is multisensory (PALLASMAA, 2011), thus studying birds and perceiving them as part of the urban landscape, can be useful to stimulate the imaginability of cities and, at the same time, contribute to the conservation of a group of animals that is particularly important for the ecological balance of urban ecosystems.

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CHAPTER V

Araucaria project: Sustainable campus 2030 throughout nature-based- solutions



5.1. INTRODUCTION

In 2019, the United Nations General Assembly (UNGA) proclaimed 2021-2030 as the Decade of Ecosystem Restoration, because the conditions on planet Earth that allow a quality life for humanity and other living beings are approaching a point of inflection (IPCC, 2021). Thus, there is an urgent need for innovative approaches to ecological restoration, nature conservation and addressing social challenges to meet the global needs of society. Scientists estimates that 2 billion hectares of forest areas need restoration interventions (MINNEMAYER et al., 2011), much of which is found in tropical regions (ITTO, 2002).

There is strong evidence linking the degradation of nature with the decline in human well-being, so the conservation, restoration and sustainable management of ecosystems are essential for tackling the climate crisis (MEA, 2005). Thinking about the role of cities to face the climate crisis is essential, because despite urban ecosystems occupy only 2% of the 29% of planet Earth not covered by water, cities are responsible for 75% of gas emissions responsible for global warming and harbor 53% of the world's population (BURDETT; SUDJIC, 2011). Considering this, Nature-Based Solutions (SBN) appear as efficient alternatives to overcome these challenges.

NBS have been increasingly cited in the scientific literature (ROSA, 2021; DALBELO, 2019; KEESSTRA et al., 2018; RAYMOND et al., 2017;) and in government policies of many countries (WWAP, 2018) as an alternative to face the global challenges related to the environment. According to International Union for Conservation of Nature (IUCN), "Nature-based Solutions are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2016). It is a broad concept that encompasses specific or multiple social challenges, while providing benefits for human well-being and biodiversity (COHEN-SHACHAM et al., 2016).

NBSs originate from the Ecosystem Approach, which supports the Convention on Biological Diversity (CBD) and considers biodiversity conservation and human well-being as dependent on the functioning and resilience of natural ecosystems (CBD, 2004). NBSs can involve very different actions ranging from

protection, management and even the creation of new forms of city. There are five approaches that nest under the SBNs: 1) Restoration (Ecological Restoration, Forest Landscape Restoration, Ecological Engineering); 2) Specific issues (ecosystem-based adaptation; ecosystem-based mitigation; ecosystem-based disaster risk reduction; climate adaptation services); 3) Infrastructure (natural infrastructure; green infrastructure); 4) Management (Integrated management of the coastal zone or water resources); and 5) Protection (conservation approaches based on protected areas (COHEM-SHACHAM et al. 2019)).

Ecological restoration is defined as the process of assisting in the recovery of a degraded ecosystem (MCDONALD et al. 2016) and the role of human during this process is to intervene in order to trigger, facilitate or accelerate the natural process of ecological succession. (RODRIGUES et al. 2015). International agreements and conventions consider restoration one of the main goals, hence some countries are committed to invest financial resources to achieve them (CBD, 2004). International policies highlight the necessity of understanding the effects of restoration process on soil nutrients and soil organic carbon (SOC) stock status, on temporal and spatial scales (CHENU et al., 2019; MINASNY et al., 2017). This is a key factor in sustainability and conservation (QUIJANO et al. 2021). The increase of SOC generates a great impact on the soil, positively influencing its functions, such as water storage and filtration, nutrient recycling and habitat for biological activity (WIESMEIER et al., 2019 ; UNCCD, 2015).

Green infrastructure is a multifunctional network of natural areas and other green spaces that conserve and mimic functions of natural ecosystems within cities, providing broad benefits to people and wildlife (EU COMMISSION 2013). Applying green infrastructure in cities consists of planning, designing and managing new and existing buildings and infrastructures, in order to transform them into multifunctional spaces with the presence of parks, gardens and other green areas, which can become productive (e.g. agroforest and urban agriculture) (SANCHES, 2019; HERZOG, 2013). It helps restructure the mosaic of land uses that form urban landscapes at various scales, such as connecting parks and other green spaces through wooded streets that function as ecological corridors (HERZOG, 2016).

Corridors are defined as homogeneous areas of a landscape unit, which are distinguished from neighboring units and which have a special linear arrangement (METZGER, 1999). This concept was originally proposed for rural areas in order to connect isolated wildlife habitats through the establishment of migration passages. The urban ecological corridor has the basic characteristics of the ecological corridor, but its definition has been largely extended to integrated aesthetic functions, landscape, recreation and historical and cultural protection (PENG et al. 2017).

The implementation of forest restoration and green infrastructure brings ecosystem services, contributing to achieving the Sustainable Development Goals (SDGs), proposed by the 2030 Agenda (SDG, 2017; COHEM-SHACHAM et al. 2019). Specifically, NBS are directly relevant to SDGs 2 (food security), 3 (health and well-being), 6 (safe drinking water and sanitation), 11 (sustainable cities and communities), 13 (climate change), 14 (conservation of aquatic life), and 15 (protection, restoration and promotion of sustainable use of terrestrial ecosystems) (VASSEUR et al., 2017; COHEM-SHACHAM et al. 2019). The scope of the SDGs contributes to the regulation of microclimate conditions, food production, basic sanitation, preservation of flora and fauna and many other services. Therefore, it is not possible to disconnect the SDGs from the ecosystem services they provide, as they all influence each other.

Indirectly, NBS contribute to all SDGs, as they are all interconnected and interdependent. By implementing solutions that solve health problems and guarantee food security, for example, it contributes to the access of the entire population to this service, helping to reduce inequalities (SDG 10) and eliminate poverty (SDG 1). The same is true for other SDGs: it is only possible to implement SBNs if we have effective and fair institutions (SDG 16) and implementation partnerships (SDG 17). There are countless examples, so it is clear that the implementation of SBNs has a vast field of action and support many ecosystem services, in addition to providing the scope of the SDGs.

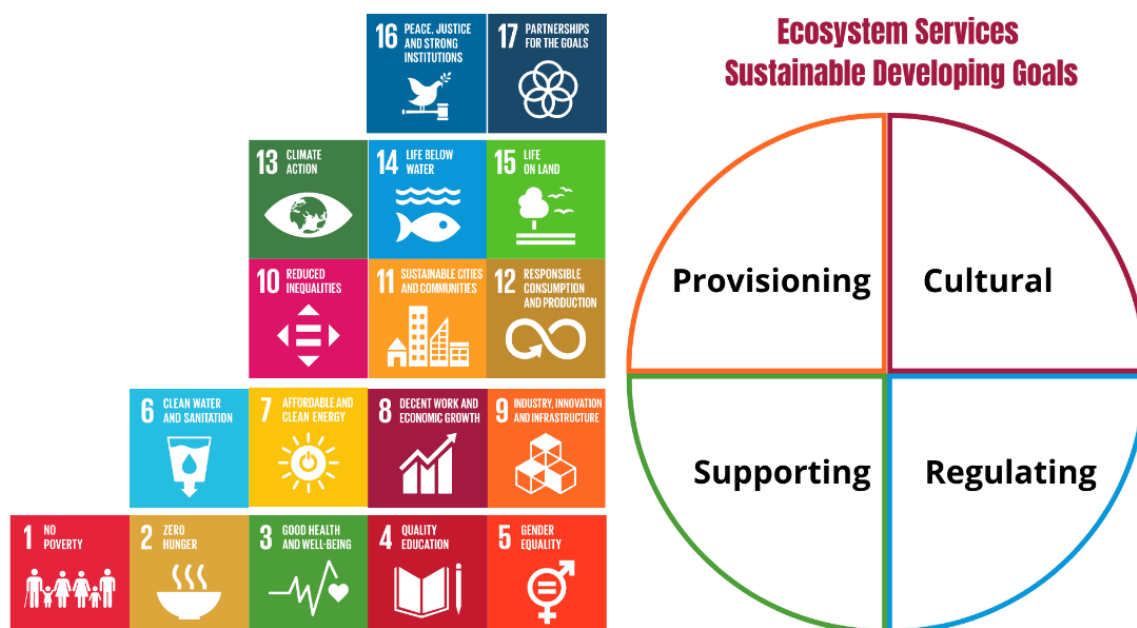


Figure 5.1: Schematic representation of the Sustainable Development Goals and the four categories of ecosystem services

The purpose of this chapter is to report the experience of participating on Challenge Campus 2030 and to discuss how science can be used to propose practical solutions to overcome environmental challenges and problems. On June 11, 2021, the Araucária team project – representing UNESP/Rio Claro – won the Challenge Campus 2030, Edition 2. Overall, 680 teams and 1997 people from 79 countries around the world participated in this challenge, organized by Agorize, in partnership with the United Nations (UNRIC) and the Agence Universitaire de la Francophonie (AUF). The aim was to encourage students and professors from all over the world to create sustainable solutions for their university campuses that would achieve at least 3 of the 17 UN Sustainable Development Goals (SDGs).

Our proposal was to bring sustainability by offering new views of planning the landscape, by applying Nature Based Solutions (NbS). Our great differential was to bring scientific knowledge to practical solutions in the urban context. Based on this experience, the project aims to be a reference for the implementation of similar projects in other parts of Brazil. The proposals fit into the Nature-Based Solutions (SBN) 1 (restoration) and 3 (infrastructure) approaches.

5.2. THE CHALLENGE CAMPUS 2030

Challenge Campus 2030 was an international challenge organized by Agorize, in partnership with the United Nations (UNRIC) and the Agence Universitaire de la Francophonie (AUF). Its objective was to encourage University campuses to achieve at least 3 of 17 SDG in 10 years, by proposing solutions that could be considered socially, economically and environmentally sustainable. The challenge was composed by 3 stages⁴:

- 1) From September, 24th, 2020 to February, 7th, 2021, we had to create a diverse team of 5 people maximum and upload a presentation explaining our project idea in 5 slides. *In total, 1997 people from 680 teams and 79 countries participated*
- 2) *31 teams from all over the world were selected:* From March, 2nd until April, 18th, 2021, the teams were invited to take their concept further following several video on the Sustainable Development Goals proposed by the United Nations and AUF. The teams produced a five slides presentation and a two minutes video presenting themselves and their project' goals.
- 3) **3)** On June 11, 2021, the 6 finalist teams had the chance to pitch and defend their project in the presence of the Jury comprising members of the UN, AUF, UNRIC, UNESCO, AFD, IRD, Enactus, SoScience, Groupe SOS, Impact Campus, Utopies/Campus responsables.

⁴ See <https://www.agorize.com/en/challenges/campus2030-2/agreements?lang=en> for more details.

5.3. PROBLEMS TO BE SOLVED

Our São Paulo State University (UNESP) campus is located in Rio Claro, São Paulo, Brazil. Brazil faces a huge problem: the loss of forested areas. Since 2013, official deforestation rates have been on an upward trend, worsening in the last two years (INPE, 2020). In 2019, 10,129 km² of forest was clear-cut, an increase of 34% compared to 2018 (7,536 km²) and in 2020 deforestation rate is 182% higher than the established target of 3,925 km² (SILVA JUNIOR, 2019).

Brazil is also the largest user of pesticide, with some 540,000 tonnes, accounting for about 18% of global use, for a market value of USD 8.9 billion; also, Brazil is the largest buyer of Highly Hazardous Pesticides (HHPs; PAN, 2019) and together with countries such as Uruguay and Colombia, HHP use per hectare is 7-10 times higher than in EU (GABERELL; HOIKES, 2019). In 2015, Brazil planted 71.2 million hectares of crops and among them, soybean accounted for 42% of the country's total planted area (32.2 million hectares), followed by corn with 21% (15.8 million hectares) and sugar cane with 13% (10.1 million hectares). Together, these three crops accounted for 76% of Brazil's total planted area and were the ones that consumed pesticides the most, corresponding to 82% of all Brazilian consumption in 2015 (PIGNATI et al. 2017). Because of that, millions of Brazilians are exposed to a cocktail of pesticides in their drinking water, which their effects remain largely unknown (GABERELL; HOIKES, 2019).

Related to Rio Claro municipality, the city presents poor indicators of environmental quality: it has the second highest level of suspended particulate matter in São Paulo State (CETESB, 2016), and 54% of its 1447 springs. Also, urban vegetation and green spaces are poorly distributed through the urban perimeter: only 5% of its streetscape consists of wooded streets (PENA et al. 2020). Considering urban mobility, about 50% of Rio Claro inhabitants use bike (CUNHA, 2017). Despite that, there is not enough infrastructure for cyclists in city and at UNESP campus.

5.4. CREATING A TEAM

São Paulo State University (UNESP) always sends Institutional emails sharing opportunities. In one of them, there was the announcement of the Challenge Campus 2030. The opportunity of participating on this international challenge aroused in me the desire of creating a team that could develop a project to face some of the Brazilian environmental problems. However, I heard about this challenge just one week before the deadline. Thus, I quickly started looking for people to form a team.

