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ECOLOGIA E COMPORTAMENTO DAS AVES MIGRATÓRIAS NEOTROPICAIS AUSTRAIS E A URBANIZAÇÃO DA MATA ATLÂNTICA DO BRASIL

ECOLOGY AND BEHAVIOR OF NEOTROPICAL AUSTRAL MIGRANT BIRDS AND URBANIZATION IN THE ATLANTIC FOREST, BRAZIL

Karlla Vanessa de Camargo Barbosa

Tese apresentada ao Instituto de Biociências da Universidade Estadual Paulista "Júlio de Mesquita Filho", Campus de Rio Claro, para a obtenção do título de Doutora em Ciências Biológicas (Área de concentração: Zoologia)

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TÍTULO DA TESE: Ecologia e comportamento das aves migratórias neotropicais austrais e a urbanização da Mata Atlântica do Brasil

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> “Nunca deixe que lhe digam que não vale a pena acreditar no sonho que se tem.
> ou que seus planos nunca vão dar certo
> ou que você nunca vai ser alguém...
>
> Se você quiser alguém em quem confiar confie em si mesmo.
> Quem acredita sempre alcança! ”
>
> Mais uma vez - Renato Russo

Sumário

APRESENTAÇÃO

Este documento é o produto de quatro anos de pesquisa em ecologia de aves, ecologia urbana, migração das aves, história natural de aves migratórias e ciência cidadã. Esse período de pesquisa permitiu um grande conhecimento e crescimento profissional, gerando artigos em revistas científicas especializadas de grande impacto, matérias em jornais populares de ampla circulação, e encontros, estágios e discussões com especialistas no Brasil e Estados Unidos. Assim, como produto final, a presente tese de doutorado está dividida em quatro capítulos que estão estruturados em forma de artigos científicos. Apesar dos artigos serem independentes, seus resultados são complementares e apresentam resultados inéditos.

O documento se inicia com uma introdução geral sobre os assuntos abordados nos capítulos, seguida dos artigos científicos produzidos com os resultados desta tese de doutorado, sendo parte já publicada em revistas revisada por pares:

Capítulo 1: Barbosa KV, Rodewald AD, Ribeiro MC & Jahn AE (2020). Noise level and water distance drive resident and migratory bird species richness within a Neotropical megacity. *Landscape and Urban Planning*, 197, 103769.

Capítulo 2: Vitorio JG*, Frenedozo RC & Barbosa KVC* (2019). Habitat use and home range of a migratory bird, *Myiodynastes maculatus solitarius*, in an urban park in the Atlantic Forest, Brazil. *Brazilian Journal of Ornithology*, 27(2): 115–121. * Both authors contributed equally to this work.

Capítulo 3: Barbosa KV, Bejarano VA, Costa TVV, Ribeiro MC & Jahn, AE. Breeding-site fidelity of three Neotropical austral migrant flycatchers (Tyrannidae) in Brazil. *In prep.*

Capítulo 4: Barbosa KV, Develey PF, Ribeiro MC & Jahn, AE. The potential of citizen science to contribute to research and conservation of birds in Brazil. *Submitted to Ornithology Research.*

A última seção deste documento apresenta uma conclusão geral sobre os principais resultados obtidos e apresentados nos quatro capítulos e de acordo com o tema central da tese, que foi entender a ecologia e comportamento das aves migratórias neotropicais austrais na Mata Atlântica do Brasil.

Resumo geral

Vivemos em uma era onde as paisagens naturais do planeta são alteradas rapidamente, formando mosaicos de estruturas antrópicas e manchas arborizadas inseridas em contextos urbanos. Essas manchas verdes servem como importantes locais para conservação da biodiversidade, bem como para reprodução e forrageamento de espécies de aves migratórias. No entanto, os efeitos das características da paisagem urbana sobre as aves ainda são pouco entendidos na região Neotropical. Este estudo buscou entender os efeitos da urbanização sobre as aves da Mata Atlântica e conhecer as demandas de habitat das aves migratórias em áreas urbanas. Nesse contexto, o estudo teve quatro objetivos: 1) Avaliar as respostas das aves a um conjunto de atributos de cobertura do solo na paisagem urbana da cidade de São Paulo; 2) Descrever o habitat e a área de vida do tiranídeo migratório *Myiodynastes maculatus solitarius* em um parque urbano da Mata Atlântica; 3) Verificar se os tiranídeos migratórios têm fidelidade de sítio reprodutivo, e se sexo, habitat ou condição corpórea afetam a fidelidade de sítio; e 4) Revisar o desenvolvimento da ciência cidadã e sua contribuição para a ornitologia no Brasil, bem como conhecer, através dessa fonte de dados, a agenda migratória e os requisitos mínimos de habitat de quatro espécies de aves migratórias Neotropicais austrais no Brasil. Como resultado encontramos que na paisagem urbana o uso de áreas verdes pelas aves migratórias e residentes são afetadas negativamente pelo alto índice de ruído e a distância dos corpos d´água, e que ambos grupos de espécies são afetados de maneira similar. Além disso, os efeitos da urbanização podem afetar comportamentos das espécies, como por exemplo mudar o uso do espaço. Para *M. m. solitarius* encontramos uma área de vida média de 5.4 hectares em parque urbano em São Paulo, sendo que quanto mais estruturas antrópicas maior é a área explorada pelo indivíduo. Assim como o *M. m. solitarius,* alguns indivíduos de *Tyrannus savana* e *Empidonomus varius*, segundo nossos resultados, retornam após migração ao sítio reprodutivo. No entanto, o sexo e o tipo de ambientes (rurais vs. urbano) são características que afetam para essa fidelidade. Segundo dados de ciência cidadã, essas espécies e *P. rubinus*, apresentaram diferentes requerimentos de habitat com relação a tamanho de áreas verdes, sendo para *M. m. solitarius* 10 hectares, *P. rubinus* 5 hectares, *E. varius* 1 hectare e *T. savana* no mínimo ruas urbanizadas. A ciência cidadã, que contribuiu de forma importante para obtenção de respostas nos estudos desta tese, tem crescido no Brasil e gerado conhecimento sobre as espécies brasileiras. Os dados provenientes da ciência cidadã

mostram-se eficientes no fornecimento de informações relevantes em áreas urbanizadas, onde se concentram os observadores de aves que contribuem para as bases de dados. Para a implementação de iniciativas de conservação de forma mais efetiva, é necessário um maior foco em diferentes mosaicos da paisagem, sendo as áreas verdes urbanas partes dessa composição como refúgio para diversas espécies de aves. O desafio que se apresenta está em conhecer e conciliar as necessidades da sociedade humana e da biodiversidade para manter condições ecologicamente sustentáveis para ambos.

Palavras-chave: conservação das aves, ecologia urbana, ciência cidadã, Tyrannidae

General abstract

We live in an era, when the planet's natural landscapes are rapidly changing, forming mosaics of both anthropogenic and green patches within urban areas. These green patches serve as important sites for biodiversity, for instance supporting reproduction and foraging for migratory bird species. However, the effects of urban landscape features on birds are still poorly understood in the Neotropical region. This study sought to understand the effects of urbanization on birds in the Atlantic Rainforest and to evaluate habitat requirements of migratory birds in urban areas. In this context, the study had four objectives: 1) To evaluate the responses of birds to a set of ground cover attributes in the urban landscape of the city of São Paulo; 2) To describe the habitat and home range of the migratory tyrannid flycatcher *Myiodynastes maculatus solitarius* in an urban park in the Atlantic Forest; 3) To evaluate the breeding site fidelity of migratory tyrannid flycatchers, and whether sex, habitat or body condition affect site fidelity; and 4) To review the development of citizen science and its contribution to ornithology in Brazil and to use citizen science to study migration timing and the minimum habitat requirements of four austral migratory bird species in Brazil. As a result, we found that the use of urban green areas by migratory and resident birds is negatively affected by high noise levels and distance from water and that both groups of species are similarly affected. In addition, the effects of urbanization can affect the behavior of species, such as changing the use of space. For *M. m. solitarius*, we found an average home range of 5.4 hectares in an urban park in São Paulo and a positive relationship between area explored by an individual and number of anthropic structures. Similar to *M. m. solitarius*, some individuals of *Tyrannus savana* and *Empidonomus varius* return to the breeding site; however, sex and environment (rural vs. urban) affect their breeding site fidelity. According to citizen science data, these species and *P. rubinus* have different habitat requirements with respect to the size of green areas, being 10 hectares for *M. m. solitarius*, 5 hectares for *P. rubinus*, 1 hectare for *E. varius* and, at the minimum, a few meters wide for *T. savana*. Citizen science, the origin of a significantly proportion of the data in this thesis, has grown in Brazil and generated substantial knowledge about Brazilian bird species. Citizen science is efficient in providing relevant information from urbanized areas, where bird observers who contribute to the databases are concentrated. In order to implement conservation initiatives more effectively, a greater focus is needed on various landscape mosaics besides forest remnants, including urban green areas that are also important to many bird species. The challenge is to understand and reconcile the needs of human society and biodiversity to maintain ecologically sustainable conditions for both.

Keywords: bird conservation, citizen science, Tyrannidae, urban ecology

INTRODUÇÃO GERAL

Vivemos numa era onde as paisagens naturais por todo planeta são alteradas rapidamente, formando mosaicos de origem antrópica e natural (Metzger 2006). Nos grandes centros urbanos esse fenômeno é ainda mais complexo, restando muitas vezes apenas manchas verdes inseridas na matriz urbana (Alberti et al. 2001). Nesse contexto, essas manchas verdes representam áreas de extrema importância para as aves residentes e migratórias, particularmente para espécies que têm maior capacidade de tolerar distúrbios de origem antrópica. No entanto, aves que usam áreas dentro ou próximo a cidades são susceptíveis a diversos desafios, como o aumento das taxas de predação, parasitismo de ninhos e escassez de recursos (Bolger 2001; Tewksbury et al. 2006), podendo assim diminuir as chances de sobrevivência dos indivíduos. Além disso, outros fatores inerentes aos centros urbanos podem também prejudicar a ocorrência e sobrevivência de aves nas manchas verdes, tais como os altos índices de ruído (Brumm 2004; Pena et al. 2017; da Silva et al. 2020), alta porcentagem de áreas impermeáveis (McKinney 2002; Evans et al. 2018; Souza et al. 2019) e densidade da população humana (Fontana et al. 2011). Portanto, o desafio que se apresenta está em conhecer e conciliar as necessidades da sociedade humana e da biodiversidade para manter condições ecologicamente sustentáveis para ambos.

Grande parte do conhecimento sobre os efeitos da urbanização nas aves provém de estudos realizados na região temperada, sendo esse padrão de distribuição do conhecimento ainda mais acentuado quando se trata especificamente das aves migratórias (e.g., Blake & Karr, 1987; Rodewald & Bakermans, 2006; Loss et al. 2009; Husté & Boulinier 2011; Evans et al. 2018). Alguns desses estudos demonstraram efeitos negativos sobre as aves migratórias, tais como sobre aspectos reprodutivos das aves (Rodewald & Bakermans 2006; Rodewald & Shustack 2008) e alteração das datas de chegada e partida (Norris et al. 2004). Em contrapartida, outros estudos mostraram que manchas florestais urbanas podem oferecer vantagens para algumas espécies por prover recursos durante a migração (Matthews & Rodewald 2010). Um outro aspecto que tem sido abordado nos estudos do hemisfério Norte é que, de uma forma geral em comparação às espécies residentes, as aves migratórias são mais propensas a serem impactadas pela urbanização. Essa diferença pode se dever ao fato das aves migratórias serem, geralmente, mais especialistas em habitat, enquanto que as aves residentes têm uma capacidade melhor de responder às flutuações de disponibilidade de recursos (Martin & Fahrig 2018; Ortega-Álvarez & MacGregor-Fors 2009).