Because one of the aspects that would be evaluated was the diversity and plurality of the team, I looked for people with different ages, academic backgrounds and also a balance between men and women. The first invitations were to my supervisor Dr. Milton Cezar Ribeiro (computer scientist, PhD in Ecology and professor at UNESP) and my co-supervisor João Carlos Pena (biologist and PostDoc fellow in Urban Ecology). Then I started looking for undergraduate students to be part of the project. I also invited Leticia Bulascoschi, an ecologist and at the time a Master student in Forest Sciences at ESALQ/USP. She has experiencing in forest restoration process and would strengthen the team. Finally, I looked for a person outside the academic and environmental areas. I chose to invite Monique Lara Rosas, a Mexican friend who is a publicist from Universidad Veracruzana (Mexico) and works as an agile marketing facilitator. Her background would be perfect to communicate our idea. Moreover, it would be a way to increase the diversity of the group, by bringing people from other areas and from other countries to join the project. Together with me (an ecologist and a PhD student in Ecology and biodiversity), we would form a specialized team with different backgrounds.

After the acceptance of the invitations, Araucaria Team was born on the last day of the application deadline, February, 7th, 2021. The name was chosen to honor Araucaria tree (*Araucaria angustifolia*), a 200-million-year-old pine species, native from Brazil, that is a critically endangered species from the Atlantic Forest. The tree refers to the idea of resilience, strength, and ancestry, so we expect our project can be a driver for a more sustainable future and have the capacity to endure over time.



Figure 5.2: Team members; from left to right: Leticia Bulascoschi, Milton Cezar Ribeiro, Gabriela Rosa, João Carlos Pena e Monica Lara Rosas. Source: figure created by Monica Lara Rosas

Our project idea was to transform life on campus, by creating a network of cycling paths to promote connectivity between the main areas of the campus; expanding three thousand square meters of the agroforest area to increase organic food production; and restoring 10 ha of the riparian forest of the Ribeirão Claro River. From this experience, we hope to inspire other campuses, institutions and cities to implement new similar projects, using NBS. The first prototype would be implemented at the São Paulo State University (UNESP), campus Rio Claro.

5.5. CONTEXTUALIZING OUR CAMPUS LOCATION

Campus Rio Claro of UNESP has 2448 undergraduate students, 1299 graduate students, 266 professors and 392 technicals and occupies a total area of 1,555,147 m², in which 63,684 m² is occupied by built structures. Our campus is considered a gathering space for exercise and leisure activities, due to its many green spaces inhabited by different animal species. However, many of these areas and several university buildings are not connected. Even though more than a half of the university community go to the University by bike, the cycling paths are inadequate and unevenly distributed. Sometimes it's really uncomfortable riding a bike under the sun and through muddy places during the summer and rainy season. Furthermore, the riparian forest of the Ribeirão Claro stream is degraded.

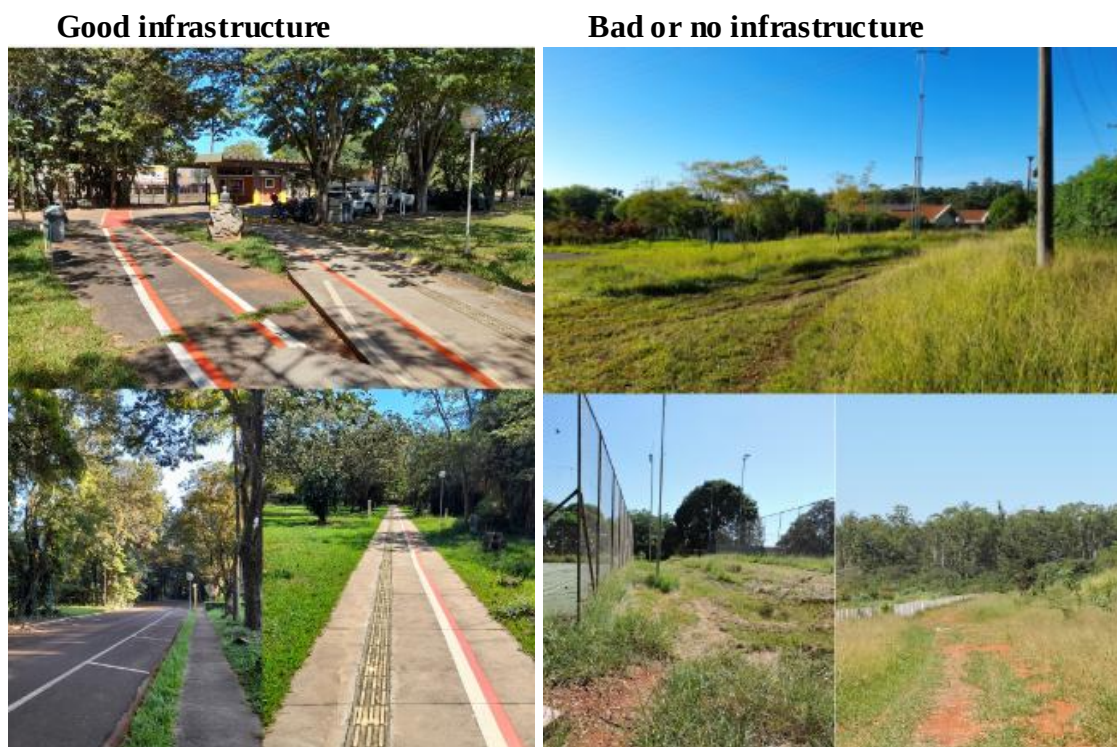


Figure 5.3: Examples of good and bad infrastructure at Rio Claro's campus (São Paulo, Brazil). Source: own authorship



Figure 5.4: Ribeirão Claro river (São Paulo, Brazil). Source: own authorship

In order to assess if other students and the university staff had the same opinions, our team conducted a survey in April 2021, with the use of an online questionnaire created using the Google Forms application. The answers to the questionnaires were anonymous. The only personal information requested was to mention if the person were a researcher, student, technician or professor and, optionally, from which course. The following questions were closed and structured in the form of choice of yes/no:

- 1) Do you use the bicycle to go to the campus and to move between the buildings at UNESP Rio Claro campus? If you answered yes in the previous answer, how often (in days per week) did you use it?
- 2) Do you miss better infrastructure for cycling on campus?
- 3) Did you know that there is an agroforest on Campus?
- 4) Would you buy or consume food on campus?
- 5) Do you think there is thermal comfort for cyclists and pedestrians within the campus?
- 6) Do you believe there is a lack of connectivity between campus buildings, considering the needs of bike paths and pedestrian paths?
- 7) Do you believe that there is a lack of connectivity between forest fragments, considering the afforestation?

We received 409 answers. Among them 52,1% of people go to University by bike. This result confirmed to us the need to improve the cycling paths. Considering agroecology issue, 40.1% didn't know about the existence of the agroforest in the campus. This showed us that despite the existence of an agroforestry area on the campus with more than 10 years, it is necessary to improve the dissemination of works and projects offered within the university itself. Related to food production, 89% affirmed that if offered, they certainly would buy organic food produced in the campus, 10,3% affirmed that maybe would buy organic food and only 0,7% (three people) affirmed that they wouldn't buy organic food.

The results also showed that 61% agreed about the poor microclimate conditions for walking; 63%: believe that there are poor microclimate conditions for walking, cycling and leisure activities in the campus; 73% agreed that the University buildings are poorly connected for cyclists and pedestrians and the infrastructure is inadequate; and 83% believed in the necessity of increasing landscape connectivity for fauna movement.

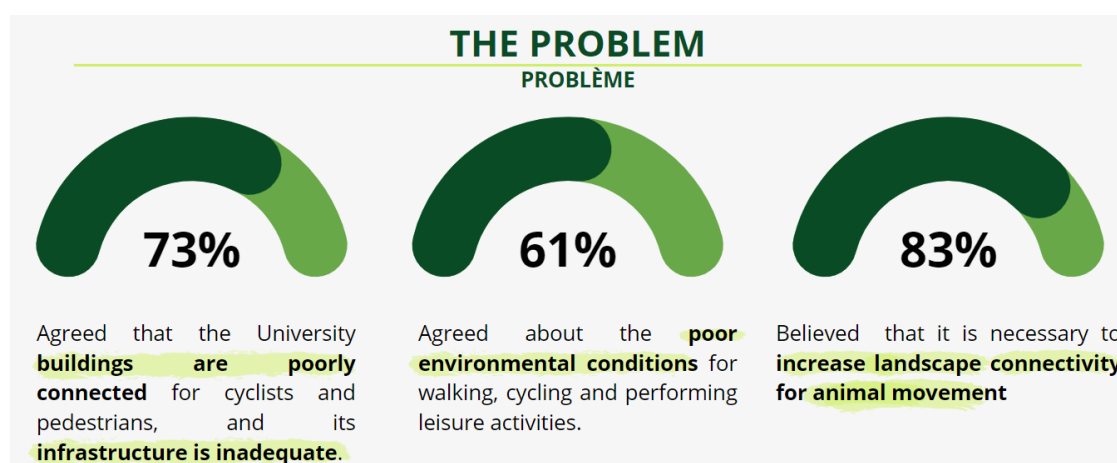


Figure 5.5: Slide picture from results presented at final stage of Challenge Campus 2030, on June 11, 2021.

5.6. OUR PROJECT IDEA

By 2030, the university will offer a more efficient network of cycling paths, promoting connectivity between its main areas, will restore the riparian forest and the adoption of agroecology practices will be consolidated among our community. Our project proposes to achieve at least 8 of the 17 sustainable development goals.

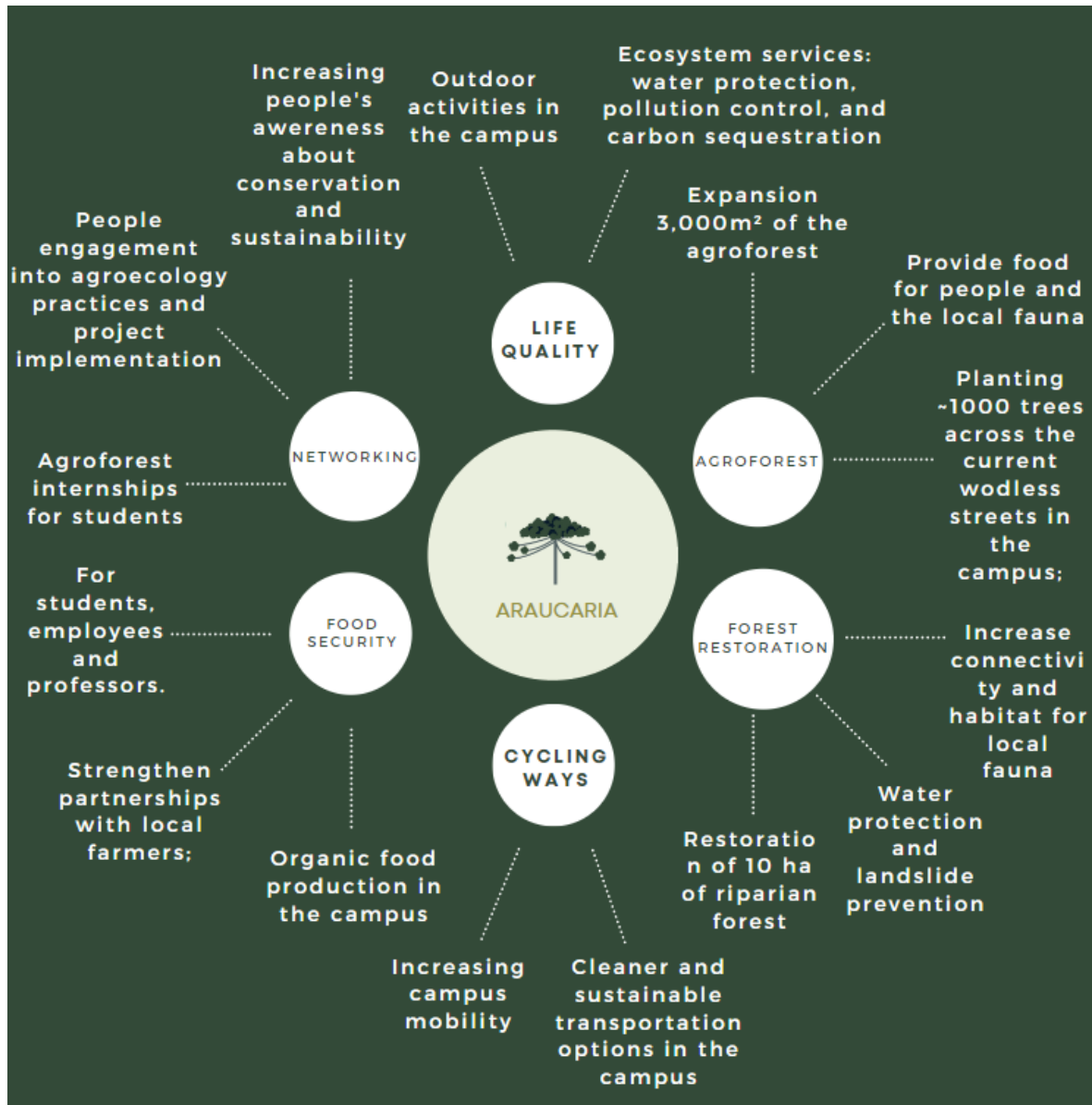


Figure 5.6: brainstorming of ideas and goals of Araucaria project presented at second stage of Challenge Campus 2030.

First, we will expand **3 thousand m²** of the agroforest area, increasing food production by **30 tons**, totaling **56 tons of** organic food produced annually inside the campus. This will encourage people to consume healthy food, will strengthen

partnerships with local farmers, and will promote easier access to organic food. These impacts are related to SGD 2 (SGD 2 – zero hunger and food security), 3 (health and well-being), 10 (reduce inequality) and 12 (sustainable consumption and production)

Second, we will build **3 kilometers** of wooded cycling paths applying agroforestral techniques. We will plant **a thousand trees** to increase the connectivity between the university buildings. This will encourage people to walk and ride bikes even more inside the campus. Finally, we will plant **4 thousands** seedlings to restore **10 hectares** of the riparian forest of Ribeirão Claro River. By doing this, we will increase the carbon stock by adding **50 thousand kilos** in the stock rate, annually. This will help mitigate climate change (SGD 13), by promoting thermal comfort and pollution control, and will also improve water quality and facilitate fauna movement. This will help climate action, by promoting thermal comfort and pollution control, and will also improve water quality and facilitate fauna movement (SDG 14 – conservation of aquatic life and 15 – protection, restoration of terrestrial ecosystems). All these actions are directly relevant to SDGs 11 (sustainable cities and communities),

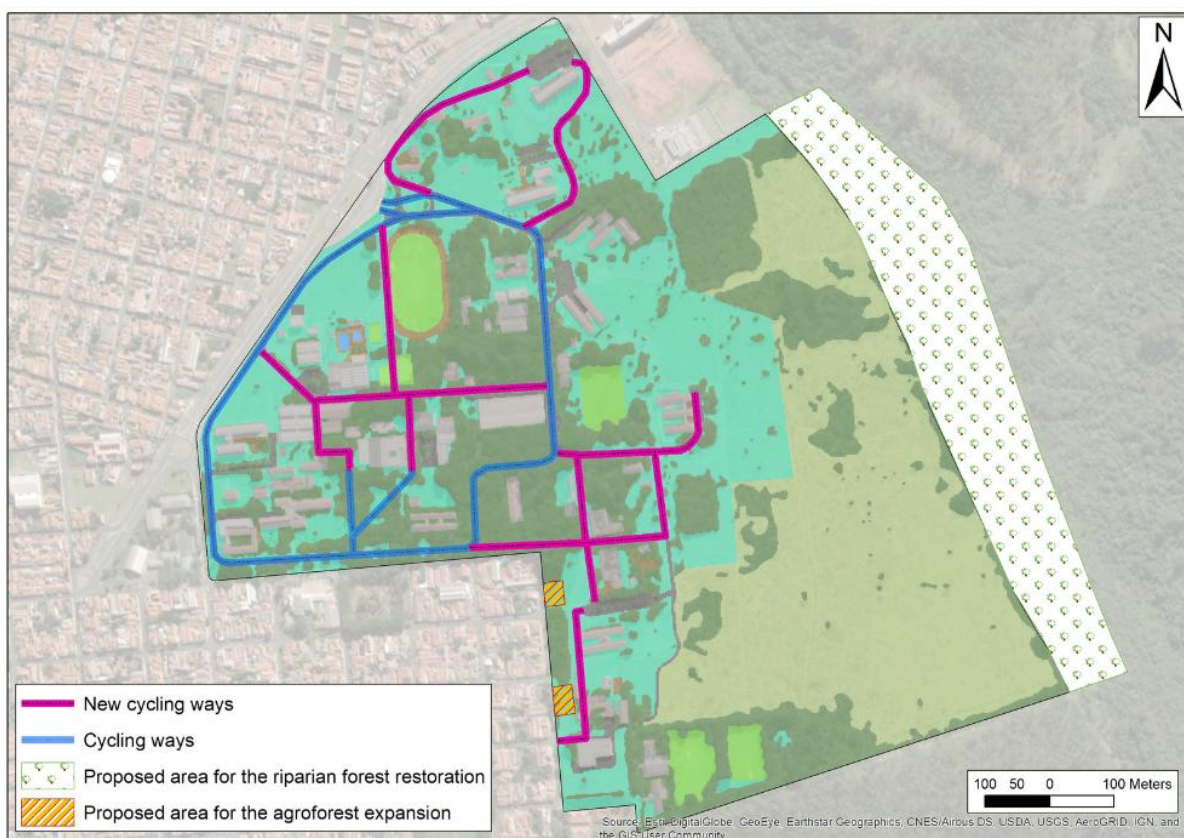


Figure 5.7: Nature-Based Solutions (SBN) proposed for the Rio Claro campus. Source: created by João Carlos Pena



Figure 5.8: Project of a cycling paths with green infrastructure, created by the author with SkechUp and the 8 goals of sustainable development that Araucaria proposes to achieve

ONU News (France)¹³. It was also released via radio UNESP and UNESP's Youtube channel.¹⁴

The Araucaria team received as the challenge's prize the amount of 1000 euros for project implementation and 4 months of training on entrepreneurship and innovation, given by the French company Pulse. We also received an honorable mention from the city hall of Rio Claro (Figure 5.9).

¹³ [Challenge Campus 2030 : six projets qualifiés pour la finale \(unric.org\)](https://unric.org/fr/france/actualites/2030/Challenge-Campus-2030-six-projets-qualifies-pour-la-finale)

¹⁴ <https://youtu.be/e9UHNBT00ZE>
<https://youtu.be/vYp4FDG34q8>

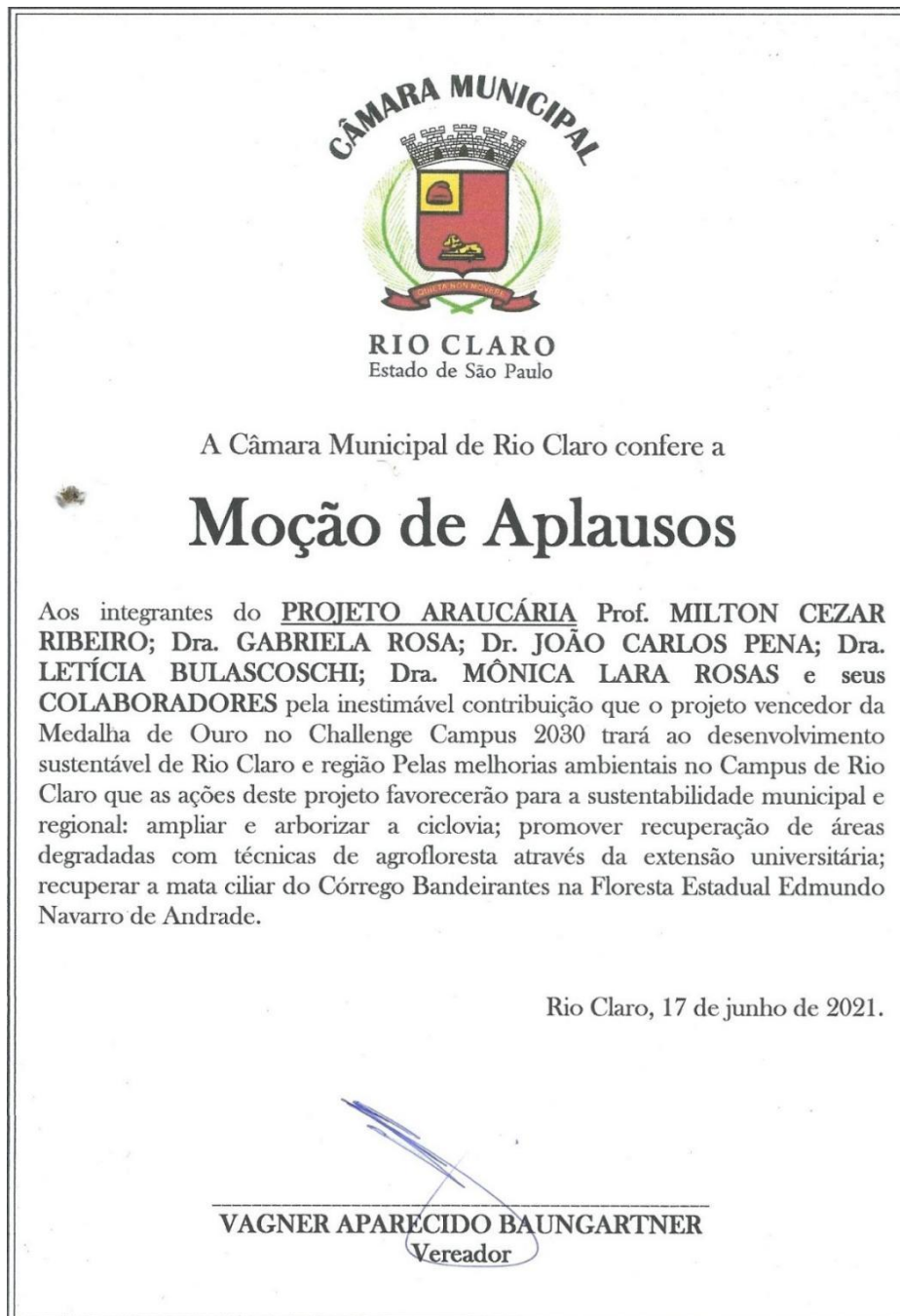


Figure 5.9: honorable mention from the city hall of Rio Claro

5.8. PULSE TRAINING

During the pulse training on entrepreneurship we had 3 workshops to learn about tools to prototype your ideas, 3 webinars about training on impact measurement and 2 co-development sessions on financing and community building. Also, we had individual meetings every month with tutors from Pulse and received a book with several concepts about entrepreneurship and innovation:

Chaper 1 - Social Mission and value proposition

Chaper 2 - Build your socio-economic model

Chaper 3 - Impact assessment

Chaper 4 - Pitching

Chaper 5 - Define your marketing strategy

Chaper 6 - Communication strategy

Chaper 7 - Business Plan

Chaper 8 - Commercial prospection

Chaper 9- Funding mechanism

Chaper 10 - Budget Pricing.

During the program, we have learned about the importance of having a critical view about our project and its limitations. Also, the material provided by Pulse gave us an in-depth overview of how to transform projects into concrete products and solutions. Because of our academic background, most information received was new. So, all the experience during the program was very useful, once we could be in touch with some new tools and knowledge to start our project.

We have also learned about several new concepts such as business model canvas, “minimum viable products”, and our “personas”. It also helped us to understand how to measure our impact, how to pitch and how to define our marketing strategy. Also, it helped us to identify our social problem and social mission, and to distinguish who are our “clients” and who are our beneficiaries. Because our project aims to change the life on our campus (environmental quality, urban infrastructure) our “clients” and beneficiaries can be different “personas”. The clients will be our funders and donors (companies, government and the University), while the beneficiaries will be the entire University community. Finally, we could understand what a business plan is so that we could develop our economic plan and our communication strategy.

In order to develop and formalize the project, we created LASI (Laboratory Araucária for Sustainability and Innovation). The idea is to engage students and professors in the development of our project. We thought about creating an NGO, but we realized that we would have to deal with the huge amount of legal bureaucracy to start and maintain an NGO in Brazil. Furthermore, after the Challenge Campus 2030, the first place received by our project triggered a 2030 Agenda within the university.

The co-development sessions and the interaction with teams from different countries and backgrounds helped us think on how to engage the community, helped us to have an overview of ourselves, and gave us new ideas and new solutions to the challenges and difficulties that we will face. Presenting our ideas and receiving feedback from people with different backgrounds and from different countries was one of the most interesting and important aspects of the program. It allowed us to assess if we are able to present our goals to a broader audience and to realize if our decisions were the best ones to reach our objectives. The workshops also helped us in defining our legal structure - the new LASI lab - and planning the steps for the construction and improvement of the cycling paths and for the restoration project. As final products, we had defined the LASI, our Social Business Plan and the “minimum viable products” we want to deliver to our community.