Na região Neotropical, especialmente no Brasil, poucos estudos avaliaram os efeitos da urbanização sobre as aves e quais variáveis ambientais e antrópicas podem ter maior influência sobre a riqueza e abundância das espécies (Fontana et al. 2011; Pena et al. 2017; Souza et al. 2019; da Silva et al. 2020). Ademais, apesar das estimativas serem de quase 200 espécies de aves que realizam movimentos migratórios no Brasil (Somenzari et al. 2018), pouco se sabe sobre ecologia e biologia dessas espécies, principalmente em ambientes antropizados. Ou ainda, se aves migratórias e residentes são impactadas de maneiras diferentes pela urbanização, como é o padrão encontrado para o Hemisfério Norte.

Aves migratórias no Brasil

A migração é o movimento direcional, regular e sazonal de um grande contingente de indivíduos de uma espécie, de uma determinada localidade para outra (Begon et al. 1990). Esse movimento anual das aves geralmente envolve um sítio de reprodução e outro de invernada ou repouso reprodutivo (Schüz et al. 1971; Webster et al. 2002) e permite que elas busquem recursos em localidades distantes (Sick 1983; Joseph & Stockwell 2000). No entanto, movimentos migratórios e uso das áreas de invernada ou reprodução podem ser fortemente impactados por alterações ambientais de origem antrópica, tais como a urbanização (Wilson et al. 2018; Bonnet-Lebrun et al. 2020).

No planeta existem diversos sistemas migratórios conhecidos para as aves (Newton 2008). Na região Neotropical são encontradas espécies migrantes neárticos (Hayes 1995), no qual os indivíduos reproduzem na América do Norte e migram para o sul para passar o período de invernada (*e.g.* Newton, 2008; Greenberg & Marra, 2004); migrantes altitudinais, no qual qualquer espécie de ave ou população da espécie migra regularmente de uma altitude para outra (Hayes 1995; Barçante et al. 2017); e os migrantes neotropicais-austrais, onde as espécies se reproduzem na região continental temperada da América do Sul e migram para o norte do continente durante o inverno austral (Cueto & Jahn 2008). O sistema neotropical-austral é o terceiro maior sistema migratório em número de espécies conhecido (Chesser 1994) e também um dos menos estudados. Estimativas indicam que cerca de 220 espécies realizam esse tipo de movimento migratório (Chesser 1994).

Considerando todas as aves migratórias neotropicais austrais, cerca de um terço são da família Tyrannidae, porém pouco ainda se conhece sobre os diversos aspectos da história natural dessas espécies. Estudos sobre aves migratórias no Brasil começaram na década de 80 dando início ao entendimento sobre a migração no país (Sick 1983; Antas 1986; Stotz et al. 1992), porém apenas alguns estudos focaram em espécies da família Tyrannidae (Erickson 1982; Marini & Cavalcanti 1990). Nos últimos 20 anos apesar de novos estudos sobre aves migratórias da família Tyrannidae terem surgido (e.g. Joseph & Stockwell 2000; Joseph et al. 2003; Alves 2007; Areta & Bodrati 2008; Jahn et al. 2013; Guaraldo el al 2016; Bejarano & Jahn 2018) muitas espécies relativamente comuns, ou mesmo abundantes, têm sua biologia e ecologia pouco ou nada conhecidas.

História natural e ecologia das aves migratórias neotropicais austrais em ambientes urbanos

As aves migratórias neotropicais austrais são conhecidas por se reproduzirem principalmente em ambientes abertos (Chesser 1994; Chesser & Levey 1998; Bejarano & Jahn 2018), o que não significa necessariamente que também não sejam afetadas por eventual falta de recursos, tal como baixa cobertura vegetal e arbórea (Cockle et al. 2010; Amaya-Espinel & Hostetler 2019) ou mesmo a urbanização (Wilson et al. 2018). Por serem abundantes, amplamente distribuídas e muitas dependerem de áreas florestais (Fitzpatrick 2004), as aves da família Tyrannidae podem ser bons indicadores para entendermos se os padrões do efeito da urbanização encontrados no hemisfério norte sobre as aves migratórias também se aplicam aos migrantes neotropicais austrais.

Para se entender os efeitos da urbanização sobre as aves migratórias, é essencial conhecer seus requerimentos ecológicos, como elas utilizam o habitat e o tamanho de sua área de vida. Com relação a hábitat e área de vida, ou seja, o espaço usado pelo indivíduo durante suas atividades diárias (Burt 1943, Brown & Orians 1970, Powell 2000), é esperado que atenda às necessidades básicas da espécie (Hutto 1985). Portanto, quando a disponibilidade de recursos na área de vida é afetada, pode ocorrer maior competição por recursos, diminuindo, por exemplo, as chances de sucesso reprodutivo das espécies (Greenberg 1986).

Outro aspecto de história natural pouco conhecido ou documentado sobre essas espécies é se elas apresentam fidelidade aos sítios reprodutivos. Atualmente, entre as cerca de 220 espécies de migrantes neotropicais austrais, apenas para 10 espécies há documentação de que podem retornar para o mesmo local de reprodução de anos anteriores após a migração (McNeil 1982; Rumboll et al. 2005; Brown et al. 2007; Jahn et al. 2009). Esse fenômeno é, possivelmente, muito mais difundido entre as espécies do que tem sido documento. De fato, existem benefícios claros para as aves apresentarem fidelidade ao local de reprodução, geralmente relacionados ao fato do indivíduo ter conhecimento prévio do local. Em geral, se um território apresenta recursos de boa qualidade, é presumivelmente mais vantajoso que a ave retorne ao local ao qual está familiarizado do que procurar e defender um novo território (Bollinger & Gavin 1989; Greenwood 1980).

O conhecimento prévio da área dá ainda vantagem nas interações competitivas com outros indivíduos, pois os tornam mais capazes de defender seus locais de alimentação e nidificação contra possíveis competidores. No entanto, essas interações só são vantajosas quando a qualidade do ambiente compensa o retorno (Black 1996). Portanto, é importante entender em que condições as manchas verdes urbanas podem fornecer habitat para as aves migratórias e a manutenção da biodiversidade em longo prazo.

Ciência cidadã no Brasil

Entender os diversos fatores que afetam as aves residentes e migratórias em ambientes urbanos em um país como o Brasil, que tem uma rica biodiversidade e dimensões continentais, é oneroso e difícil. Nesse contexto emerge a ciência cidadã moderna, que permite a todo cidadão acadêmico ou não acadêmico contribuir com o conhecimento de diversos aspectos ecológicos importantes das aves (Silvertown 2009; La Sorte et al. 2017; McKinley et al. 2017). Dados de observação de aves são frequentemente colectados com ajuda do aplicativos e depositados em banco de dados online, como eBird e WikiAves, que fornecem oportunidade de dados para pesquisas acadêmicas. No Brasil, alguns estudos nos últimos 5 anos têm utilizado dados de ciência cidadã para conhecer diferentes aspectos da migração das espécies (Lees & Martin 2015; Lees 2016; Schubert et al. 2019; Somenzari et al 2018). A coleta de dados por cidadãos cientistas pode, portanto, ser uma importante ferramenta para o conhecimento das aves migratórias (Hochachka et al. 1999; Lees 2016), principalmente em centros urbanos onde as observações das espécies costumam ser mais acessíveis.

No Brasil, os efeitos da urbanização sobre as aves (Fontana et al. 2011; Toledo et al. 2011; Pena et al. 2017; Souza et al. 2019) ou o comportamento migratório das espécies (Lees & Martin 2015; Lees 2016; Jahn et al. 2016; Lees 2016; Somenzari et al. 2018; Bejarano & Jahn 2018; Schubert et al. 2019) são assuntos ainda pouco explorados, sendo que nenhum estudo investigou o impacto da urbanização nas aves migratórias neotropicais austrais. Esse é, portanto, o primeiro estudo que investiga o comportamento de aves migratórias neotropicais austrais em ambientes urbanos e seus impactos, e que sugere novas direções para estudos com aves migratórias que utilizam áreas verdes urbanas.

Os estudos existentes sugerem que o comportamento e ecologia das aves são influenciados pela composição da paisagem, sendo que em paisagem urbana os efeitos podem ser ainda mais complexos. Assim, a hipótese central dessa tese é que a riqueza, ecologia e comportamento das aves migratórias neotropicais austrais são afetadas em diferentes níveis pela urbanização. Para testar essa hipótese, o estudo dessa tese objetivou entender como a urbanização pode afetar as aves migratórias neotropicais austrais que usam manchas verdes urbanas da Mata Atlântica brasileira. Esse objetivo geral foi dividido em quatro objetivos específicos: 1) Avaliar as respostas das aves a um conjunto de atributos de cobertura do solo na paisagem urbana da cidade de São Paulo; 2) Descrever o habitat e a área de vida do tiranídeo migratório *Myiodynastes maculatus solitarius* em um parque urbano da Mata Atlântica; 3) Verificar se os tiranídeos migratórios têm fidelidade de sítio reprodutivo, e se sexo, habitat ou condição corpórea afetam uma possível fidelidade de sítio; e 4) Revisar o desenvolvimento da ciência cidadã e sua contribuição para a ornitologia no Brasil, bem como conhecer, através dessa fonte de dados, a agenda migratória e os requisitos mínimos de habitat de quatro espécies de aves migratórias Neotropicais austrais no Brasil

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CAPÍTULO 1

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Noise level and water distance drive resident and migratory bird species richness within a Neotropical megacity

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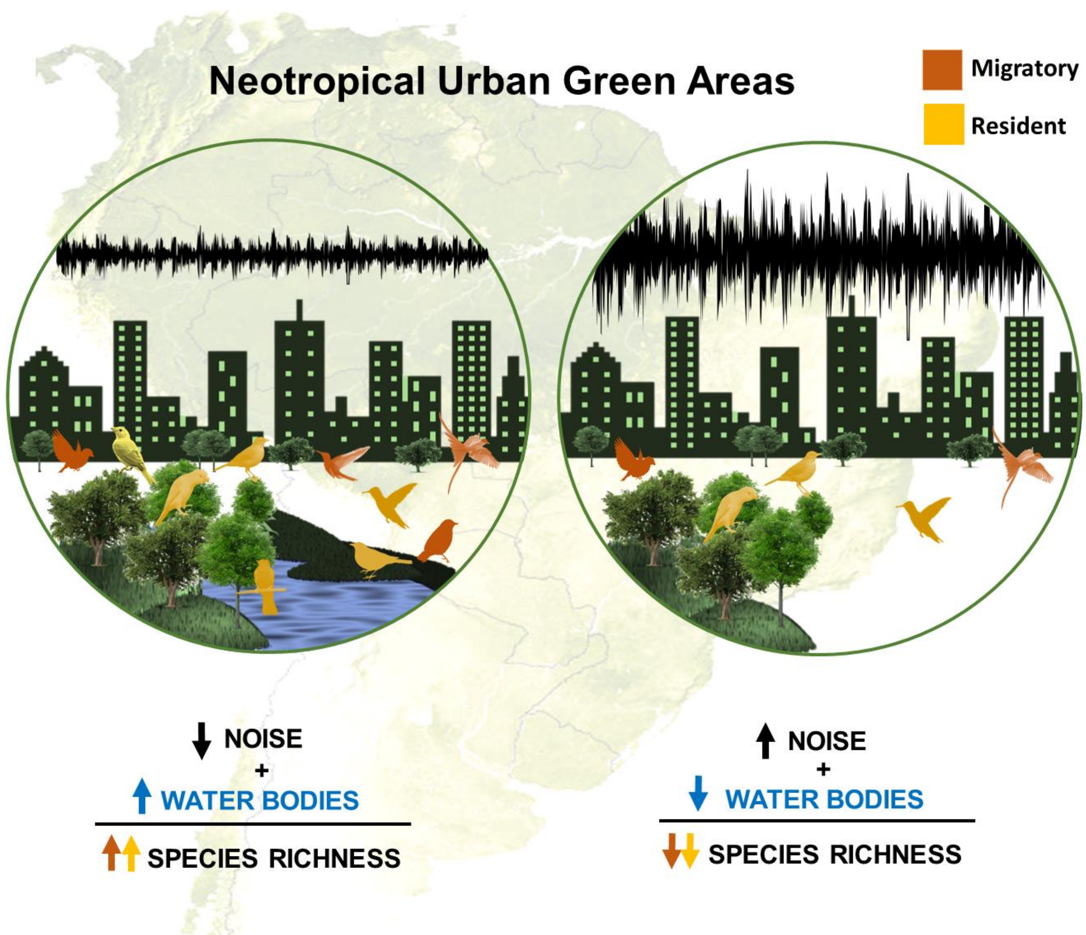

Noise level and distance to water drive resident and migratory bird species richness within a Neotropical megacity

Abstract

A large body of evidence indicates that urbanization profoundly affects ecological communities, but the extent to which patterns are generalizable across regions, such as in the Neotropics, remains unclear. We examined responses of migratory and resident birds to human disturbance and habitat attributes in São Paulo, Brazil, a tropical megacity in South America. In 2017-2018, we surveyed birds across 31 landscapes distributed across the urban landscape and evaluated competing models that included five non-correlated variables explaining variation in species richness: ambient noise level, distance to water, tree cover, human population size, and impervious surface. We recorded 142 bird species, 128 of which were resident and 14 migratory. Richness of both resident and migratory birds declined with increasing noise level and distance to water, which best explained variation in bird communities among the sampled landscapes. Although resident and migratory birds presented similar response patterns to local and landscape attributes, noise level was the best predictor of migratory species occurrence, whereas distance to water best explained the occurrence of resident species. Our results suggest that, although tree cover is important to biodiversity in urbanized landscapes, proper management of urban water bodies and reduction of noise levels are also essential to maintaining avian diversity within tropical urban areas and suggest novel avenues for future research in tropical urban ecology.