4.8.1 Social Business Model Pulse training

Based on the examples of the “Socio-economic Model” chapter from Pulse material, our project can be classified as:

- **“Fabrication”**, once it will provide a sustainable lifestyle by offering an adequate infrastructure of cycling paths, a healthier environment and organic food production.
- **B2B and B2C relationships with customers:** we will have two different customers. The first partners will be the public institutions and companies that will provide donations, fundings, and scholarships (B2B relationship). Furthermore we will also offer and sell online courses, t-shirts and mugs directly to students and professors who will also be the beneficiaries (B2C relationship)
- **Our sales strategy is “free”:** although we will sell online courses, workshops, mugs and t-shirts, our main source of income will be financing of companies and public institutions. The revenues will be applied into advertising, scientific information, and sales of scientific data. We will use the three different ways of funding for free: advertising, sales of data and crowdsourcing.
- **A mix distribution channel:** “shops” (people pay for products during events, for example, the seedlings planting events) and also from our Website.

What does the project provide?	Fabrication
Who does it sell it to?	B2B and B2C
How does it sell it?	Free
Where does it sell it?	Shops and E-commerce

Our key partners are: The Rio Claro City Hall, Spatial Ecology and Conservation Lab (LEEC) , NGO SOS Mata Atlântica, University of São Paulo (ESALQ) and Consórcio PCJ.

Our key activities: Tree planting, Agroecology experiences, Maintenance, Communication, Marketing, Cycling path construction, Networking.

Key resources: seedlings, resources for planting, cyclings paths project, cyclings paths material, voluntary labor, cycling paths material.

Value propositions: Transforming life on campus, by bringing sustainability to the Rio Claro community.

Costs structure: Operative costs, scientific researches, data survey, marketing and cycling paths.

Surplus: To invest in Araucaria for in the future creating an NGO

Client relation: Using cycling path going to University, Leisure activities on campus.

Distribution channels: new building for the Sustainability and Innovation center, Website, Instagram Page, workshops and events

Customer Segments: Rio Claro campus community, companies interested in sustainability.

Beneficiaries: Rio Claro campus community, cyclists

Source of income: Companies donation; crowd-funding; sale of courses; t-shirts and mugs; sale of projects and consultancy.

5.9. PROJECT IMPLEMENTATION

The project was launched on April 12, 2022 and we planted 12 trees near the LASI as a symbolic action (Figure 5.10 and 5.11). Since then it has had the adhesion of 12 undergraduate (7 with scholarship) and graduate students who are participating in the project and developing scientific indications from it.



Figure 5.10: Araucária launch at UNESP. Source: own authorship



Figure 5.11: First tree planting during project launch. Source: own authorship

We got a greenhouse (Figure 5.12) for the production of our own seedlings. Here one of our team members, Tomas Jovchelevich, is coordinating the production of seedlings from seeds. He is developing a super interesting scientific project about this subject.



Figure 5.12: greenhouse at UNESP. Source: Tomas Jovchelevich

During the months of August and September 2022, we started to demarcate the area of the riparian forest to restore and prepare the soil with limestone, phosphorus and manure. In October we received donations of 200 different seedlings from the department of water and sewage from Rio Claro, DAE (Departamento de Água e Esgoto) – to be planted along the cycling paths – and 200 seedlings from the agroecology project in Botucatu, the Instituto Giramundo, which will be used in the restoration of riparian vegetation.

The restoration of the riparian forest is a mid to long term action and has been coordinating by the student Tomás Jovchelevich. During November 2022, seedling plantations will be carried out. From December, students and professors will conduct the fauna survey, the floristic study and soil analysis, to assess the current state of the area. During the next years, the area will be monitored and more trees will be planted. Our community will be responsible for all those actions, together with the work force provided by the university. With the restoration of the riparian forest, we expect to enhance the preservation of Ribeirão Claro river and to increase the connectivity of our landscape leading to a higher abundance and diversity of different animal species in our campus.



Figure 5.13: photos of Araucaria team preparing the soil for receiving the seedlings.
Source: own authorship

Regarding communication, the project has account on the main social media. I was responsible for creating the website (<https://www.2030araucaria.com/pt>), the Instagram account (https://www.instagram.com/araucaria_2030/) and the Youtube Channel (<https://www.youtube.com/channel/UC111dSkdavl5UK8fDSil7iQ>). João Carlos Pena created the Twitter account (<https://twitter.com/Araucaria2030>). We are also finalizing the page on Facebook and LinkedIn. Regarding towards publishing and dissemination of project, we have been contacting the main national and regional newspapers and television programs. We have sent several emails, but we have not had any response. In July and September 2022, I went to the offices of TV Globo and TV Record in São Paulo, but I was not successful in talking to journalists. Contacting these media will be an important step in the project.

5.10. FINAL CONSIDERATIONS

Engaging the academic community in the pursuit of improvement in quality of life and conservation of natural resources for future generations is of utmost importance for a more sustainable urban future. The experience of creating and developing Araucaria shows the potential of science to produce outcomes far beyond theoretical knowledge and papers. We as scientists know how important scientific theories are. However, technical products are also equally essential for the development of society. Science and academia must serve Brazilian and global society, so thinking about practical solutions that benefit everyone is also very important. Having created and participated in the Araucaria project brought a series of skills such as project coordination, team leadership, ability to dialogue with different social groups and entrepreneurship - which are essential in life in society.

Considering the 2030 Agenda and that we are on Decade of Ecosystem Restoration, the university has a fundamental role in leading initiatives that make us meet global goals. The Araucaria Project proved to be fundamental in this process, because through knowledge about landscape ecology, urban ecology, forest restoration and green infrastructure, it was possible to create a project that encompasses all of this. In addition, it was the project that stimulated the creation of LASI (Laboratory Araucaria of Sustainability and Innovation) which intend to be the nursery of many projects, scientific research and innovation initiatives related to sustainability and the 17 sustainable development goals of the UN. Thereby, we hope that science can be more present at the heart of society, in order to strengthen it and reaffirm its fundamental role for human and planet development.

GENERAL THESIS CONCLUSION

Urban ecology is recognized as a well-established science but still need improved understanding of interdisciplinary concepts that are applicable to urban environments (QURESHI et al. 2013). It has also substantially contributed to the activities strengthening and improving social wellbeing in urban environments across the globe (BREUSTE et al. .2013). In this thesis, we worked into five chapters showing different - but complementary - approaches related to studies within Urban Ecology.

The Society of Urban Ecology (SURE) has five goals (BREUSTE; QURESHI, 2011):

1. **Develop** an understanding of the structure and function of urban ecosystems;
2. **Advance** a balanced interaction between humans and their environments in cities and towns;
3. **Foster** and develop knowledge and implementation of urban ecology;
4. **Strengthen** contacts and enrich the dialogue between researchers, practitioners and teachers;
5. **Make** the collective expertise of urban ecologists available.

Here, the first three chapters contributed to the understanding of how the urban landscape influences biodiversity. Specifically, we analyzed how urban environmental characteristics influence the taxonomic and functional richness of birds and also the bird's coloration. This knowledge is linked to goal 1 from SURE. The chapter four investigated the human-bird relationship and the human perception of birds, which contribute to goals 2. Finally, the chapter five shows a practical application of how science and academia can bring concrete contributions to society, which is related to the goals 3, 4 and 5. The thing that connect all these chapters is the contribution that their knowledge brings to understanding about how nature and society can coexist. The results generated here have the potential to direct public policies, governmental actions and private initiatives to think about solutions that are beneficial to both nature and to humans in our society.

Moreover, all chapters are linked to some of the Sustainable Development Goals of the 2030 Agenda, especially those related to environmental conservation.

Therefore, considering that the public university is at the service of Brazilian society, it is essential to reflect on what is generated from the product within universities. Here we show that both theoretical and practical knowledge are fundamental for the strengthening of science. Therefore, we hope that this thesis can broaden the view on the potential of products generated by science and universities and that our results can generate insights into practical solutions for a more sustainable future.

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Appendix A

Specie	Abundance	Family	Ordem
<i>Buteo brachyurus</i>	1	Accipitridae	Accipitriformes
<i>Ictinia plumbea</i>	3	Accipitridae	Accipitriformes
<i>Rupornis magnirostris</i>	3	Accipitridae	Accipitriformes
<i>Chaetura meridionalis</i>	1	Apodidae	Apodiformes
<i>Amazilia lactea</i>	2	Trochilidae	Apodiformes
<i>Chlorostilbon lucidus</i>	1	Trochilidae	Apodiformes
<i>Eupetomena macroura</i>	5	Trochilidae	Apodiformes
<i>Florisuga fusca</i>	3	Trochilidae	Apodiformes
<i>Cariama cristata</i>	2	Cariamidae	Cariamiiformes
<i>Coragyps atratus</i>	19	Cathartidae	Cathartiformes.
<i>Vanellus chilensis</i>	18	Charadriidae	Charadriiformes
<i>Columba livia</i>	23	Columbidae	Columbiformes
<i>Columbina squammata</i>	6	Columbidae	Columbiformes
<i>Columbina talpacoti</i>	14	Columbidae	Columbiformes
<i>Patagioenas picazuro</i>	50	Columbidae	Columbiformes
<i>Zenaida auriculata</i>	66	Columbidae	Columbiformes
<i>Chloroceryle amazona</i>	1	Alcedinidae	Coraciiformes
<i>Crotophaga ani</i>	8	Cuculidae	Cuculiformes
<i>Guira guira</i>	2	Cuculidae	Cuculiformes
<i>Piaya cayana</i>	1	Cuculidae	Cuculiformes
<i>Caracara plancus</i>	9	Falconidae	Falconiformes
<i>Milvago chimachima</i>	1	Falconidae	Falconiformes
<i>Penelope supercilialis</i>	1	Cracidae	Galliformes
<i>Cantorchilus leucotis</i>	1	Troglodytidae	Passeriformes
<i>Cyanocorax chrysops</i>	3	Corvidae	Passeriformes
<i>Lepidocolaptes angustirostris</i>	1	Dendrocolaptidae	Passeriformes
<i>Paroaria dominicana</i>	1	Emberizidae	Passeriformes
<i>Euphonia chlorotica</i>	19	Fringillidae	Passeriformes
<i>Furnarius rufus</i>	23	Furnariidae	Passeriformes
<i>Synallaxis frontalis</i>	2	Furnariidae	Passeriformes
<i>Progne chalybea</i>	1	Hirundinidae	Passeriformes
<i>Progne subis</i>	2	Hirundinidae	Passeriformes
<i>Progne tapera</i>	6	Hirundinidae	Passeriformes
<i>Pygochelidon cyanoleuca</i>	65	Hirundinidae	Passeriformes
<i>Tachycineta leucorrhoa</i>	1	Hirundinidae	Passeriformes
<i>Gnorimopsar chopi</i>	6	Icteridae	Passeriformes
<i>Molothrus bonariensis</i>	8	Icteridae	Passeriformes
<i>Mimus saturninus</i>	3	Mimidae	Passeriformes
<i>Basileuterus culicivorus</i>	1	Parulidae	Passeriformes
<i>Myiothlypis flaveola</i>	2	Parulidae	Passeriformes

<i>Passer domesticus</i>	58	Passeridae	Passeriformes
<i>Zonotrichia capensis</i>	12	Passeridae	Passeriformes
<i>Todirostrum cinereum</i>	6	Rhynchocyclidae	Passeriformes
<i>Herpsilochmus atricapillus</i>	2	Thamnophilidae	Passeriformes
<i>Taraba major</i>	1	Thamnophilidae	Passeriformes
<i>Thamnophilus doliatus</i>	2	Thamnophilidae	Passeriformes
<i>Thamnophilus pelzelni</i>	3	Thamnophilidae	Passeriformes
<i>Coereba flaveola</i>	7	Thraupidae	Passeriformes
<i>Coryphospingus cucullatus</i>	1	Thraupidae	Passeriformes
<i>Dacnis cayana</i>	1	Thraupidae	Passeriformes
<i>Sicalis flaveola</i>	5	Thraupidae	Passeriformes
<i>Sporophila caerulescens</i>	1	Thraupidae	Passeriformes
<i>Sporophila lineola</i>	6	Thraupidae	Passeriformes
<i>Tangara cayana</i>	10	Thraupidae	Passeriformes
<i>Tangara palmarum</i>	2	Thraupidae	Passeriformes
<i>Tangara sayaca</i>	21	Thraupidae	Passeriformes
<i>Volatinia jacarina</i>	1	Thraupidae	Passeriformes
<i>Troglodytes musculus</i>	12	Troglodytidae	Passeriformes
<i>Turdus amaurochalinus</i>	3	Turdidae	Passeriformes
<i>Turdus leucomelas</i>	22	Turdidae	Passeriformes
<i>Turdus rufiventris</i>	2	Turdidae	Passeriformes
<i>Arundinicola leucocephala</i>	1	Tyrannidae	Passeriformes
<i>Camptostoma obsoletum</i>	2	Tyrannidae	Passeriformes
<i>Elaenia chiriquensis</i>	1	Tyrannidae	Passeriformes
<i>Elaenia flavogaster</i>	1	Tyrannidae	Passeriformes
<i>Empidonomus varius</i>	9	Tyrannidae	Passeriformes
<i>Fluvicola nengeta</i>	3	Tyrannidae	Passeriformes
<i>Machetornis rixosa</i>	7	Tyrannidae	Passeriformes
<i>Megarhynchus pitangua</i>	13	Tyrannidae	Passeriformes
<i>Myiarchus ferox</i>	1	Tyrannidae	Passeriformes
<i>Myiarchus swainsoni</i>	1	Tyrannidae	Passeriformes
<i>Myiarchus tyrannulus</i>	1	Tyrannidae	Passeriformes
<i>Myiodynastes maculatus</i>	7	Tyrannidae	Passeriformes
<i>Myiozetetes similis</i>	5	Tyrannidae	Passeriformes
<i>Pitangus sulphuratus</i>	64	Tyrannidae	Passeriformes
<i>Pyrocephalus rubinus</i>	1	Tyrannidae	Passeriformes
<i>Serpophaga subcristata</i>	1	Tyrannidae	Passeriformes
<i>Tyrannus melancholicus</i>	37	Tyrannidae	Passeriformes
<i>Tyrannus savana</i>	3	Tyrannidae	Passeriformes
<i>Vireo chivi</i>	1	Vireonidae	Passeriformes
<i>Ardea alba</i>	1	Ardeidae	Pelecaniformes
<i>Egretta thula</i>	1	Ardeidae	Pelecaniformes