Keywords: biodiversity, urbanization, urban parks, Atlantic Forest, South America

1. Introduction

There is a growing urban footprint across the planet, with over half of the world's human population now living in cities (United Nations, 2018). One of the effects of urban expansion is the transformation of landscapes into a mosaic of patches with different land uses embedded within an urban-dominated matrix. This landscape-level conversion alters the functioning of ecosystem and ecological processes (Grimm, Grove, Pickett, & Redman, 2000), contributing to biodiversity loss and environmental homogenization (Chace & Walsh, 2006). Therefore, the challenge of the 21st Century is to reconcile the needs of human society and those of biodiversity to maintain conditions that are ecologically sustainable for both. To be effective, such efforts require information about which landscape characteristics drive the maintenance of biodiversity within urban green spaces (Aronson et al., 2017; Lepczyk et al., 2017).

Perhaps no other taxonomic group within cities has been well studied as birds (Palacio, Ibañez, Maragliano, & Montalti, 2018). Birds are relatively easy to detect and survey, are often sensitive to disturbance, and are generally effective sentinels of environmental change (MacGregor-Fors, 2008; McKinney, 2002; Barbosa, Knogge, Develey, Jenkins, & Uezu, 2017). Among the documented proximate drivers that shape urban bird communities are: changes in vegetation cover, floristics, and microclimate (Chace & Walsh, 2006; Rodewald & Shustack, 2008; Rodewald, Shustack, & Hitchcock, 2010; Lowry, Lill, & Wong, 2012), abundance of predators and brood parasites (Rodewald, Kearns, & Shustack, 2011), urbanization and the spatial distribution of green patches (Husté & Boulinier, 2011), and food resource availability (Rodewald et al., 2011; Lowry et al., 2012). Thus, urbanization can profoundly impact bird community composition and structure.

In particular, urbanization has been linked both to declines of sensitive species and to positive effects on synanthropic or non-native species (Ortega-Alvarez & MacGregor-Fors, 2009). Although species richness of birds within cities tends to increase with tree cover (Emlen, 1974; Chace & Walsh, 2006; MacGregor-Fors, 2008), richness typically declines with impervious surface area (McKinney, 2002; Evans, Reitsma, Hurlbert, & Marra, 2018; Souza et al., 2019), density of buildings (Palacio et al., 2018), proximity to urban parks (Loss, Ruiz, & Brawn, 2009), ambient noise level (Brumm, 2004; Pena, Martello, Ribeiro, Armitage, Young & Rodrigues, 2017), and human population density (Fontana, Burger, & Magnusson, 2011).

One of the most consistent patterns reported in urban bird studies from temperate regions is the negative relationship between urbanization and migratory bird abundance (Loss et al., 2009; Husté & Boulinier, 2011; Evans et al., 2018). Migratory birds that breed in temperate latitudes are thought to be more sensitive than resident birds (*i.e.*, which do not migrate) to landscape composition and configuration, such as patch size, forest cover, edge effects and connectivity (e.g., Blake & Karr, 1987; Rodewald & Bakermans, 2006). Compared to residents, migratory birds are also more likely to be habitat specialists, since residents presumably have a better capacity to respond to fluctuations in resource availability and habitat quality (Martin & Fahrig, 2018). Additionally, migratory birds generally have lower reproductive potential (i.e., are usually single-brooded) and tend to be more vulnerable to nest predation (Robinson, Thompson III, Donovan, Whitehead, & Faaborg, 1995; Rodewald et al., 2011), whereas resident birds tend to be better at exploiting anthropogenic resources, are more tolerant of human disturbance, and are more resistant or resilient to nest predation (Blair, 2001; Ortega-Álvarez & MacGregor-Fors, 2009). Thus, understanding how the quality and configuration of urban green spaces can limit the richness of migratory bird species during breeding season is key to informing conservation planning for those species (Lepczyk et al., 2017).

However, due to the scarcity of research on the urban ecology of birds at tropical latitudes, we still know little about the urban ecology of tropical birds and whether they respond in similar ways as species that breed at temperate latitudes. Given that the tropics harbor the highest levels of bird species on the planet, a sound understanding of the mechanisms that shape tropical urban avian communities is essential to effectively conserve their populations on an increasingly urbanized planet. In particular, research is needed on the urban ecology of migratory birds at tropical latitudes, to understand which landscape characteristics determine their use of urban habitats during migration and winter (Amaya-Espinel & Hostetler, 2019).

To contribute to filling this gap in our knowledge, we assessed the responses of birds to a suite of land cover attributes across the urban landscape of São Paulo, a tropical Brazilian megacity. Based on what has been previously reported about the effects of urbanization on bird assemblages, we hypothesized that: a) tree cover, ambient noise level, distance to water, human population density and urban structures act as filters on avian communities in São Paulo's urban green spaces, and b) these factors affect migratory and resident birds differently. We expected that avian species richness would be positively related to tree cover and negatively related to ambient noise level, distance to water, human population density, and area of urban structures. We also expected that the response of migratory birds to these variables would be stronger than that of residents.

2. Material and methods

2.1 Study area

The study was conducted in the city of São Paulo, in southeastern Brazil (S 23º32′51″; W 46°38′10). The city is embedded within the Atlantic Forest biome, which has less than 16% of its original cover remaining and is today primarily composed of relatively small patches, most of ≤50 ha or less in size (Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009). São Paulo is one of the most populous cities in the world, where more than 12 million people occupy an area of 1,521 km² (IBGE, 2018). Even though urban structures dominate São Paulo's land cover, the city contains numerous small parks and is bordered by two large blocks of forest, the Serra da Cantareira to the northwest and the Serra do Mar to the southwest. Land cover in São Paulo city is comprised of approximately 32% tree cover, 51% urban structures (e.g., buildings and impervious surface), 10% lawn and 7% water (Laboratório de Silvicultura Urbana, 2010).

2.2 Site selection and attributes

Landscape composition metrics were calculated using land cover maps made available by Laboratório de Silvicultura Urbana (2010), which were generated from satellite imagery (infrared orthophotos with 5-m resolution) of the year 2010 data collection (UTM-WGS84 zone 23S). The land cover maps include the following cover classes: trees, lawn, water, impervious surfaces (streets, avenues, and concrete), and buildings. We then selected 31 sampling sites located in green spaces, at least 2 km apart, distributed across the city and which represent the range of green space sizes present in the city: 11 to 73% tree cover within a 1 km buffer at the center of the green space. Three sampling sites were located in large public protected areas of continuous forest (numbers 11, 12 and 13 in Fig. 1) and 28 were located urban parks and smaller green spaces (locally known as *praças* – Fig. 2).

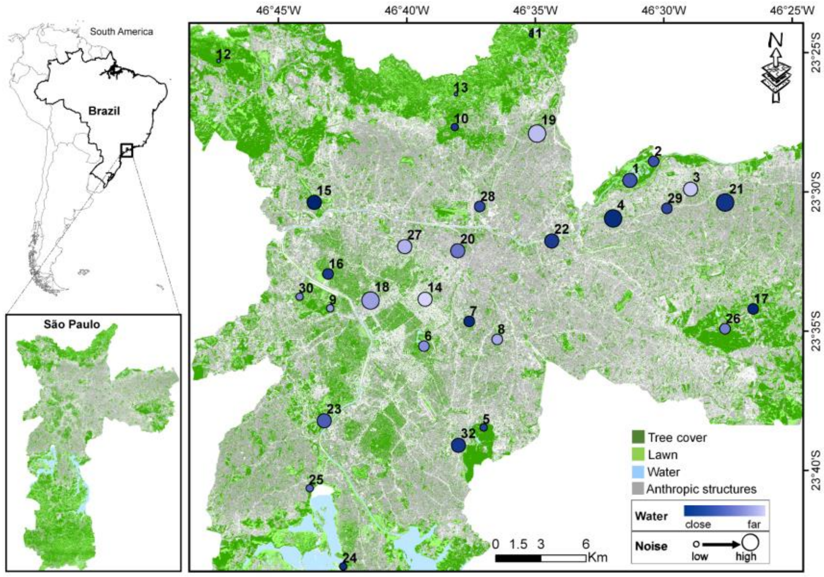

Figure 2: Location of 31 point count sites in the city of São Paulo, Brazil. Circle size represents noise level and color hue of each circle represents distance to water. The number next to each circle represents the green space referred to in Appendix A1. Tree cover, lawn, water and urban structures (impervious surface and building cover) is also shown. Map classification is from Laboratório de Silvicultura Urbana (2010).

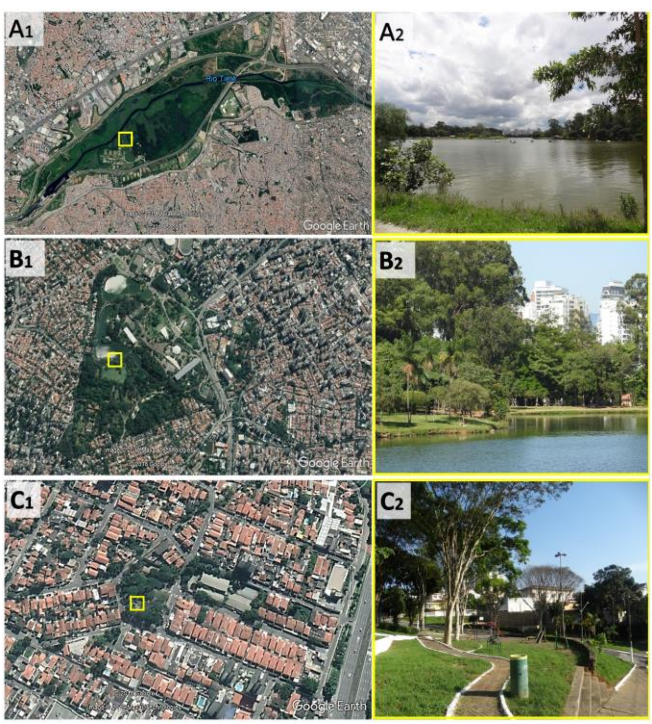

Figure 1: Contextual photos representing the essential nature of the landscape of São Paulo city. Yellow squares represent the locality where the picture was taken; A1, B1 and C1 are Google Earth images and A2, B2 and C2 are pictures by KVCB. **A** - Ecológico do Tietê Park, a typical Brazilian green space embedded among urban structures and with a lake and trails; **B –** Ibirapuera Park, an urban green space with more trees in the landscape and smaller population around; and **C** – Praça Comendador Vargas – a typical small green space called *praça* (see Fig.2, map location numbers 1, 6 and 32).

At each sampling site, we quantified the percent of land cover in landscape (tree, lawn, and impervious surface; Fig. 1) and human population density (extracted from GeoSampa; www.geosampa.prefeitura.sp.gov.br). These variables were selected because they have been shown to affect urban bird communities in previous studies (Emlen, 1974; Chace & Walsh, 2006; MacGregor-Fors, 2008; McKinney, 2002; Fontana et al., 2011; Evans et al., 2018; Amaya-Espinela & Hostetler, 2019; Souza et al., 2019). We also measured distance (meters) to the nearest water body, up to any distance (log10 transformed), and ambient noise level. The latter was measured at the center point of the sample site and it refers to the mean noise level recorded during three visits in the center of the green area where we did the survey. Ambient noise was recorded for 2-min during each visit (for a total of 6 min at each sample point), using the ‘Sound Meter’ application on a smartphone (Asus Zenfone 3 Max 5.2). This app measures the noise level in decibels and displays a graphic the last 30 seconds, with the minimum, average and maximum ambient noise from 0 to 95 db. We used the average value generated by the app for each of the three visits and made a weighted average of that value, which is a proxy for ambient noise. To ensure consistency, we used the same protocol and cell phone equipment across all point count (Zamora, Calafate, Cano, & Manzoni, 2017) and calibrated our ambient noise measurements to avoid errors (Maisonneuve, Stevens, Niessen, & Steels, 2009).

2.3 Bird surveys

The bird community in this city is composed of both residents and migrants from three migratory systems: a) breeding Neotropical austral migrants, which breed at south-temperate latitudes and spend the non-breeding season closer to the Equator (Cueto & Jahn, 2008); b) breeding altitudinal migrants, which migrate up and down mountain slopes (Barçante, Vale, & Alves, 2017); and c) non-breeding Nearctic-Neotropical migrants, which breed at north-temperate latitudes and spend the non-breeding season in the Neotropics (Joseph, 1996). The most recent report from the municipality of São Paulo shows that 464 bird species have been recorded in the city (SVMA, 2018).

Birds were surveyed between October 2017 and January 2018 (spring/summer), which represents the breeding season of most birds in southeastern Brazil, when birds are most active and singing, and when most migratory species are in the region. We conducted a point count in each landscape, which consisted of one 20-minute fixed-radius count (Bibby, Burgess, & Hill, 1992). The location of each count was recorded in UTM (Datum WGS84) using a GPS receiver. Each point count was conducted three times at each sample location and all point counts were conducted in the early morning (7:00 to 10:00) within a 20 to 30-day interval, to increase the chances of species detection. We alternated the order in which each point count was conducted, to avoid bias in detection of species during the counts. Counts were always conducted on weekdays (excluding holidays) to minimize the effect of visitors, since parks usually have more visitors on weekends. All surveys were conducted by KVCB, who has extensive experience identifying birds in the region by sight and sound. Any records that were suspicious, such as unconfirmed species or individuals that were likely captive/pets, were not included in the analysis.

2.4 Statistical analysis

We first identified multi-collinearity between explanatory variables (*i.e.*, building cover, impervious surface area, lawn area, tree cover, human population density, distance to water, and ambient noise level) using Pearson's correlation coefficient (r), and excluded those that were highly correlated ($r > 0.7$; see Supplementary Material S1 and S2). After this step, we constructed candidate models with the five remaining and uncorrelated variables.

We developed a multi-scale approach to relate bird responses to our environmental and landscape attributes (impervious surface area, tree cover, and human population density). The evaluated spatial extents were 50, 250, 500, 750 and 1,000 m around the sample locations within each of our 31 point count sites. Because the spatial scale at which landscape modification most strongly influences species distributions and richness remains unclear for many species and taxa worldwide (Jackson & Fahrig, 2015), we used model selection to identify the scale at which each of our explanatory variables best explained migratory and resident species richness (Burnham & Anderson, 2002 - Supplementary Material S3). After this step, we selected 1,000 m radius around the sample point, as the difference between scales were not strong and this spatial extent best explained the effect of most explanatory variables. Furthermore, 1,000 m is a radius size that is often used to understand the impact of urbanization on bird community dynamics (e.g., Stratford & Robinson, 2005; Loss et al, 2009; Evans et al, 2018; see Supplementary Material S3).

We evaluated a list of competing models (i.e., different Generalized Linear Models; GLMs) explaining variation in species richness using Akaike Information Criterion corrected for small sample sizes (AICc). A total of 17 models, which were composed by a single-model, adding model with combination of two variables (impervious surface area, tree cover, human population density, distance to water, and ambient noise level), one model with the anthropogenic variable (impervious surface area, human population density, and ambient noise level), and a null model were used to explain patterns of resident and migratory bird richness. The difference between the AICc of each model and the best model (i.e., with the lowest AICc; ΔAICc) was calculated for each competing model. Models having a $\Delta AICc < 2.0$ were considered equally plausible (Burnham and Anderson, 2002). We also calculated the weight of evidence (wAICc) for each competing model, which is the sum of the weights of the models in which the variable appears (Burnham & Anderson, 2002; Barbosa et al., 2017). All analyses were conducted using program R version 3.4.1 (R Core Team, 2017).

3. Results

Approximately one-third (142 species from 48 families) of all bird species already recorded in São Paulo (464 species – SVMA, 2018) were detected at our 31 sample sites. Of the 128 resident species recorded, 29 are endemic to the Atlantic Forest. Most species were insectivores (63), followed by frugivores (24), omnivores (23), carnivores (16), granivores (10) and nectarivores (6). Most species foraged in the canopy (45) and/or mid-story (40), with fewer foraging in the understory (26), on the ground (26) or in water (19). Fourteen species were Neotropical austral or altitudinal migrants that breed in the study area (for more details, see Appendix B1), with most migratory species belonging to the Tyrannidae (43% of species) and Turdidae (18%).

Resident bird species richness across point count sites varied from 7 to 49 (mean = 22.1; SD = 9.9) and migratory bird species richness varied from 0 to 10 (mean 4.2; SD=2.1 species/point). The average ambient noise level at each sample site varied from 19.8 to 48.8 db, and the distance from each point count to a body of water varied from 1 to 1,500 meters.

The model that combined *distance to water* and *noise level* best explained variation in resident (wAIC = 0.70) and migrant (wAIC = 0.43) species richness (Fig. 3). Species richness was negatively related to both *noise level* and *distance to water* (Table 1). Although tree cover was not among the selected models, both resident and migratory species richness were positively related to it (Fig. 4).

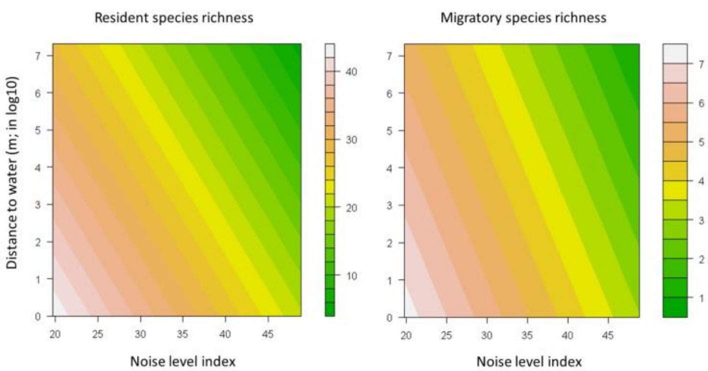

Figure 0-3: Patterns obtained in the multivariate models assessing the effects of exposure to ambient noise and distance to water on the richness of resident and migratory bird species in the city of São Paulo, Brazil. The bright colors represent higher response values.

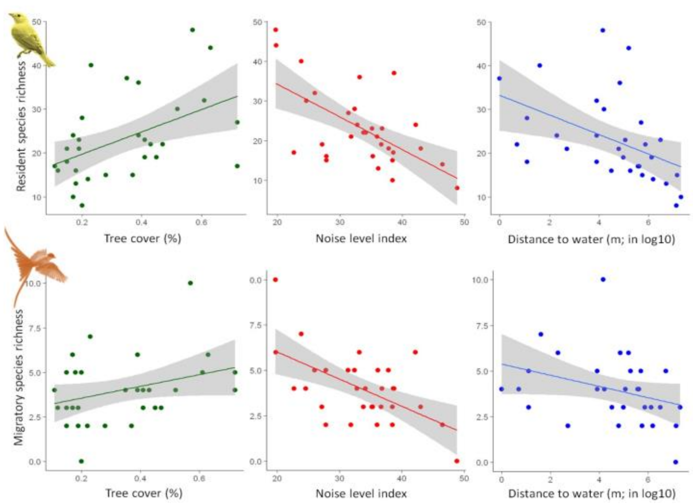

Figure 4: Influence of noise level index and distance to water (meters, log10 transformed) on resident and migratory bird species richness for 31 green areas within the city of São Paulo, Brazil. Tree cover (%) was calculated within a 1 km radius around each point count site. Gray areas represent 95 % confidence intervals.

In terms of the contribution of explanatory variables (weight of evidence), *distance to water* had a sum of Akaike weight of 0.96 and *noise level* had a weight of 0.73 for resident bird species. For migratory birds, *noise level* had a sum of Akaike weight of 0.79 and *distance to water* had a weight of 0.54. The sum of the weights of other explanatory variables for resident species were: 0.05 - *tree cover*, 0.23 - *impervious surface*, and 0.01- *human population density*, and for migratory species they were: 0.06 - *tree cover*, 0.26 - *impervious surface*, and 0.07 - *human population density* (Fig. 5).

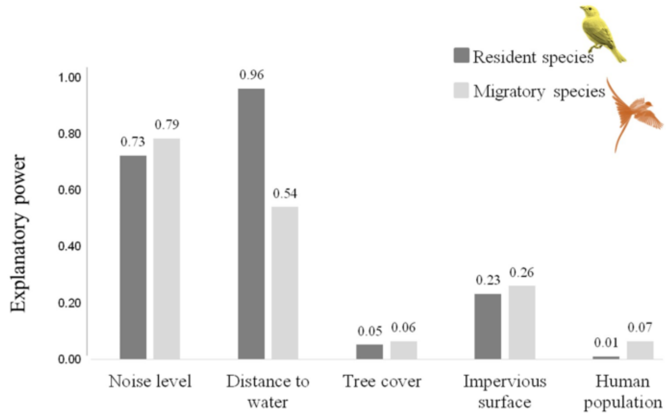

Figure 0-5: Explanatory power of environmental variables in explaining bird species richness in green spaces in the city of São Paulo, Brazil. The weight of evidence (wAIC) is the sum of the weights of the models in which the variable appears

.**Table 1:** Model performance using Akaike´s Information Criterion on multiple regression to explain resident and migratory bird species richness as a function of different environmental variables within green areas in the megacity of São Paulo, Brazil. For the best models (ΔAICc < 2.0), we present AICc - Akaike Information Criterion corrected for small sample sizes, ΔAIC and weight of evidence (wAIC). Explanatory variables measured within a 1,000 m buffer are: Tree cover – percent tree cover; population – human population density; impervious – percent impervious surface (asphalt and concrete); water - distance from the point count site to the closest lake or river; noise – ambient noise level recorded during the point count; null – uncertainty of the relationship between selected variables and species presence.