<i>Syrigma sibilatrix</i>	1	Ardeidae	Pelecaniformes
<i>Mesembrinibis cayennensis</i>	1	Threskiornithidae	Pelecaniformes
<i>Theristicus caudatus</i>	4	Threskiornithidae	Pelecaniformes
<i>Colaptes melanochloros</i>	2	Picidae	Piciformes
<i>Drycopus lineatus</i>	1	Picidae	Piciformes
<i>Melanerpes candidus</i>	1	Picidae	Piciformes
<i>Picumnus albosquamatus</i>	1	Picidae	Piciformes
<i>Picumnus cirratus</i>	1	Picidae	Piciformes
<i>Veniliornis passerinus</i>	1	Picidae	Piciformes
<i>Ramphastos toco</i>	1	Ramphastidae	Piciformes
<i>Brotogeris chiriri</i>	37	Psittacidae	Psittaciformes
<i>Forpus xanthopterygius</i>	1	Psittacidae	Psittaciformes
<i>Psittacara leucophthalmus</i>	55	Psittacidae	Psittaciformes
<i>Athene cunicularia</i>	4	Strigidae	Strigiformes

Appendix B: Color characteristics of Bauru (São Paulo, Brazil), using the color plumage patches method

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Species	Crown	Head	Cheek	Mantle	Primaries	Wing coverts	Back	Rump	Tail	Belly	Breast	Throat	Dimorp hism	Polym orphis	Irides ense	Size
<i>Amazilia lactea</i>	green	green	blue_green	green_blue	black	green	green	gray	black	white_green	blue	blue	0	0	30	9.5
<i>Ardea alba</i>	white	white	white	white	white	white	white	white	white	white	white	white	0	0	0	92
<i>Arundinicola leucocephala</i>	white	white	black	black	black	black	black	black	black	black	black	white	1	0	0	12.75
<i>Athene cunicularia</i>	brown_white	brown_white	white_brown	brown_white	brown_white	brown_white	brown_white	brown_white	brown_white	white	white_brown	brown_white	0	0	0	22.5
<i>Brotogeris chiriri</i>	green	green	green	green	blue	green_yellow	green	green	green	green	green	green	0	0	0	22.5
<i>Buteo brachyurus</i>	brown	brown	brown	brown	white_brown	brown	brown	brown	brown	white_brown	white_brown	white_brown	0	1	0	44
<i>Camptostoma obsoletum</i>	gray	gray	gray	gray	gray	gray_yellow	olive	olive	gray	yellow	yellow	white_gray	0	0	0	9.75
<i>Caracara plancus</i>	black	white_red	white	white_brown	white_brown	brown	brown	brown_white	white_brown	brown	brown_white	white	0	0	0	57
<i>Chaetura meridionalis</i>	gray_brown	gray_brown	gray_brown	gray_brown	black	brown_black	gray_brown	gray_brown	brown	brown	brown_white	gray_brown	0	0	0	12.5
<i>Chloroceryle amazona</i>	green	green_white	green	green	green	green	green	green	green	white	rufous	white	1	0	15	30
<i>Chlorostilbon lucidus</i>	green	green	green	green	blue	green	green	green	blue	green	green	blue	1	0	30	10
<i>Coereba flaveola</i>	black	gray_white	black	gray	gray	gray	gray	yellow	gray_white	yellow	yellow	white	0	0	0	10.5
<i>Columba livia</i>	gray	gray	gray	green	gray_black	gray	gray	gray	gray_black	purple_green	purple	gray	1	1	10	32.5
<i>Columbina squammata</i>	brown_white	brown_white	brown_white	brown_white	white_brown	brown_white	brown_white	brown_white	brown_white	white_brown	white_brown	white_brown	0	0	0	20
<i>Columbina talpacoti</i>	gray	gray	gray	gray_brown	black_rufous	brown	brown	brown_pink	brown_pink	brown_pink	brown	pink	1	0	0	16.5
<i>Coragyps atratus</i>	black	black	black	black	gray_white	black	black	black	black	black	black	black	0	0	0	63.5
<i>Crotophaga ani</i>	black	black	black	black	black	black	black	black	black	black	black	black	0	0	0	34.5
<i>Cyanocorax chrysops</i>	black	black_white	blue_black	blue_white	blue	blue	blue	blue	blue_white	yellow	black	black	0	0	0	33.5
<i>Drycopus lineatus</i>	red	black_red	black_white	black	black	black_white	black	black	black	white_black	white_black	black_white	1	0	0	33
<i>Egretta thula</i>	white	white	white	white	white	white	white	white	white	white	white	white	0	0	0	58
<i>Elaenia chiriquensis</i>	gray	gray	gray	olive	white_black	white_black	olive	olive	gray	white	yellow	gray	0	0	0	14
<i>Empidonomus varius</i>	brown	black_brown	gray_white	gray_white	gray_white	gray_white	gray_brown	brown	brown	yellow	white_brown	white	0	0	0	18.5
<i>Eupetomena macroura</i>	blue	blue	blue	blue_green	black	green	green	green	blue	green	blue	blue	0	0	30	16
<i>Euphonia chlorotica</i>	yellow	black	blue	blue	blue	blue	blue	blue	blue_white	yellow	yellow	black	1	0	5	9.5
<i>Florisuga fusca</i>	black	black	black	black	gray	olive	black	black	white_black	black	black	black	0	0	10	12.5
<i>Fluvicola nengeta</i>	white	white	black	white	black	black	gray	white	black	white	white	white	0	0	0	15
<i>Forpus xanthopterygius</i>	green	green	green	green	blue	green	green	blue	green	green	green	green_yellow	1	0	0	12.5
<i>Furnarius rufus</i>	brown	brown	brown	brown	brown	brown	brown	brown	rufous	white	brown	white	0	0	0	19.5
<i>Gnorimopsar chopi</i>	black	black	black	black	black	black	black	black	black	black	black	black	0	0	0	23
<i>Guirra guirra</i>	orange	orange	yellow	brown_white	brown_white	brown_white	white	white	black_white	white	white_brown	white_brown	0	0	0	39
<i>Ictinia plumbea</i>	gray	gray	gray	gray	rufous	gray	black	gray	black	gray	gray	gray	0	0	0	33.5
<i>Lepidocolaptes angustirostris</i>	black	white	black	rufous	rufous	rufous	rufous	rufous	rufous	white_rufous	white	white	0	0	0	20
<i>Machetornis rixosa</i>	gray_red	gray	gray	olive	brown	brown	brown	brown	brown	yellow	yellow	white	0	0	0	19.5
<i>Megarhynchus pitangua</i>	black	black_white	black	brown	brown	brown	brown	brown	brown	yellow	yellow	white	0	0	0	23
<i>Mesembrinibis cayennensis</i>	black	black_olive	black	black_olive	blue	black_olive	black_olive	black_olive	blue	gray	gray	black_olive	0	0	20	53
<i>Mimus saturninus</i>	brown	brown	white_black	gray	brown_white	brown_white	gray	brown	brown	white	white	white	0	0	0	24.75
<i>Molothrus bonariensis</i>	black_blue	black_blue	black	black_blue	black	black_blue	black_blue	black_blue	black	black_blue	black_blue	black	1	0	0	19.25
<i>Myiarchus ferox</i>	gray	gray	gray	gray	brown	bron_white	brown	brown	brown	yellow	white_yellow	white	0	0	0	18
<i>Myiarchus swainsoni</i>	gray	brown	brown	brown	brown	bron_white	brown	brown	brown	yellow	white_yellow	white	0	0	0	20.5
<i>Myiarchus tyrannulus</i>	brown	gray	gray	brown	brown	bron_white	brown	brown	brown	yellow	white_yellow	white	0	0	0	20.5
<i>Myiodynastes maculatus</i>	brown	yellow_white	black	brown_white	brown_white	brown_white	brown_white	rufous	brown	white_brown	white_brown	white_brown	0	0	0	20
<i>Myiothlypis flaveola</i>	olive	olive_yellow	olive	olive	olive	olive	olive	olive	olive	yellow	yellow	yellow	0	0	0	14.5
<i>Myiozetetes similis</i>	red	black_white	black	brown	brown	brown	brown	brown	brown	yellow	yellow	white	0	0	0	17
<i>Paroaria dominicana</i>	red	red_white	red	black_gray	gray_white	black	gray_black	gray	gray	white	white	red	0	0	0	32
<i>Passer domesticus</i>	gray	gray	white	black_brown	black_brown	brown_white	black_brown	gray	black	gray	gray	black	1	0	0	17
<i>Patagioenas picazuro</i>	pink_purple	pink_purple	pink_purple	brown	gray	gray_white	gray	gray	gray_black	gray	pink_purple	pink_purple	0	0	10	34
<i>Penelope supercilialis</i>	black	black_white	black	brown	black_orange	black_orange	brown	brown	brown	orange	brown	red	0	0	0	64
<i>Piaya cayana</i>	rufous	rufous	rufous	rufous	rufous	rufous	rufous	rufous	rufous_black	gray	white	rufous	0	0	0	45.5
<i>Picumnus albosquamatus</i>	red	black_white	black_white	brown_white	brown_white	brown_white	brown_white	brown_white	brown_white	white_brown	white_brown	white_brown	1	0	0	10.5
<i>Picumnus cirratus</i>	red	brown_white	black_white	brown_white	brown_white	brown_white	brown_white	brown_white	brown_white	white_brown	white_brown	brown_white	1	0	0	10
<i>Pitangus sulphuratus</i>	black_yellow	black_white	black	brown	brown	brown	brown	brown	brown	white	yellow	white	0	0	0	22
<i>Progne chalybea</i>	blue	blue	blue	blue	black	blue	blue	blue	black	white	white	gray	1	0	0	17
<i>Progne subis</i>	blue	blue	blue	blue	black	blue	blue	blue	black	blue	blue	blue	1	0	30	19
<i>Progne tapera</i>	brown	brown	brown	brown	brown	brown_white	brown	brown	brown	white	white	white	0	0	0	16