Response variable	Model	AICc	ΔAIC	df	wAIC
Resident bird species richness	**~ water + noise**	211.34	**0**	**4**	**0.6966**
	~ impervious + water	213.68	2.3	4	0.2171
	~ tree cover + water	216.82	5.5	4	0.0450
	~ impervious + noise	219.34	8.0	4	0.0128
	~ noise	220.16	8.8	3	0.0085
	~ impervious + noise + population	221.14	9.8	5	0.0052
	~ tree cover + noise	221.42	10.1	4	0.0045
	~ population + water	221.79	10.4	4	0.0038
	~ population + noise	222.16	10.8	4	0.0031
	~ impervious	223.86	12.5	3	0.0013
	~ tree cover + impervious	224.98	13.6	4	0.0010
	~ population + impervious	225.86	14.5	4	0.0010
	~ tree cover	226.55	15.2	3	0.0010
	~ tree cover + population	227.26	15.9	4	0.0010
	~ water	227.28	15.9	3	0.0010
	~ null	232.64	21.3	2	0.0010
	~ population	233.43	22.1	3	0.0010

Migratory bird species richness	**~ water + noise**	**117.66**	**0**	**4**	**0.4305**
	~ noise	120.09	2.4	3	0.1281
	~ impervious + noise	120.16	2.5	4	0.1234
	~ impervious + water	120.53	2.9	4	0.1028
	~ impervious + noise + population	121.44	3.8	5	0.0652
	~ population + noise	121.85	4.2	4	0.0531
	~ tree cover + noise	121.97	4.3	4	0.0500
	~ impervious	123.82	6.2	3	0.0198
	~ population + impervious	125.66	8.0	4	0.0079
	~ tree cover + population	125.78	8.1	4	0.0074
	~ tree cover + water	126.57	8.9	4	0.0050
	~ population + water	128.29	10.6	4	0.0021
	~ water	129.02	11.4	3	0.0015
	~ tree cover	129.10	11.4	3	0.0014
	~ tree cover + population	130.49	12.8	4	0.0010
	~ null	130.52	12.9	2	0.0010
	~ population	132.05	14.4	3	0.0010

4. Discussion

Our findings provide mixed support for our original expectations. Contrary to other studies from north-temperate (e.g., Emlen, 1974; Chace & Walsh, 2006; Loss et al., 2009) and South American cities (e.g., Fontana et al., 2011 Leveau, 2013; Pena et al., 2017), avian species richness was only weakly related with tree cover in São Paulo's green spaces. Instead, patterns of species richness in urban parks in the city of São Paulo were best explained by, and negatively related to, distance to water and ambient noise, as shown in prior research in South American cities (Fontana et al., 2011; Pena et al., 2017). To the best of our knowledge, ours is the first study to show that urban Neotropical bird species richness is related to distance to water, but see Faggi and Perepelizin (2006), who found that urban water bodies may contribute to bird species richness in Argentina. Overall, we found little evidence that migratory birds were more sensitive to these variables than residents.

4.1 Urban green spaces as biodiversity refuges

Urbanization can exclude more sensitive bird species (Jokimäki, Jukkab, & Marja-Liisaa, 2018), but small green spaces may serve as refuges for birds within the urban matrix, especially those that are less sensitive to human disturbance (Aronson et al., 2017; Lepczyk et al., 2017; Barbosa et al., 2017). Green spaces within Neotropical urban areas likely play an important role as a refuge for birds in megacities as São Paulo. For instance, in isolated parks we recorded >20% (>30 species) of the total number of bird species that occur in São Paulo (Fig. 1, numbers 26, 5, 7), including 35% (five species) of the number of migratory species that occur in the city.

Species differ in regards to sensitivity to urbanization (Stotz, Fitzpatrick, & Parker III, 1996), and their use of green spaces is related to their traits (Pena et al., 2017). For example, foraging behavior or diet can be decisive to successfully living in the most highly urban areas (Husté & Boulinier, 2011; Pena et al., 2017). Notably, 44% of the bird species we recorded in urban green spaces were insectivorous, which may be related to the greater resilience that certain insectivores display to increasing levels of urbanization (Trollope, White, & Cooke, 2009).

Urbanization may also alter the temporal dynamics of resource availability, influencing bird community composition and dynamics across space and time (McKinney, 2002). Future studies on both the spatial and temporal foraging patterns of birds relative to food resource availability across São Paulo's urban gradient may help explain the patterns we detected.

4.2 The influence of noise level and water proximity on urban birds

We found that occurrence of both resident and migratory birds was well explained by a combination of ambient noise level and distance to water. However, the sum of weights of those models differed between the two groups, with resident species occurrence having a stronger association with distance to water and occurrence of migratory species being more strongly associated with noise level.

Our findings corroborate those of other studies in South America, in which noise was shown to negatively impact bird species richness in urban green spaces (Fontana et al., 2011; Pena et al., 2017). Moreover, a growing body of evidence has shown that acoustic environments or soundscapes can affect the distribution, abundance, and activity of birds (Brumm, 2004; Pena et al., 2017; Narango & Rodewald, 2015). Anthropogenic noise is primarily composed of low frequencies in the 0 to 3 kHz range (Wood & Yerezinac, 2006; Goodwin & Shriver, 2011), such that species that vocalize within this frequency range may be affected by acoustic masking (Narango & Rodewald, 2015; Roca et al., 2016).

Over the long-term, anthropogenic noise can act as a novel selective pressure, potentially favoring habitat generalists over specialists (McKinney, 2002), thereby contributing to low species richness in urban areas. In our study region, more than 12 million people live and work, and roughly 8 million motorized vehicles are on the streets (IBGE, 2018), such that even inside of the parks in the central region of the city, or in *praças* surrounded by avenues, the noise level can reach higher level. The consistently lower bird species richness detected in the city center further suggests that noise level may negatively influence the use of parks by birds.

Similar to noise level, distance to water explained much of resident and migratory bird richness in São Paulo's urban green spaces. The apparent preference of species to be closer to water is not necessarily due to their use of water as a resource; rather, it may be because water supports or ameliorates other physiological demands related to heat and water balance (Karr & Freemark, 1983) or food resource availability (Faggi & Perepelizin, 2006; Leveau, 2018). The heat island effect created by the city of São Paulo (Tarifa & Armani, 2000; Ferreira et al., 2012) is typical of large cities (Trusilova, Jung & Churkina, 2009). Such urban heat may have an indirect effect on birds, impacting the resources they depend upon, such as arthropods abundance and plant growth (Leveau, 2018).

Urban water bodies and green spaces also help regulate a region's microclimate (Bolund & Hunhammar, 1999), which may attract birds seeking a favorable thermal gradient. This may potentially explain species occurrence at Cidade Toronto Park (Fig 2 – number 15), which is surrounded by a high area of concrete, but which has a lake and holds six of the 14 migratory species we detected, and 36 of 49 resident species were detected.

The positive relationship between distance to water and species richness may also be a product of higher food resource abundance for insectivores closer to water (Leveau, 2018). Water is essential for the reproduction of many arthropods, such that water may increase availability of arthropods. Even birds that are not primarily insectivorous often consume arthropods during specific life stages or feed on arthropods as a dietary supplement (Jordano, 2000). In particular, the strong relationship between migratory species richness and distance to water may be related to the dietary ecology of these species, since nine of 14 austral migratory species in our study were insectivores. Indeed, seven of these species are in the family Tyrannidae, a highly insectivorous family (Stotz et al., 1996).

4.3 Responses to urbanization: resident *versus* migratory birds

As opposed to most studies on north-temperate urban bird communities (e.g. Stratford & Robinson, 2005; Rodewald & Bakermans, 2006; Husté & Boulinier, 2011), migratory birds in São Paulo were no more sensitive to urbanization than residents, potentially due to the relatively low habitat specificity that characterizes Neotropical austral migrants (Stotz et al., 1996). In contrast to many migratory birds that breed at north-temperate latitudes, which largely occupy forests, most Neotropical austral migrant bird species more frequently use open and edge-dominated habitats (Chesser, 1994) and may thus be more pre-adapted to urban environments than most migratory birds at north-temperate latitudes. Nevertheless, given that temporal availability of food resources is often dampened in urban *versus* rural environments (Leveau, 2018) and that birds often depend on such surpluses, the temporal homogenization of food resource availability has the potential to negatively impact birds in urban areas (Leveau, 2018).

Results of our study suggest several promising avenues for research on specific ecological, behavioral and physiological mechanisms driving spatio-temporal patterns of avian biodiversity in urban environments. For example: Which mechanisms drive the relationship between avian species richness, noise level and distance to water that we detected? Given that nearly half of São Paulo's rivers are polluted (SOS, 2017), future studies could evaluate the combined impact of distance to water and water quality on the presence of birds in the city across space and time. Why do resident and migratory birds respond similarly to São Paulo's urban landscape? Are there specific life history and ecological characteristics of some groups of birds that make them more or less vulnerable to urbanization in the Atlantic Forest?

5. Conclusions

Variation in avian diversity within São Paulo green spaces was best explained by noise level and distance to water. As such, our findings suggest that managing anthropogenic noise and water resources are two pathways to support bird communities within Neotropical cities. Additionally, given that tree cover had a weak but positive influence on both resident and migratory species richness in our study, maintaining healthy urban forests is important for providing adequate habitat for many urban birds. The maintenance of water bodies and their related vegetation is also essential for creating a bird-friendly city and improving human welfare

(Faggi & Caula, 2017). Indeed, natural areas within the urban matrix have been shown to provide multiple social and psychological benefits for humans, and environmental services such as air purification, regulation of microclimate, and noise level reduction (Bolund & Hunhammar, 1999; Chiesura, 2004). We encourage landscape and city planners to carefully consider the composition and configuration of green spaces within tropical cities to optimize ecological and social benefits. Further research on the relationship between birds and urbanization in the tropics is imperative, given that our results and those of other studies show that tropical birds may be responding to urbanization in unique ways than do birds at north-temperate latitudes.

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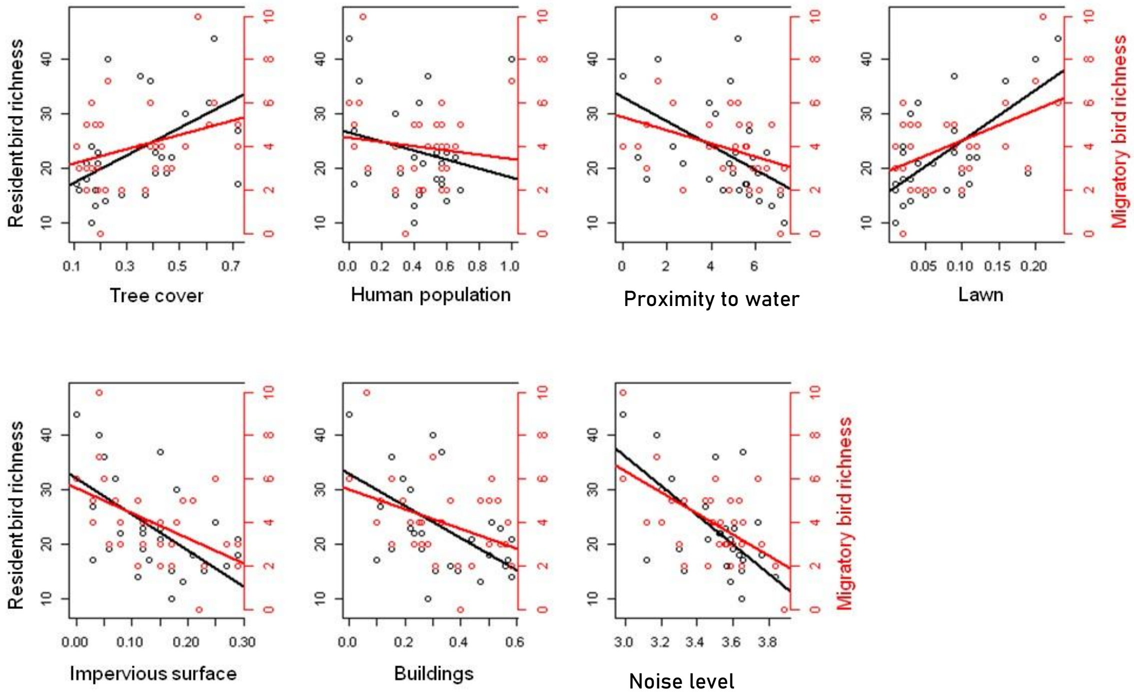
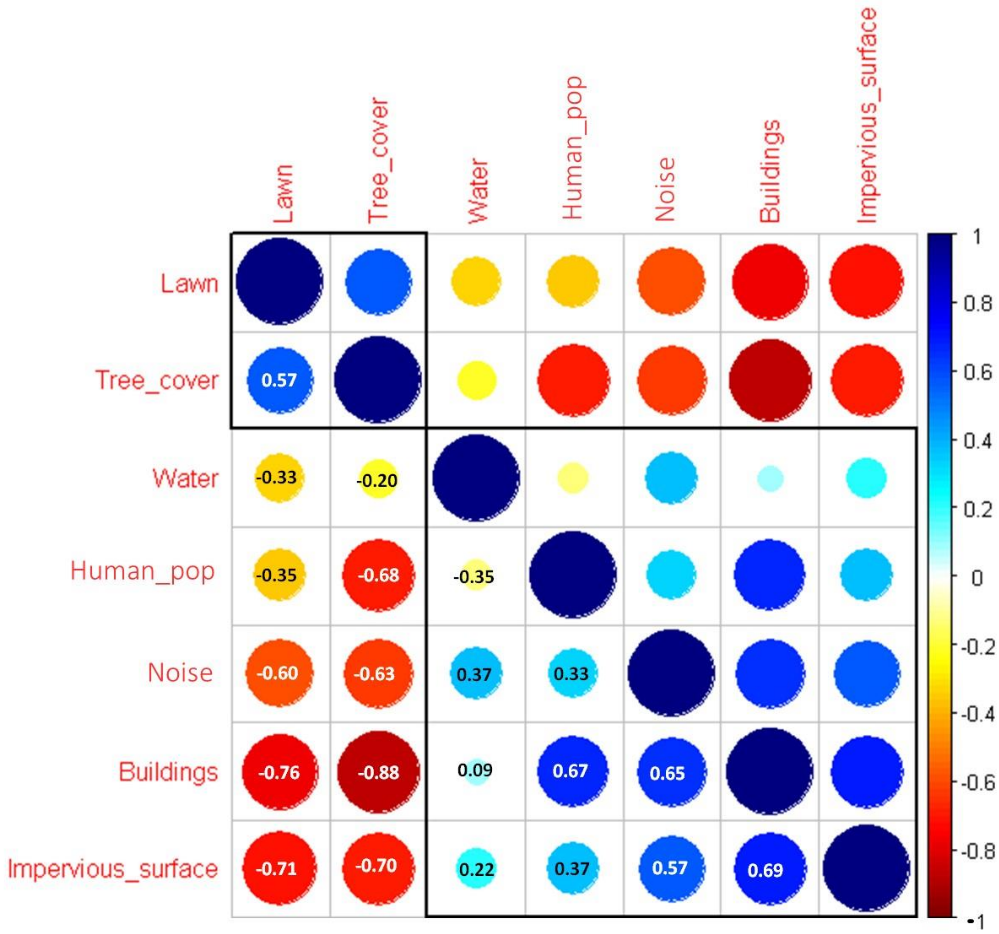
Supplementary material