<i>Psittacara leucophthalmus</i>	green	green	green	green	yellow_red	green	green	green	green	green	green_yellow	green	green	0	0	0	33
<i>Pygochelidon cyanoleuca</i>	blue	blue	blue	blue	black	black	blue	blue	tail	white	white	white	0	0	20	12.5	
<i>Pyrocephalus rubinus</i>	red	red_brown	brown	brown	brown	brown	brown	brown	brown	red	red	red	1	0	0	13.5	
<i>Ramphastos toco</i>	black	white_black	orange_white	black	black	black	black	black	black_white	black_red	black	white	0	0	0	58	
<i>Rupornis magnirostris</i>	gray	gray	gray	gray_brown	rufous	brown	gray_brown	gray_brown	brown_gray	white_brown	brown_white	brown_white	0	1	0	37	
<i>Serpophaga subcristata</i>	gray	gray	gray	gray	black_white	black_white	gray	gray	gray	olive	gray_white	white	0	0	0	11	
<i>Sicalis flaveola</i>	orange	yellow	yellow	yellow_black	black_yellow	brown_yellow	brown_yellow	yellow	black_yellow	yellow	yellow	yellow	1	0	0	14.25	
<i>Sporophila caerulescens</i>	gray	gray	gray	gray	brown	brown	gray	gray	gray	white	white_black	black_white	1	0	0	11	
<i>Sporophila lineola</i>	white	black	black_white	black	white	black	black	black	black	white	white	black	1	0	0	10.5	
<i>Synallaxis frontalis</i>	rufous	gray_brown	gray_brown	brown	brown	rufous	brown	brown	rufous	gray	gray	white_gray	0	0	0	15	
<i>Syrigma sibilatrix</i>	black	yellow_brown	blue_brown	gray	gray	yellow_black	gray	gray	white	yellow	yellow	yellow	0	0	0	57	
<i>Tachycineta leucorrhoa</i>	blue	blue	blue	blue	black	black	blue	white	black	white	white	white	0	0	0	13	
<i>Tangara cayana</i>	yellow	black	yellow_black	yellow	blue	blue	yellow	yellow	blue	yellow	black	black	1	0	10	13.5	
<i>Tangara palmarum</i>	yellow_olive	olive	olive	olive	olive_brown	olive	olive	olive	olive_brown	olive	olive	olive	0	0	0	17	
<i>Tangara sayaca</i>	gray_blue	gray_blue	gray_blue	gray_blue	blue	blue	blue	blue	blue	gray	gray	gray	0	0	0	16.5	
<i>Taraba major</i>	black	black	black	black	black_white	black_white	black	black	black_white	white	white	white	1	0	0	19.5	
<i>Thamnophilus doliatus</i>	black	black_white	black_white	black_white	black_white	black_white	black_white	black_white	black_white	white_black	white_black	white_black	1	0	0	15.5	
<i>Thamnophilus pelzelni</i>	black	gray	gray	gray	black_white	black_white	gray	gray	black_white	white	white	white	1	0	0	14	
<i>Theristicus caudatus</i>	rufous	yellow_rufous	black_yellow	brown_white	black	brown_white	brown_white	brown_white	black	black	rufous_gray	yellow	0	0	0	73.5	
<i>Todirostrum cinereum</i>	black	black_yellow	black	gray_olive	black_yellow	black_yellow	gray_olive	gray_olive	black_white	yellow	yellow	yellow	0	0	0	9.5	
<i>Troglodytes musculus</i>	gray_brown	brown	brown	brown	brown_rufus	brown_rufus	brown	brown_rufus	brown_rufus	buffish_brown	buffish_brown	buffish_brown	0	0	0	12	
<i>Turdus amaurochalinus</i>	brown_olive	brown_olive	brown_olive	brown_olive	brown_olive	brown_olive	brown_olive	brown_olive	brown_olive	creamy	creamy	brown_white	0	0	0	23.5	
<i>Turdus leucomelas</i>	gray	gray	gray	brown	brown	brown	brown	brown	brown_gray	brown_gray	brown_gray	brown_white	0	0	0	25	
<i>Turdus rufiventris</i>	brown	brown	brown	brown	brown	brown	brown	brown	brown	orange	brown	brown_white	0	0	0	24	
<i>Tyrannus melancholicus</i>	gray	gray	gray	olive	brown	brown	olive	brown	brown	yellow	yellow	gray	0	0	0	21.2	
<i>Tyrannus savana</i>	black_yellow	black	black	gray	black	gray	gray	black	black	white	white	white	0	0	0	34.25	
<i>Vanellus chilensis</i>	gray	gray	gray	gray	gray	green	gray	gray	white_black	white	black	gray_black	0	0	10	35	
<i>Volatinia jacarina</i>	black	black	black	black	black	black	black	black	black	black	black	black	0	1	30	9.8	
<i>Zenaida auriculata</i>	blue	gray	gray_black	pink	gray_black	gray	gray	gray	gray	gray	gray	gray	1	0	10	25	
<i>Zonotrichia capensis</i>	black_gray	black_gray	black_gray	rufous	brown	brown_black	brown	brown	brown	white	gray	white	0	0	0	12.6	

Appendix C: Color characteristics of Xalapa (Veracruz, México), using the color plumage patches method

Species	Crown	Head	Cheek	Mantle	Primaries	Wing_coverts	Back	Rump	Tail	Belly	Breast	Throat	Dimorphism	Polymorphism	Irides	Size
<i>Aimophila rufescens</i>	rusty_gray	gray_rusty	gray	rufous_gray	rusty_gray	rusty	rufous_gray	rufous	rusty	buff	buff	white_black	0	0	0	18.2
<i>Amazilia cyanocephala</i>	blue	green_blue	green	green	black	black	green	green	green	brown	white	white	1	0	30	10.5
<i>Amazona albifrons</i>	white_blue	green_red	green	green	blue_red	green	green	green	green	green	green	green	1	0	0	27
<i>Arremon brunneinucha</i>	rusty	black_rusty	black	olive	darkolive	olive	olive	olive	darkolive	white	gray	white	0	0	0	17.9
<i>Basileuterus culicivorus</i>	black	black_white	gray	darkolive	gray	darkolive	darkolive	darkolive	darkolive	yellow	yellow	yellow	0	0	0	12.5
<i>Bubulcus ibis</i>	yellowbare	white	white	white	white	white	white	yellowbare	white	white	yellowbare	white	1	0	0	51
<i>Campylopterus curvipennis</i>	blue	green_blue	green	green	gray	gray	green	green	green_blue	white	white	white	0	0	30	13
<i>Campylorhynchus zonatus</i>	gray	black_white	black_white	black_white	black_white	black_white	black_white	black_white	black_white	rusty	white_black	white_black	0	0	0	18.5
<i>Cardellina pusilla</i>	black	yellow	yellow	olive	darkolive	darkolive	olive	olive	darkolive	yellow	yellow	yellow	1	0	0	12
<i>Catharus mexicanus</i>	black	gray	gray	brownolive	brownolive	brownolive	brownolive	brownolive	brownolive	white	gray	white	0	0	0	15.7
<i>Chlorospingus flavopectus</i>	gray	gray	gray	olive	olive	olive	olive	olive	olive	yellow_white	yellow_white	white	0	0	0	23.5
<i>Colaptes rubiginosus</i>	gray	buff_red	buff	olive	olive	olive	olive	olive	brown	yellow_black	yellow_black	yellow_black	1	0	0	20.5
<i>Columba livia</i>	gray	gray	gray	green	gray_black	gray	gray	gray	gray_black	purple_green	purple	gray	1	1	10	32.5
<i>Columbina inca</i>	brownpink	graypink	graypink	graybrown	graybrown	graybrown	graybrown	graybrown	white	white	whitepink	white	0	0	0	20.5
<i>Dives dives</i>	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue	0	0	30	25.5
<i>Dumetella carolinensis</i>	black	gray	gray	gray	gray	gray	gray	gray	black	gray_rusty	gray	gray	0	0	0	22.5
<i>Empidonax minimus</i>	gray	gray	gray	brownolive	darkgray_white	darkgray_white	brownolive	brownolive	darkgray	yellowbare	gray_yellowbare	white	0	0	0	13.3
<i>Empidonax occidentalis</i>	olive	olive	olive	olive	darkbrown_bu	darkbrown_bu	olive	brownolive	darkgray	yellow	yellow	yellow	0	0	0	15
<i>Euphonia hirundinacea</i>	yellow	black	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue	irisblue_white	yellow	yellow	yellow	1	0	10	10
<i>Geothlypis trichas</i>	olive	olive_black	black	olive	olive	olive	olive	olive	olive_yellow	white	yellow	yellow	1	0	0	12.3
<i>Icterus parisorum</i>	black	black	black	black	black_white	black	black	black	black_yellow	yellow	black	black	1	0	0	20.5
<i>Leptotila verreauxi</i>	brownpink	white_pink	white_pink	graybrown	graybrown	graybrown	graybrown	graybrown	graybrown	white	gray	white	0	0	0	26.5
<i>Megarhynchus pitangua</i>	black	black_white	black	brown	brown	brown	brown	brown	brown	yellow	yellow	white	0	0	0	23
<i>Melanerpes aurifrons</i>	red	gray_yellow	gray	black_white	black_white	black_white	black_white	black_white	black_white	white	white	white	1	0	0	24
<i>Melanerpes formicivorus</i>	red	black_yellowb	yellowbare	black	black	black	black	black	black	black_white	white	yellowbare_black	1	0	0	23
<i>Micrastur semitorquatus</i>	black	black_white	black_white	black	black	black	black	black	black_white	white	white	white	0	1	0	52
<i>Molothrus aeneus</i>	black	black	black	black	irisblue	irisblue	black	black	irisblue	black	black	black	1	0	30	20
<i>Momotus momota</i>	blue_black	green_blue	black	green	green	green	green	green	green_blue	olive	olive	rufous	0	1	0	40.5
<i>Myiarchus tuberculifer</i>	gray	gray	gray	olive	brownolive	brownolive	olive	olive	brownolive	yellow	gray	gray	0	0	0	16
<i>Myiopagis viridicata</i>	yelow_olive	gray	gray	olive	darkolive	olive	olive	olive	darkolive	yellow	gray	white	0	0	0	13.5
<i>Myiozetetes similis</i>	red	black_white	black	brown	brown	brown	brown	brown	brown	yellow	yellow	white	1	0	0	17
<i>Ortalis vetula</i>	gray	gray	gray	brown	brown	brown	brown	brown	gray_white	rusty	rusty	red	1	0	0	53
<i>Parkesia motacilla</i>	graybrown	graybrown	white_black	graybrown	graybrown	graybrown	graybrown	graybrown	graybrown	white	white_graybro	white	0	0	0	15.3
<i>Parkesia noveboracensis</i>	brownolive	brownolive	white_black	brownolive	brownolive	brownolive	brownolive	brownolive	brownolive	yellowbare	yellowbare_brown	yellowbare_brown	0	0	0	13.3
<i>Passer domesticus</i>	gray	gray	white	black_brown	black_brown	brown_white	black_brown	gray	black	gray	gray	black	1	0	0	17
<i>Pheugopedius maculipectus</i>	rufous	white_black	white_black	rufous	brown	rufous	rufous	rufous	rufous_black	white_black	white_black	white_black	0	0	0	13.3
<i>Pionus senilis</i>	white	green_blue	blue	green	blue	green	green	green	green_blue	green_red	blue	white_blue	0	0	0	24
<i>Polioptila caerulea</i>	grayblue_black	grayblue	grayblue	grayblue	black_white	grayblue	grayblue	grayblue	black_white	white	white	white	1	0	0	11
<i>Psarocolius montezuma</i>	black	black_white	white_black	rufous	black	rufous	rufous	rufous	yellow	rufous	black_rufous	black	0	0	0	47.5

<i>Psittorhinus morio</i>	darkbrown	darkbrown	darkbrown	darkbrown	darkbrown	darkbrown	darkbrown	darkbrown	darkbrown	darkbrown_wf	brown	darkbrown	darkbrown	0	1	0	41
<i>Quiscalus mexicanus</i>	irisblue	irisblue	irisblue	black	black	irisblue	irisblue	black	black	black	irisblue	irisblue	1	0	0	43	
<i>Saltator atriceps</i>	black	black_white	gray	green	black	green	green	green	green	gray	gray	white_black	0	0	20	24	
<i>Setophaga petechia</i>	rufous	yellow	yellow	olive	brown	olive_brown	olive	olive	brown	yellow	yellow_rufous	yellow	1	0	0	11.8	
<i>Setophaga virens</i>	olive	yellow_olive	yellow_olive	olive	black_white	gray	olive	olive	black_white	white	black_white	black	1	0	0	12.9	
<i>Sittasomus griseicapillus</i>	olive	olive	olive	olive	rufous	rufous	rufous	rufous	rufous	olivegray	olivegray	gray	0	0	0	17.3	
<i>Stelgidopteryx serripennis</i>	graybrown	graybrown	graybrown	graybrown	graybrown	gray	graybrown	graybrown	graybrown	white	gray_white	gray	0	0	0	13.5	
<i>Streptopelia decaocto</i>	gray	gray_black	gray	brown	brown_white	brown	graybrown	brown	graybrown	gray	gray	gray	0	0	0	31	
<i>Thraupis abbas</i>	blue	blue	blue	bluegray	black	blue_yellow	bluegray	olive	bluegray_black	olive_yellow	bluegray	blue	0	0	0	17	
<i>Tityra semifasciata</i>	white	white	black_red	white	black	white	white	white	white_black	white	white	white	1	0	0	22	
<i>Troglodytes aedon</i>	brown	brown	brown	brown	brown	brown	brown	brown	brown	brown_white	rufous	rufous	white	0	1	0	12.2
<i>Trogon collaris</i>	green	green_black	black	green	white_black	white_black	green	green	blue_white_black	red	red_white	green_black	1	1	0	27	
<i>Turdus grayi</i>	brown	brown	brown	brown_orange	brown	brown	brown	brown	brown	orange	orange	brown_white	0	0	0	24.8	
<i>Vireo solitarius</i>	gray	gray_white	gray	darkolive	black_white	gray_yellow	darkolive	darkolive	darkolive	white	white	white	0	0	0	14	

Appendix D: Color percentages of Bauru (São Paulo, Brazil), using the color percentage method

SPECIES	black	blue	blue gray	blue2	brown gray	brown olive	brown1	brown2	brown3	dark blue gray	light blue gray	dark brown	dark green	dark olive	green	green olive	gray1	gray2	iris blue	iris dark blue	iris green	olive	orange	red	rose	rufous	violet gray	white	yellow	yellow1
Amazilia lactea	16.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.4	0	1.9	12.5	0	49.2	0	0	1.1	0	0	0	5	0	0
Ardea alba	16.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.1	0	0	0	0	82.8	0	0
Arundinicola leucocephala	76.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0
Athene cunicularia	0	0	0	0	30.1	0	0	0	0	0	0	12.1	0	0	0	0	0	23.7	0	0	0	0	0	0	0	0	0	33.6	0.5	0
Brotogeris chiriri	0	1.7	0	0	0	0	4.3	0	0	0	0	0	12.7	0	76	0	0	0	0	0	0	0	0	0	0	0	0	1.2	4.1	0
Buteo brachyurus	0	0	0	0	61	0	0	0	0	0	0	0	0	0	0	0	0	2.2	0	0	0	0	0	0	0	0	0	33.5	0	3.3
Camptostoma obsoletum	5.8	0	0	0	0	27.9	0	0	0	0	0	0	0	0	0	0	0	18.4	0	0	0	0	0	0	0	0	0	14	0	33.9
Caracara plancus	73.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.1	0	0	0	0	22.9	0	2.8
Chaetura meridionalis	15.1	0	0	0	57	0	0	8.3	19.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chloroceryle amazona	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	59.7	0	0	0	3.9	0	23.4	0	0	0
Chlorostilbon lucidus	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41.1	0	42.3	0	0	1.6	0	0	0	0	0	0
Coereba flaveola	52.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.2	0	0	0	0	0	0.9	0	0	0	8.4	28.2	0
Columba livia	12.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54.3	25.4	0	0	4	0	0	0	0	0	2.8	0.7	0	0
Columbina squammata	0	0	0	0	56.4	0	0	0	0	0	0	0	0	0	0	0	0	16.9	0	0	0	0	0	0	0	0	0	26.7	0	0
Columbina talpacoti	0	0	0	0	0	0	52.1	17.6	14.8	0	0	10.7	0	0	0	0	4.8	0	0	0	0	0	0	0	0	0	0	0	0	0
Coragyps atratus	96.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.65	0	0	0	0	0	0	0	0	0	0	0	0
Crotophaga ani	99.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0
Cyanocorax chrysops	15.4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.2	43.4	0	0	0	0	0	0	0	0	2.5	0	27.5
Drycopus lineatus	62.1	0	0	0	0	0	0	0	0	2.6	0	5.7	0	0	0	0	0	5.6	0	0	0	0	0	16.1	0	0	0	7.9	0	0
Egretta thula	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.4	0	0	0	0	84.6	0	0
Elaenia chiriquensis	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	33.4	0	0	0	0	0	0	0	0	0	11.6	0	15
Empidonomus varius	0	0	0	0	29.8	0	0	0	0	0	0	0	0	0	0	0	0	24.6	0	0	0	0	0	0	0	3.2	0	42.4	0	0
Eupetomena macroura	23.7	0	0	10.3	0	0	0	0	0	12	0	0	0	0	5.4	0	0	0	25.2	0	23.4	0	0	0	0	0	0	0	0	0
Euphonia chlorotica	0	0	0	0	0	0	0	0	0	4.7	0	0	0	0	0	0	0	1.65	36.55	13.5	0	0	0	0	0	0	0	0	0	43.6
Florisuga fusca	66.9	0	0	0	0	0	0	0	0	0	0	0	0	17.6	0	0	0	4	0	0	0	0	0	0	0	0	0	11.5	0	0
Fluvicola nengeta	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	57	0	0
Forpus xanthopterygius	0	10.4	0	0	0	0	0	0	0	0	0	0	11.7	0	73.9	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Furnarius rufus	0	0	0	0	9.9	0	0	25.1	0	0	0	0	0	0	0	0	9.4	0	0	0	0	0	0	0	0	38	0	17.6	0	0
Gnorimopsar chopi	98.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0
Guira guira	0	0	0	0	39.2	0	0	15.6	0	0	0	0	0	0	0	0	0	10.4	0	0	0	0	0	0	0	10	0	23	0	1.8
Ictinia plumbea	0	0	0	0	0	0	0	0	0	49.5	45.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.4	0	0	0	1.9
Lepidocolaptes angustirostris	0	0	0	0	0	0	35.9	0	7.6	0	0	18.1	0	0	0	0	22.4	0	0	0	0	0	0	0	0	0	0	16	0	0
Machetornis rixosa	3.6	0	0	0	0	19.5	0	0	0	0	0	0	0	44	0	0	9	0	0	0	0	0	0	0	0	0	0	2.5	21.4	0
Megarhynchus pitangua	7.3	0	0	0	19.3	53.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	12.6	0
Mesembrinibis cayennensis	54	0	0	0	0	37.7	0	0	0	0	0	0	0	0	0	0	0	8.3	0	0	0	0	0	0	0	0	0	0	0	0
Mimus saturninus	4.7	0	0	0	35.3	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	35	0	0
Molothrus bonariensis	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	93	0	0	0	0	0	0	0	0	0	0
Myiarchus ferox	0	0	0	0	8.3	0	0	0	0	0	0	0	0	0	0	0	26.7	47.7	0	0	0	0	0	0	0	0	0	4.6	0	12.7
Myiarchus swainsoni	0	0	0	0	0	0	0	0	46.4	0	0	0	0	0	0	0	0	11.5	0	0	0	0	0	0	0	0	0	14.1	0	28
Myiarchus tyrannulus	0	0	0	0	0	0	0	0	54.6	0	0	0	0	0	0	0	0	17.4	0	0	0	0	0	0	0	0	0	11.2	0	16.8
Myiodynastes maculatus	18.2	0	0	0	25.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	34.6	0	15.9
Myiothlypis flaveola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9.7	0	0	0	38.6	0	0	0	0	0	0	51.7	0
Myiozetetes similis	16.3	0	0	0	0	8.3	0	0	0	0	0	0	0	32.6	0	0	0	4	0	0	0	0	0	0.4	0	0	0	5.2	33.2	0
Paroaria dominicana	23.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15.2	0	0	0	0	0	0	16	0	0	0	45.6	0	0
Passer domesticus	5.4	0	0	0	0	0	12.8	11.1	0	0	0	5.9	0	0	0	0	54	7.3	0	0	0	0	0	0	0	0	0	3.5	0	0
Patagioenas picazuro	18.4	0	0	0	29.3	0	0	0	0	0	0	0	0	0	0	0	12.3	19.7	0	0	0	0	0	0	0	0	15.1	5.2	0	0
Penelope supercilialis	0	0	0	0	70	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	2.5	0	9.5	0	0	0	0
Piaya cayana	28.7	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	15.2	0	0	0	0	0	0	0	0	17.1	0	24	0	2
Picumnus albosquamatus	17.6	0	0	0	43.1	0	0	0	0	0	0	0	0	0	0	0	0	17.9	0	0	0	0	0	1.3	0	0	0	20.1	0	0

<i>Picumnus cirratus</i>	7.6	0	0	0	0	0	0	0	0	41.6	0	0	10.3	0	0	0	0	0	7.2	0	0	0	0	0	1.4	0	0	0	31.9	0	0		
<i>Pitangus sulphuratus</i>	10.2	0	0	0	0	0	16.5	0	0	0	0	0	28.6	0	0	0	0	0	9.2	0	0	0	0	0	0	0	0	0	12.1	23.4	0		
<i>Progne chalybea</i>	38.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.4	0	42.6	0	0	0	0	0	0	0	14.8	0	0		
<i>Progne subis</i>	41.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.9	0	51.8	0	0	0	0	0	0	0	0	0	0		
<i>Progne tapera</i>	0	0	0	0	51.4	0	0	3.7	0	0	0	0	0	0	0	0	0	0	29.3	0	0	0	0	0	0	0	0	0	15.6	0	0		
<i>Psittacara leucophthalmus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85.4	0	0	3.9	0	0	0	0	0	1.4	1.2	0	0	1.4	6.7	0		
<i>Pygochelidon cyanoleuca</i>	34.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	41.6	0	0	0	0	0	0	0	0	20.9	0	0		
<i>Pyrocephalus rubinus</i>	0	0	0	0	0	0	0	0	0	0	0	0	40.4	0	0	0	0	0	4.2	0	0	0	0	0	55.4	0	0	0	0	0	0		
<i>Ramphastos toco</i>	52	0	0	0	0	0	0	0	0	6.8	0	0	0	0	0	0	0	0	0	0	0	0	0	24	3	0	0	0	14.2	0	0		
<i>Rupornis magnirostris</i>	0	0	0	0	48.4	0	0	0	18.7	0	0	0	0	0	0	0	0	5.6	0	0	0	0	0	0	0	0	0	0	19.5	0	7.8		
<i>Serpophaga subcristata</i>	0	0	0	0	0	30.6	0	0	0	0	0	0	14.8	0	0	0	0	0	19.6	0	0	0	0	0	0	0	0	0	20.4	0	14.6		
<i>Sicalis flaveola</i>	4.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.4	0	0	0	0	0	32.3	3.3	0	0	0	0	0	56.4	0		
<i>Sporophila caerulea</i>	7.1	0	0	0	18.5	0	0	0	0	0	0	0	0	0	0	0	0	0	42.5	0	0	0	0	0	0	0	0	0	31.9	0	0		
<i>Sporophila lineola</i>	43.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	51.1	0	0		
<i>Synallaxis frontalis</i>	6.5	0	0	0	0	0	0	0	19.6	0	0	0	0	0	0	0	0	0	27.3	0	0	0	0	0	0	0	0	41.8	0	4.8	0	0	
<i>Syrigma sibilatrix</i>	8.7	3.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33.8	0	0	0	0	44.8	0	1	0	0	0	8.4	0	0	
<i>Tachycineta leucorrhoa</i>	37.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44.5	0	0	0	0	0	0	0	0	18	0	0	0	
<i>Tangara cayana</i>	17.7	21.1	0	0	0	0	0	0	0	7.2	0	0	0	0	0	0	0	0	0	8.7	0	0	0	0	0	0	0	0	0	45.3	0	0	
<i>Tangara palmarum</i>	0	0	0	0	0	12.2	0	0	0	0	0	0	0	0	11.2	0	62	0	14.6	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Tangara sayaca</i>	0	27.4	47.5	0	0	0	0	0	0	8	17.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Taraba major</i>	0	0	47.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	3.5	0	0	0	41	0	0	0	
<i>Thamnophilus doliatus</i>	53.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.7	0	0	0	0	0	0	0	0	0	34.2	0	0	0	
<i>Thamnophilus pelzelni</i>	35.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45.2	0	0	0	0	0	0	0	0	0	19.7	0	0	0	
<i>Theristicus caudatus</i>	9.6	0	0	0	35.8	0	0	0	0	0	0	0	0	0	0	0	0	0	7.9	0	0	0	0	0	0	5.9	6.4	0	23.3	0	11.1	0	
<i>Todirostrum cinereum</i>	31.7	0	0	0	0	0	0	0	0	0	0	0	0	0	4.3	0	0	0	18	0	0	0	0	0	0	0	0	0	0	46	0	0	
<i>Troglodytes musculus</i>	0	0	0	0	0	0	44.5	26.1	0	0	0	21.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.9	0	0	0	0	0	
<i>Turdus amaurochalinus</i>	0	0	0	0	57.3	0	0	0	0	0	0	0	0	0	0	0	24.5	0	0	0	0	0	0	1.7	0	0	0	0	16.5	0	0	0	
<i>Turdus leucomelas</i>	0	0	0	0	0	0	0	22.8	0	0	0	49.7	0	0	0	0	0	0	19.2	0	0	0	0	0	0	0	0	0	8.3	0	0	0	
<i>Turdus rufiventris</i>	0	0	0	0	58.8	0	0	13.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25.3	0	0	0	0	0.3	0	1.8	0	
<i>Tyrannus melancholicus</i>	0	0	0	0	32.6	0	0	0	0	0	0	0	0	0	17.1	0	0	16	11	0	0	0	0	0	0	0	0	0	0	23.3	0	0	
<i>Tyrannus savana</i>	56.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.2	0	0	0	0	0	0	0	0	0	0	0	30.7	0	0	0	
<i>Vanellus chilensis</i>	15.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17.2	40.9	0	0	0	0	0	0	0	6.1	0	12.1	8	0	0	0	
<i>Volatinia jacarina</i>	94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Zenaida auriculata</i>	4.8	0	0	0	42.9	0	0	28.1	0	6.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.2	0	13.8	1.8	0	0	0	0	0
<i>Zonotrichia capensis</i>	14.9	0	0	0	11.8	0	23	15.7	0	0	0	0	0	0	0	0	13.5	0	0	0	0	0	0	0	0	0	3.7	0	17.4	0	0	0	0

Appendix E: Color percentages of Xalapa (Veracruz, México), using the color percentage method