S1: Variables vs richness of migratory and resident birds - Graphics of variables tendency versus resident and migratory species.



S2: Correlation matrix of variables: **Lawn** – Percentage of lawn, **Tree_cover (veg)** – percentage of cover tree; **Water** - measurement of the distance from the point count until the closest lake or river (selected just primary or secondary river); **Human_pop (pop)** – index of population living inside the buffer (Prefeitura da Cidade de São Paulo – GeoSampa); **Noise** – index of noise in the point count - the average value generated by the cellphone app for each of the three visits and made a weighted average of that value; **Buildings:** percentage of buildings in the landscape; **Impervious_surface** – Percentage of impervious surface (asphalt and concrete areas). We consider the landscape for measure the variables a buffer or 1km from the bird species point count. We collected the noise in the point count using the cellphone app 'Sound Meter' for 1 min, 3 times, during each visit. For collecting these data, we used the same cell phone, by the same person and protocol. We create an index of noise using the average of collected data from each landscape, and the index vary between 19.8 to 48.8.

S3: Selection procedure to choose the best scales of response for each dependent variable: **imp** – percentage of impervious surface (asphalt and concrete areas) in the landscape; **veg** – percentage of tree cover in the landscape; **pop** – index of population living in the landscape. We define scale as the spatial extent of a measured landscape (buffer size), from the point count: 50m, 250m, 500m, 1000m and 2000m.

Residents			
Scales and variables	**ΔAIC**	**df**	**wAIC**
res.imp_500	0	3	0.7677
res.imp_1000	3.3	3	0.1453
res.imp_250	4.7	3	0.0741
res.imp_2000	8.5	3	0.011
res.imp_50	12	3	0.0019
res.veg_1000	0	3	0.67
res. veg_500	2.7	3	0.177
res. veg_l2000	3.5	3	0.114
res. veg_250	6.5	3	0.026
res. veg_50	7.8	3	0.013
res.pop50	0	3	0.27
res.pop250	0.2	3	0.24
res.pop500	0.4	3	0.22
res.pop1000	1.1	3	0.16
res.pop2000	1.8	3	0.11

Migratory			
Scales and variables	**ΔAIC**	**df**	**wAIC**
migra.imp_1000	0	3	0.4074
migra.imp_500	0.7	3	0.2836
migra.imp_2000	1.8	3	0.1638
migra.imp_250	2.2	3	0.1377
migra.imp_50	8	3	0.0075
migra. veg_1000	0	3	0.293
migra. veg_50	0.6	3	0.221
migra. veg_2000	0.6	3	0.218
migra. veg_500	0.6	3	0.213
migra. veg_50	3.3	3	0.055
migra.pop1000	0	3	0.4074
migra.pop500	0.7	3	0.2836
migra.pop2000	1.8	3	0.1638
migra.pop250	2.2	3	0.1377
migra.pop50	8	3	0.0075

Appendix A

Sites and characteristics

Table A1: Green areas visited in São Paulo, Brazil; Pq = Park, Pr = "*Praça*" and St = Street; 'Tree cover' = percent tree cover, 'Water' = distance from the point count to the nearest water body (in meters); 'Noise' = noise index, number of migratory (M) and resident (R) bird species observed, foraging strata (CN – canopy, MI – mid-story, UN – understory, GR – ground and WA – water) and diet (CA – carnivore, FR – frugivore, IN- insectivore, NE – nectarivore and OM – omnivore). Id number refers to the location of 31 point counts in the city of São Paulo, Brazil (Fig. 1).

Id	Site	Tree cover	Water	Noise	M	R	CN	MI	UN	GR	WA	CA	FR	IN	NE	OM
1	Pq Ecológico Tietê 1	0.41	146	36.7	3	19	9	7	2	4	0	2	4	6	2	7
2	Pq Ecológico Tietê 2	0.39	128	33.2	6	36	17	12	7	6	0	3	6	20	3	8
3	Pr AntonioCastroLopes	0.17	10	42.2	6	24	11	7	8	4	0	1	3	15	2	6
4	Pq Tiquatira	0.15	3	43.0	3	18	10	5	4	2	0	0	4	7	2	6
5	Pq Jardim Botânico	0.52	67	24.6	4	30	13	12	4	3	2	3	5	16	2	7
6	Pq Ibirapuera	0.47	356	33.8	3	22	10	5	6	2	2	2	7	9	0	6
7	Pq Aclimação	0.20	3	32.4	5	28	16	7	4	2	4	5	7	13	1	5
8	Pq Independência	0.19	662	35.2	3	23	12	5	6	2	1	2	4	10	0	7
9	Pq Instituto Butantan	0.45	458	27.2	3	19	11	8	1	2	0	2	5	9	1	4
10	Pq Horto Florestal	0.61	50	26.0	5	32	15	7	3	6	6	8	8	13	2	6
11	Pq Cantareira - Engordador	0.57	64	19.8	10	48	26	22	7	2	1	1	14	29	3	10
12	Pq Anhanguera	0.72	264	22.7	4	17	9	8	2	2	0	0	3	12	1	4
13	Pq Cantareira - PedraGrande	0.63	182	19.8	6	44	17	20	8	5	0	2	9	24	2	9
14	Pq Trianon	0.17	1500	38.5	3	10	8	4	0	1	0	1	3	4	1	4
15	Pq Cidade Toronto	0.35	1	38.8	4	37	13	6	7	7	10	8	4	16	2	9
16	Pq Vila Lobos	0.39	50	32.8	4	24	13	6	6	2	1	2	8	9	2	5
17	St Aquário	0.43	2	34.2	4	22	11	4	7	4	0	1	3	11	1	7
18	Pr Amaguas	0.2	1255	48.8	0	8	4	2	1	1	0	0	2	1	1	3
19	Pr Memórias Jaçanã	0.22	488	46.5	2	14	8	4	1	3	0	1	3	3	1	6
20	Pq Luz	0.11	279	38.6	4	17	11	4	4	2	0	0	6	8	0	6
21	Pr Pedro José Nunes	0.19	15	36.0	2	21	8	4	8	3	0	1	3	8	2	5
22	Pq Piqueri	0.15	50	37.8	5	18	12	5	3	3	1	3	5	8	1	6
23	Pq BulerMarx	0.41	160	36.8	4	23	11	10	3	3	0	1	4	12	2	6
24	Pq Nove de Julho	0.23	5	23.8	7	40	15	6	9	7	12	8	4	20	0	11
25	Pq Guarapiranga	0.18	196	27.8	5	16	12	6	2	1	0	1	4	10	1	4
26	Pq Carmo	0.72	300	31.4	5	27	13	8	7	4	2	0	6	13	2	11
27	Pq Água Branca	0.18	834	36.2	5	13	9	6	2	1	0	0	4	9	1	4
28	Pq Juventude	0.15	121	31.8	2	21	10	5	5	3	0	2	5	7	1	7
29	St Vila Constância	0.12	91	35.3	3	16	8	4	5	2	0	0	3	7	2	5
30	Pq USP	0.37	314	27.8	2	15	6	7	3	1	0	0	3	7	1	5
31	Pr Comendador Vargas	0.28	1280	38.5	2	15	8	4	3	2	0	1	3	5	2	3

Appendix B

Bird species registered in the study and their traits

Table B1 – Number of parks where a given species was registered; **strata** – foraging strata: GR – Ground, UN – Understory, MI – Mid-story, CA – Canopy, and WA – Water (adapted from Stotz et al 1996*); **diet** – CA – Carnivorous, FR – mostly frugivorous, IN – mostly insectivorous/consumes arthropods, NE – Nectarivorous and OM – Omnivorous (i.e., frequently use more than two food resources – from del Hoyo et al 2018**); **dist** – Distribution: N – Native, E – Exotic and I – Introduced (species native to other parts of the country that currently are occurring in the city of São Paulo); R/M – Resident or Migratory species in this region, according to Somenzari et al (2017)*** and from observations in the city of São Paulo by ornithologists, and AM – altitudinal migrant (Barçante et al., 2017); **AF** – Atlantic Forest endemic (1) and non-endemic (0); **Sensitivity:** L – Low, M – Medium, and H – High (Stotz et al 1996).

Family	**Species**	**Total**	**strata**	**diet**	**dist**	**R/M**	**AF**	**Sensitivity**
Tinamidae	*Tinamus solitarius*	1	GR	SE	N	R	1	M
	Crypturellus obsoletus	1	GR	SE	N	R	0	L
Anatidae	*Dendrocygna viduata*	4	WA	OM	N	R	0	L
	Amazonetta brasiliensis	2	WA	OM	N	R	0	L
	Anas versicolor	1	WA	IN	N	R	1	L
Cracidae	*Penelope obscura*	1	MI	FR	N	R	0	M
Podicipedidae	*Podilymbus podiceps*	1	WA	IN	N	R	0	M
Phalacrocoracidae	*Nannopterum brasilianus*	5	WA	CA	N	R	0	L
Anhingidae	*Anhinga anhinga*	1	WA	CA	N	R	0	M
Ardeidae	*Nycticorax nycticorax*	2	WA	CA	N	R	0	L
	Butorides striata	3	WA	CA	N	R	0	L
	Bubulcus ibis	1	GR	CA	E	R	0	L
	Ardea cocoi	2	WA	CA	N	R	0	L
	Ardea alba	5	WA	CA	N	R	0	L
	Egretta thula	3	WA	CA	N	R	0	L
Threskiornithidae	*Mesembrinibis cayennensis*	3	UN	IN	N	R	0	M
Cathartidae	*Coragyps atratus*	14	GR	CA	N	R	0	L
Accipitridae	*Accipiter striatus*	2	MI	CA	N	R	0	M
	Rupornis magnirostris	2	CA	CA	N	R	0	L
Aramidae	*Aramus guarauna*	1	WA	CA	N	R	0	M
Rallidae	*Aramides saracura*	2	WA	OM	N	R	1	M
	Pardirallus nigricans	1	WA	IN	N	R	0	M
	Gallinula galeata	4	WA	OM	N	R	0	L
Charadriidae	*Vanellus chilensis*	12	GR	IN	N	R	0	L
Jacanidae	*Jacana jacana*	1	WA	IN	N	R	0	L
Rynchopidae	*Rynchops niger*	1	WA	CA	N	M	0	H
Columbidae	*Columbina talpacoti*	13	UN	SE	N	R	0	L
	Columba livia	19	GR	OM	E	R	0	L
	Patagioenas picazuro	21	CA	SE	N	R	0	M
	Patagioenas plumbea	1	CA	SE	N	R	0	H
	Zenaida auriculata	9	UN	SE	N	R	0	L
	Leptotila verreauxi	4	GR	OM	N	R	0	L
	Leptotila rufaxilla	6	GR	OM	N	R	0	M
Cuculidae	*Piaya cayana*	10	CA	CA	N	R	0	L

	Crotophaga ani	6	MI	IN	N	R	0	L
	Guira guira	2	UN	OM	N	R	0	L
Apodidae	*Chaetura meridionalis*	17	CA	IN	N	M	0	L
	Phaethornis eurynome	2	UN	NE	N	R	1	M
	Eupetomena macroura	12	MI	NE	N	R	0	L
Trochilidae	*Florisuga fusca*	1	MI	NE	N	M	0	L
	Chlorostilbon lucidus	2	MI	NE	N	R	0	L
	Thalurania glaucopis	1	MI	NE	N	R	1	M
Trogonidae	*Trogon surrucura*	1	CA	OM	N	R	1	M
Alcedinidae	*Megaceryle torquata*	1	WA	CA	N	R	0	L
Buccinidae	*Malacoptila striata*	1	MI	IN	N	R	1	M
Ramphastidae	*Ramphastos dicolorus*	4	CA	OM	N	R	1	M
	Picumnus temminckii	5	MI	IN	N	R	1	M
	Veniliornis spilogaster	3	MI	IN	N	R	0	M
Picidae	*Colaptes campestris*	5	UN	IN	N	R	0	L
	Celeus flavescens	11	MI	IN	N	R	1	M
	Dryocopus lineatus	4	MI	IN	N	R	0	L
Falconidae	*Caracara plancus*	7	GR	CA	N	R	0	L
	Milvago chimachima	6	CA	OM	N	R	0	L
	Diopsittaca nobilis	12	CA	FR	I	R	0	M
	Psittacara leucophthalmus	3	CA	FR	N	R	0	L
	Pyrrhura frontalis	3	CA	FR	N	R	1	M
Psittacidae	*Forpus xanthopterygius*	8	CA	FR	N	R	0	M
	Brotogeris tirica	29	CA	FR	N	R	1	L
	Pionus maximiliani	5	CA	FR	N	R	0	M
	Amazona aestiva	10	CA	FR	I	R	0	M
	Rhopias gularis	1	UN	IN	N	R	1	M
	Dysithamnus mentalis	2	UN	IN	N	R	0	M
	Herpsilochmus rufimarginatus	2	CA	IN	N	R	0	M
	Thamnophilus caerulescens	1	MI	IN	N	R	0	L
Thamnophilidae	*Hypoedaleus guttatus*	1	MI	IN	N	R	1	H
	Batara cinerea	1	MI	CA	N	R	0	M
	Pyriglena leucoptera	2	MI	IN	N	R	1	M
	Drymophila ferruginea	1	UN	IN	N	R	1	M
	Drymophila ochropyga	1	UN	IN	N	R	1	M
Conopophagidae	*Conopophaga lineata*	1	MI	IN	N	R	0	M
Dendrocolaptidae	*Sittasomus griseicapillus*	3	MI	IN	N	R	0	M
	Lepidocolaptes angustirostris	2	MI	IN	N	R	0	M
	Furnarius rufus	18	UN	IN	N	R	0	L
	Lochmias nematura	1	UN	IN	N	R	0	M
	Philydor rufum	2	CA	IN	N	R	0	M
Furnariidae	*Certhiaxis cinnamomeus*	2	WA	IN	N	R	0	M
	Synallaxis ruficapilla	1	UN	IN	N	R	1	M
	Synallaxis spixi	4	UN	IN	N	R	0	L
	Cranioleuca pallida	5	MI	IN	N	R	1	M
Pipridae	*Chiroxiphia caudata*	2	MI	FR	N	R	1	L
	Pachyramphus castaneus	1	CA	IN	N	R	0	M
	Pachyramphus polychopterus	1	CA	IN	N	R	0	M
Tyrannidae	*Pachyramphus validus*	1	CA	IN	N	R	0	M
	Tolmomyias sulphurescens	5	CA	IN	N	R	0	M
	Todirostrum cinereum	5	CA	IN	N	R	0	L
	Poecilotriccus plumbeiceps	1	CA	IN	N	R	0	L

	Camptostoma obsoletum	11	MI	IN	N	R	0	L
	Elaenia flavogaster	7	MI	IN	N	R	0	L
	Elaenia sp.	1	CA	IN	N	R	NA	L
	Attila rufus	1	MI	OM	N	R	1	M
	Legatus leucophaius	2	CA	IN	N	M	0	L
	Myiarchus swainsoni	2	MI	IN	N	M	0	L
	Myiarchus ferox	1	MI	IN	N	R	0	L
	Pitangus sulphuratus	29	CA	OM	N	R	0	L
	Machetornis rixosa	4	UN	IN	N	R	0	L
	Myiodynastes maculatus	22	MI	IN	N	M	0	L
	Megarynchus pitangua	12	CA	IN	N	R	0	L
	Myiozetetes similis	8	CA	IN	N	R	0	L
	Tyrannus melancholicus	24	CA	IN	N	M	0	L
	Tyrannus savana	5	CA	IN	N	M	0	L
	Empidonomus varius	18	CA	IN	N	M	0	L
	Fluvicola nengeta	1	GR	IN	N	R	0	L
	Lathrotriccus euleri	5	MI	IN	N	M	0	M
	Cyclarhis gujanensis	21	CA	OM	N	R	0	L
Vireonidae	*Hylophilus poicilotis*	1	CA	IN	N	R	1	M
	Vireo chivi	13	CA	IN	N	M	0	L
Hirundinidae	*Pygochelidon cyanoleuca*	17	CA	IN	N	R	0	L
Troglodytidae	*Troglodytes musculus*	27	UN	IN	N	R	0	L
	Turdus flavipes	3	MI	FR	N	AM	1	M
	Turdus leucomelas	19	MI	FR	N	R	0	L
Turdidae	*Turdus rufiventris*	31	MI	OM	N	R	0	L
	Turdus amaurochalinus	9	UN	FR	N	M	0	L
	Turdus subalaris	2	MI	FR	N	M	0	L
	Turdus albicollis	2	UN	FR	N	R	0	M
Mimidae	*Mimus saturninus*	7	UN	OM	N	R	0	L
Motacillidae	*Anthus lutescens*	1	GR	IN	N	R	0	L
Passerellidae	*Zonotrichia capensis*	13	GR	OM	N	R	0	L
	Setophaga pitiayumi	7	CA	IN	N	R	0	M
Parulidae	*Geothlypis aequinoctialis*	5	UN	IN	N	R	0	L
	Basileuterus culicivorus	6	MI	IN	N	R	0	M
	Myiothlypis leucoblephara	1	UN	IN	N	R	1	M
	Cacicus chrysopterus	1	CA	OM	N	R	0	M
Icteridae	*Gnorimopsar chopi*	1	GR	OM	N	R	0	L
	Molothrus bonariensis	12	UN	OM	N	R	0	L
	Pipraeidea melanonota	2	MI	FR	N	R	0	M
	Tangara seledon	1	CA	FR	N	R	1	M
	Tangara desmaresti	2	CA	FR	N	R	1	M
	Tangara sayaca	30	CA	FR	N	R	0	L
	Tangara palmarum	6	CA	OM	N	R	0	L
	Tangara cayana	1	CA	FR	N	R	0	M
Thraupidae	*Conirostrum speciosum*	1	CA	IN	N	R	0	L
	Sicalis flaveola	2	GR	SE	N	R	0	L
	Volatinia jacarina	3	UN	SE	N	R	0	L
	Tachyphonus coronatus	2	MI	OM	N	R	0	L
	Tersina viridis	1	CA	FR	N	R	0	L
	Dacnis cayana	1	CA	FR	N	R	0	L
	Coereba flaveola	26	MI	NE	N	R	0	L
	Sporophila caerulescens	3	UN	SE	N	R	0	L

	Saltator similis	2	MI	OM	N	R	0	L
	Thlypopsis sordida	3	MI	OM	N	R	0	L
	Spinus magellanicus	1	UN	SE	N	R	0	L
Fringillidae	*Euphonia chlorotica*	4	MI	FR	N	R	0	L
	Euphonia pectoralis	1	MI	FR	N	R	1	M
	Chlorophonia cyanea	1	CA	FR	N	R	1	M
Estrildidae	*Estrilda astrild*	3	MI	SE	E	R	0	L
Passeridae	*Passer domesticus*	9	GR	OM	E	R	0	L

*Stotz et al. (1996). Neotropical Birds: Ecology and Conservation. University of Chicago Press, Chicago.
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***Somenzari et al. (2017). An overview of migratory birds in Brazil. Papéis Avulsos de Zoologia, v.58: e20185803, http://doi.org/10.11606/1807-0205/2018.58.03

CAPÍTULO 2

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ARTICLE

Habitat use and home range of a migratory bird, *Myiodynastes maculatus solitarius*, in an urban park in the Atlantic Forest, Brazil

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Foto: Karlla VC Barbosa – Parque Ecológico do Tietê

Habitat use and home range of a migratory bird, *Myiodynastes maculatus solitarius*, in an urban park in the Atlantic Forest, Brazil

Abstract

Detailed studies on the home range size and habitat use of a species are important for the understanding of population dynamics and density. The Southern Streaked Flycatcher (Myiodynastes maculatus solitarius) is a common, widely distributed austral migrant in Brazil that inhabits open areas, forest edges and urban parks. Surprisingly, very little information exists on even basic aspects of its natural history, and details about its habitat use and home range are essentially unknown. We estimated home range size and habitat selection by M. m. solitarius during the 2017–2018 breeding season at Parque Ecológico do Tietê, an urban park in São Paulo, Brazil. We mist-netted and banded three adult individuals, which were followed for a total of 91 h and 50 min to assess their habitat use and home range. Home range size was 5.40 ± 2.45 ha (95% kernel density) and 2.46 ± 1.70 ha (50% kernel density). We obtained 428 sight records of the three individuals, and the strata most frequently used were the canopy and mid-story, in some places with a relatively high percentage of tree cover. These individuals had a clear preference for forested areas (n = 408), as compared to isolated trees in open areas (n = 20). This study contributes to enhance our knowledge of the natural history of the species and offers important new data on various aspects related to the use of space. These results also suggest that urban green areas promote the occurrence of this species in cities, using urban parks to breed and as stopover sites during migration.

Keywords: behavior, bem-te-vi-rajado, São Paulo, Streaked Flycatcher, urbanization

1. Introduction

The urbanization process may affect migratory bird species in many different ways, since they use different sites through the year for wintering, stopover and breeding (Martin & Finch 1995, Lees & Martin 2015). Moreover, annual variation in urban food resource availability may favor the permanence of resident species and negatively affect migratory species, due to interspecific competition for food and nesting sites (Leveau 2018). For this reason, the structure of urban green areas and heterogeneity of the urban matrix may influence a variety of natural history traits of these species, such as habitat use and home range size.

Home range is the area used by the individual during its daily activities, including foraging and reproduction (Burt 1943, Brown & Orians 1970, Powell 2000), and it is expected that a bird species meets its basic needs within its home range (Hutto 1985). The habitat selection in birds is a behavioral, physiological and ecological response (Cody 1985), which may result in a disproportionate use of habitat, directly influencing its survival (Hutto 1985). However, resource availability for birds in disturbed habitats can be diminished, affecting intraspecific competition (Greenberg 1986), nest predation (Rodewald et al. 2011) and food availability (Kohut et al. 2009).