SPECIES	black	blue	blue gray	blue2	brown gray	brown olive	brown1	brown2	brown3	dark blue gray	dark brown	dark green	dark olive	green	green olive	gray1	gray2	iris blue	iris dark blue	iris green	olive	orange	red	rose	rufous	violet gray	white	yellow	yellow 1					
Aimophila rufescens	4.9	0	0	0	0	0	28.8	0	0	0	0	0	0	0	0	34.5	0	0	0	0	0	0	0	0	28.9	0	2.9	0	0					
Amazilia cyanocephala	22.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.8	0	57.6	0	0	1	0	0	0	13.5	0	0					
Amazona albifrons	0	4.6	0	0	0	0	0	2.8	0	0	0	0	0	84.5	0	0	0	0	0	0	0	3.6	2.2	0	0	0	2.3	0	0					
Arremon brunneinucha	12.1	0	0	0	0	0	0	0	0	0	0	0	54.4	0	0	0	19.3	0	0	0	0	0	0	0	4.8	0	9.4	0	0					
Basileuterus culicivorus	3.4	0	0	0	0	0	0	4	0	0	0	0	42.5	0	0	0	18.5	0	0	0	0	0	0	0	0	0	0	31.6	0	0				
Bubulcus ibis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31.9	0	0	0	0	68.1	0	0					
Campylopterus curvipennis	35.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.2	0	1.5	0	41.9	0	0	0	0	0	0	8.6	0	0					
Campylorhynchus zonatus	36.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.9	0	0	0	0	0	0	0	16.7	0	36.2	0	0					
Cardellina pusilla	9.4	0	0	0	0	0	0	0	0	0	0	0	10.5	0	39.5	0	0	0	0	0	0	0	0	0	0	0	0	40.6	0	0				
Catharus mexicanus	12.7	0	0	0	0	41.4	0	0	0	0	0	0	0	0	0	0	19.6	0	0	0	0	5	0	0	0	0	21.3	0	0					
Chlorospingus flavopectus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36.2	0	22.9	0	0	0	0	0	0	0	0	0	12.5	28.4	0	0				
Colaptes rubiginosus	4.7	0	0	0	0	0	0	0	0	0	22.5	0	0	0	38.4	4.5	0	0	0	0	0	0	3.9	0	0	0	3.8	0	22.2					
Columba livia	12.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54.3	25.4	0	0	4	0	0	0	0	0	2.8	0.7	0	0	0				
Columbina inca	0	0	0	0	33.9	0	0	20.4	0	0	0	0	0	0	0	0	45.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Dives dives	21.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78.8	0	0	0	0	0	0	0	0	0	0	0	0	0		
Dumetella carolinensis	19.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	0	0	0	0	0	0	0	3.3	0	0	0	0	0	0			
Empidonax minimus	8.2	0	0	0	0	25.6	0	0	0	0	0	0	0	0	0	14	26.8	0	0	0	0	0	0	0	0	0	25.4	0	0	0	0			
Empidonax occidentalis	0	0	0	0	0	0	0	0	0	0	25	0	24.8	0	0	0	11.1	0	0	0	26.4	0	0	0	0	0	3.2	9.5	0	0	0			
Euphonia hirundinacea	0	0	0	0	0	0	0	0	0	9.7	0	0	0	0	0	0	0	36.9	0	0	0	0	0	0	0	0	4.6	48.8	0	0	0	0		
Geothlypis trichas	4.4	0	0	0	0	0	0	0	0	0	0	0	43.6	0	0	0	0	0	0	0	20.3	0	0	0	0	0	19	12.7	0	0	0	0		
Icterus parisorum	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.5	0	0	0	0	0	0	0	0	0	4.1	42.4	0	0	0	0		
Leptotila verreauxi	0	0	0	0	59.6	0	0	0	0	0	0	0	0	0	0	15.5	0	0	0	0	0	0	0	3.4	0	9.5	12	0	0	0	0	0		
Megarhynchus pitangua	7.3	0	0	0	19.3	53.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	12.6	0	0	0	0		
Melanerpes aurifrons	37.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18.3	0	0	0	0	0	1.6	0.9	0	0	0	38.9	2.9	0	0	0	0		
Melanerpes formicivorus	62.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	5.7	0	0	0	25.8	0	0	0	0	0		
Molothrus aeneus	58.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	30.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Momotus momota	5.3	7.3	0	8.2	0	0	0	0	0	0	0	35.6	0	14.4	25.8	2.1	0	0	0	0	0	0	0	0	1.3	0	0	0	0	0	0	0	0	
Myiarchus tuberculifer	0	0	0	0	0	31.2	0	0	0	0	28.6	0	0	0	0	23.6	0	0	0	0	0	0	0	0	0	0	6.7	0	9.9	0	0	0		
Myiopagis viridicata	0	0	0	0	9.1	0	0	0	0	0	0	0	53.5	0	0	15.8	0	0	0	0	0	0	0	0	0	0	4.3	0	17.3	0	0	0	0	
Myiozetetes similis	16.3	0	0	0	0	8.3	0	0	0	0	0	0	32.6	0	0	0	4	0	0	0	0	0	0.4	0	0	0	5.2	33.2	0	0	0	0	0	
Ortalis vetula	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	31	0	0	0	0	0	1	0	35	0	0	0	0	0	0	0	0	
Parkesia motacilla	1	0	0	0	49.3	0	0	4.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45.3	0	0	0	0	0	0	
Parkesia noveboracensis	1	0	0	0	0	47.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45.3	0	0	6.1	0	0	0	
Passer domesticus	5.4	0	0	0	0	0	12.8	11.1	0	0	5.9	0	0	0	0	54	7.3	0	0	0	0	0	0	0	0	0	0	0	3.5	0	0	0	0	
Pheugopedius maculipectus	22.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.6	0	0	0	0	0	0	0	55	0	16.3	0	0	0	0	0	0	
Pionus senilis	0	7.2	0	23.4	0	0	0	5.5	0	0	0	0	32.4	26.6	0	0	0	0	0	0	0	0	1.7	0	0	0	3.2	0	0	0	0	0	0	0
Poliophtila caerulea	21.7	0	48.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29.7	0	0	0	0	0	0	
Psarocolius montezuma	16.8	0	0	0	0	0	0	0	73.7	0	0	0	0	0	0	0	2.4	0	0	0	0	2.5	0	0	0	0	1.8	2.8	0	0	0	0	0	0
Psilorhinus morio	0	0	0	0	75.1	0	0	12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12.4	0	0	0	0	0	0	0
Quiscalus mexicanus	23.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.7	0	72.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saltator atriceps	11.5	0	0	0	0	0	0	0	0	0	0	0	0	0	58.2	27.7	0	0	0	0	0	0	0	0	0	0	2.6	0	0	0	0	0	0	0
Setophaga petechia	0	0	0	0	0	0	0	0	0	0	6.2	0	21.6	0	0	0	12	0	0	0	0	0	0	0	9.7	0	0	50.5	0	0	0	0	0	0
Setophaga virens	23.6	0	0	0	0	0	0	0	0	0	0	0	0	0	15.6	19	0	0	0	0	0	0	0	0	0	0	28.5	13.3	0	0	0	0	0	0
Sittasomus griseicapillus	0	0	0	0	0	0	0	0	14.2	0	0	0	0	0	0	0	21.9	0	0	0	25.5	0	0	0	38.4	0	0	0	0	0	0	0	0	0
Stelgidopteryx serripennis	0	0	0	0	45.8	0	0	0	0	0	0	0	0	0	0	0	15.4	0	0	0	0	0	0	0	0	0	38.8	0	0	0	0	0	0	0

<i>Streptopelia decaocto</i>	10	0	0	0	0	40.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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Como você percebe as aves que vivem nas cidades?

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Você está sendo convidado(a) a participar como voluntário(a) de uma pesquisa referente a percepção da população em relação às aves urbanas na cidade de Bauru|SP, desenvolvida pela doutoranda Gabriela Rosa do programa "Ecologia e Biodiversidade" da UNESP em Rio Claro|SP.

Leia atentamente as informações a seguir:

Ao responder estas perguntas, você estará contribuindo com novas descobertas dessa pesquisa e sua colaboração ocorrerá de forma anônima. Não existe resposta certa ou errada, e algumas perguntas podem ser respondidas com mais de uma opção. A pergunta final é sobre sons, portanto, talvez precise de um fone de ouvido ou um local silencioso para responder. O tempo para preenchimento do formulário é de aproximadamente de 5 a 10 minutos. Você é livre para recusar-se a participar e sua recusa não implicará em qualquer penalidade. Em caso de dúvidas, você poderá entrar em contato através do e-mail: gabriela.rosa@unesp.br

*Obrigatório

1. Aceita os termos acima *

Marcar apenas uma oval.

☐ Sim

☐ Não

Identificação

2. Gênero *

Marcar apenas uma oval.

☐ Feminino

☐ Masculino

☐ Trans/Não-binário

☐ Prefiro não dizer

☐ Outro: _____

3. Faixa etária *

Marcar apenas uma oval.

- ☐ Até 25 anos
- ☐ 26 a 35 anos
- ☐ 36 a 45 anos
- ☐ 46 a 60 anos
- ☐ 61 a 74 anos
- ☐ Acima 75 anos

4. Escolaridade *

Marcar apenas uma oval.

- ☐ Fundamental incompleto
- ☐ Fundamental completo
- ☐ Médio incompleto
- ☐ Médio completo
- ☐ Superior incompleto
- ☐ Superior completo
- ☐ Pós-graduação
- ☐ Outro: _____

5. Renda familiar *

Marcar apenas uma oval.

- ☐ Até 1000 reais
- ☐ Entre 1000 a 3000 reais
- ☐ Entre 3000 a 5000 reais
- ☐ Entre 5000 a 10.000 reais
- ☐ Acima de 10.000 reais
- ☐ Prefiro não responder
- ☐ Outro: _____

Percepção das Aves

6. Descreva com uma palavra qual seu sentimento em relação às aves urbanas *

7. O que você acredita ser um benefício das aves nas cidades? *

8. Você acredita que há um malefício causado pelas aves nas cidades? *

9. Quantas aves diferentes você acredita já ter visto dentro da área urbana de Bauru? *

Marcar apenas uma oval.

- ☐ 1 a 5
- ☐ 6 a 10
- ☐ 11 a 20
- ☐ Mais de 20

A seguir, de acordo com sua percepção, escolha a opção de 1 a 5 que , segundo você, mais representa sua opinião a respeito das afirmações abaixo:

10. As aves ajudam na dispersão de sementes. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo totalmente	☐	☐	☐	☐	☐	Concordo totalmente

11. As aves ajudam na polinização de flores *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo totalmente	☐	☐	☐	☐	☐	Concordo totalmente

12. Aves ajudam no controle de pragas, insetos e outros animais. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo totalmente	☐	☐	☐	☐	☐	Concordo totalmente

13. Aves ajudam a prevenir incidência de doenças *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo totalmente	☐	☐	☐	☐	☐	Concordo totalmente

14. Já foram registradas 276 espécies de aves dentro de todo o território de Bauru *
(o que inclui áreas florestais, rurais e urbanas). Quantas vocês acredita que
sejam capazes de viver na área urbana?

Marcar apenas uma oval.

- ☐ Apenas 10%
- ☐ Entre 10% a 25%
- ☐ Entre 25% a 35%
- ☐ Entre 35% a 50%
- ☐ Entre 50% a 75%
- ☐ Entre 75% a 99%
- ☐ Todas (100%)

Identificação de imagens, sons e silêncios

15. Assinale abaixo todas as aves que você costuma ver na cidade: *

Marque todas que se aplicam.



☐ Opção 1



☐ Opção 2



☐ Opção 3



☐ Opção 4



☐ Opção 5



☐ Opção 6



☐ Opção 7

☐ Opção 8

☐ Opção 9

☐ Opção 10

☐ Opção 11

☐ Opção 12

☐ Opção 13

☐ Opção 14


☐ Opção 15☐ Opção 16☐ Opção 17☐ Opção 18☐ Opção 19☐ Opção 20

☐ Nenhuma. Não costumo ver e nunca vi nenhuma das anteriores.

16. Clique nos áudios abaixo e assinale todos os cantos que você costuma ouvir na cidade (marque quantas quiser): *

Marque todas que se aplicam.

- ☐ <https://talkandcomment.com/p/324b9201351893b664bad24b> (voice note)
- ☐ <https://talkandcomment.com/p/085192b0e4215270ed4d814e> (voice note)
- ☐ <https://talkandcomment.com/p/f2752e7bd7dc625c44764b42> (voice note)
- ☐ <https://talkandcomment.com/p/b3b85e2e4e2397f8cd2f4c4b> (voice note)
- ☐ <https://talkandcomment.com/p/5c6f0e97dbb044abcc7af043> (voice note)
- ☐ <https://talkandcomment.com/p/820084360065f731dca1e97d> (voice note)
- ☐ Nenhuma. Não costumo/nunca escutei nenhum dos cantos anteriores.

17. Comentários sobre sua experiência com aves na cidade (opcional)

Este conteúdo não foi criado nem aprovado pelo Google.

Google Formulários