Research on habitat requirements and behavior of migratory birds has almost exclusively occurred at temperate latitudes (e.g., Dilger 1956, Blake & Karr 1987, Saab 1999, Norris et al. 2004), such that information on even basic aspects of the natural history of most migratory birds that breed in the Neotropics is still scarce. One such species is the Streaked Flycatcher (*Myiodynastes maculatus*), which occurs throughout most of the South and Central America and includes seven subspecies. The southernmost population refers to the subspecies *M. m. solitarius*, which performs poorly-known migratory movements, breeding in southern South America and moving northwards in the fall (Cueto & Jahn 2008, del Hoyo et al. 2018). Plumage and vocal differences indicate that this taxon may represent a valid species (del Hoyo et al. 2018), inhabiting different habitat types across South America, including open second-growth, forest edge and small clearings with scattered tall trees, in rural areas or even in urban parks (Sick 1997, del Hoyo et al. 2018). However, the basic natural history aspects of this species, such as habitat use and home range size, are still poorly known in both natural and urban areas.

In this study, we assessed the habitat use and estimated the home range size of M. m. solitarius during the breeding season in an urban park in São Paulo, Brazil. We aimed to answer three main questions: 1) What is the home range size of the species in urban parks? 2) Does habitat structure influence an individual's home range size? and 3) Does phytophysiognomy influence its foraging behavior?

2. Methods

2.1 Study site

São Paulo is one of the largest and most populous cities in the world (>12 million people), composed of > 50% urban structures (e.g., buildings and impervious surfaces), embedded within the Atlantic Forest ecoregion (Muylaert *et al*. 2018).

Our study was carried out at the Parque Ecológico do Tietê (hereafter "PET"), an urban park located between the cities of São Paulo and Guarulhos (23°29'23"S; 46°31'10"W). The park represents a protected area of Atlantic Forest habitat (APA Várzea do Tietê) embedded in a highly urbanized matrix. According to park administration, the total area of the park comprises 14 million m^2 (1,400 ha), which includes early stage second-growth forests, *Eucalyptus*, and exotic ornamental vegetation, but mainly flood forest (várzea), marshes and lakes. Nearly 300,000 people visit the park each year (DAEE 2019).

We classified the park into three types of areas: A1) Areas formed by partially open vegetation and anthropic structures with relatively high numbers of people and cars, comprised of herbaceous, shrub, arboreous and canopy vegetation strata. The understory is composed secondary vegetation in an initial state of regeneration, such as *Leucaena spp*, *Enterolobium sp*, *Cecropia sp,* Handroanthus *sp, Anadenanthera sp, Bombacopsis sp, Caesalpinia sp, Trema sp, Melia sp, Tipuana sp, Tibouchina sp,* and Schinus sp. In the canopy there are native species and exotics, such as *Schizolobium sp, Chorisia sp*, *Jacaranda sp*, and mainly *Eucalyptus spp* and *Casuarina spp*; A2). This is a corridor attached to a small fragment of forest with vegetation that is beginning to regenerate, with herbaceous, shrub and arboreous strata present. Here, the understory is composed of reforested native, exotic and ornamental species, such as *Tibouchina sp,* Handroanthus sp, Libidibia sp, *Tipuana sp,* Schinus sp, Cedrela sp, *Anadenanthera sp*, *Melia sp*, *Casuarina sp*, *Leucaena sp*, *Ficus spp*, *Croton sp* and *Cecropia sp.*, as well as *Alchornea triplinervia*, which is very characteristic of the shrub stratum; A3) Located in an area of the park with limited public access, this area is mainly comprised of forest with tall trees, dominated by *Eucalyptus spp* and *Casuarina sp*; most of the *Eucalyptus* is dry or dead (JGV, pers. observation). The understory comprises a less diverse, mostly secondary plant community, with such species as *Anadenanthera spp*, *Melia sp*, *Leucaena spp* and Schinus sp. This area is also bordered by a lake.

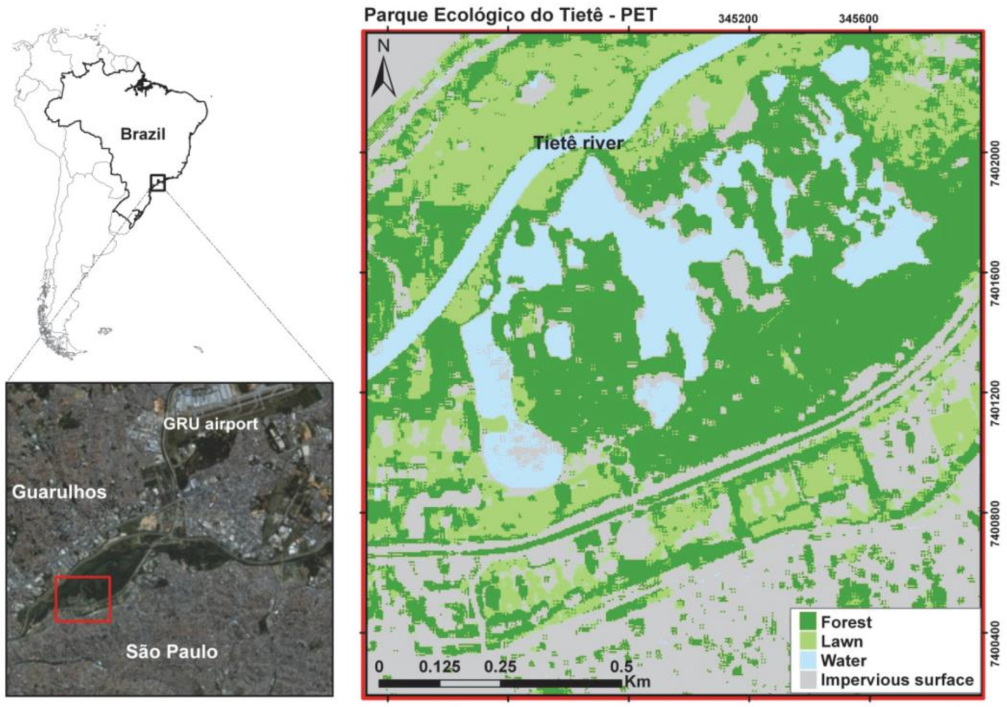

Figure 1. Map of the study area (Parque Ecológico do Tietê – PET) and its landscape components in São Paulo, Brazil.

2.2 Fieldwork

In October 2017, we mist-netted three adult *Myiodynastes m. solitarius*, which were banded with numbered and color bands for individual identification. The focal individuals were designated as A1, A2 and A3. They were followed and observed between October 17, 2017 and January 31, 2018 from 06:30 to 10:30 am, using methods described by Altmann (1974). Each individual was followed during one hour, with its location registered every 10 min with the cellphone app GPS Geotracker. The following information was collected: date, initial and final time of observation, height of the vegetation stratum it was found in (high 15-20 m, middle 8-15 m and low 5-8 m); plant species it was found in; type of environment (forest or isolated tree) it was found in, height of the perch (high 15-20 m, middle 8-15 m and low 5-8 m) and stratum of foraging.

Each sampling day started with a different individual in order to minimize any time-related bias in behavioral measurements. The conspicuous vocal behavior of this species made it easy to locate, and individual identification was made using Tasco (10x42) binoculars.

2.3 Analyses

Estimates of home range of *M. m. solitarius* were performed using kernel density estimation (Worton 1987), which is currently the most reliable and accurate home range estimator (Powell 2000, Jacob & Rudran 2003, Laver & Kelly 2008). We estimated 95% kernel density contours to determine

the total home range and 50% kernel density of each individual, and used smoothing (h) and least square cross-validation (LSCV) (Worton 1987, Laver & Kelly 2008). Analyses were performed using the R 3.4.1 environment (R Core Team
2014) and "adehabitat" assembly packages (Calenge et al. 2009). The taxonomy used here follows the Brazilian Committee of Ornithological Records (Piacentini et al. 2015).

3. Results

3.1 Home range

The mean home range size of the species was 5.40 ± 2.45 ha (95% kernel density) and 2.46 ± 1.70 ha (50% kernel density), described for each individual in Table 1. The largest home range, expressed as the 95% kernel contour was estimated for A1 (8.46 ha) and the smallest was for A3 (2.46 ha; Fig. 2). Home range size varied between months for all individuals, although it was different for each individual (Table 2). The three banded individuals were members of distinct social pairs, and we observed no home range overlap between the territories of each pair. Agonistic encounters were observed between individuals (n = 6), but only at home range boundaries.

Table 1. *Myiodynastes m. solitarius* home range (ha), expressed as 50% and 95% kernel density of three individuals at Parque Ecológico do Tietê, São Paulo city, Brazil. Sd = standard deviation.

ID	50%	95%
A1	1.41	8.46
A2	0.7	5.28
A3	0.35	2.46
MEAN±SD	**2.46±1.7**	**5.4±2.45**

Table 2. Myiodynastes m. solitarius home range (ha) according to 50% and 95% kernel density of three individuals of the species at Parque Ecológico do Tietê, São Paulo city, Brazil.

Id	October		November		December	
	50%	**95%**	**50%**	**95%**	**50%**	**95%**
A1	0	1.03	1.06	5.63	2.28	9.78
A2	0.34	0.68	0.7	3.16	0.33	1.63
A3	0.68	1.7	1.06	4.93	0.65	2.61

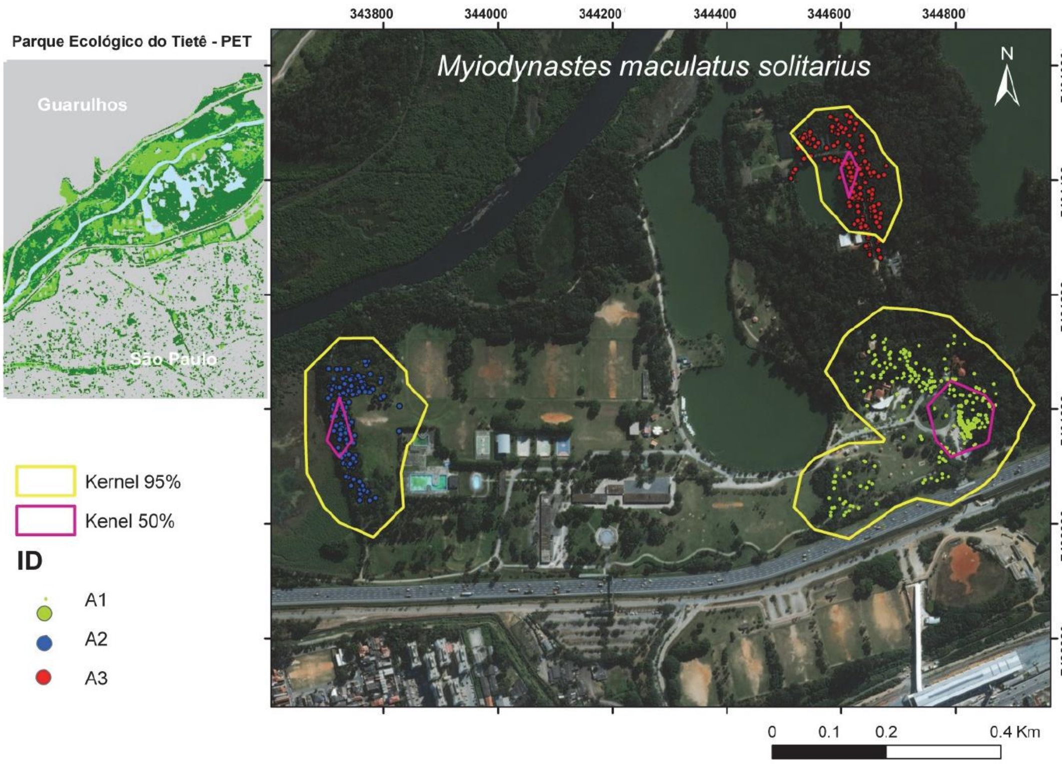

Figure 2. Points within polygons represent georeferenced fixes of observations of each bird during monitoring yellow polygons represent the 95% kernel density contours and pink polygons represent 50% kernel density, at Parque Ecológico do Tietê - SP, Brazil.

During the observation of habitat use, we obtained 428 records of the three individuals. Across records, the high tree stratum was the most used (n = 247 total observations), followed by the middle (n = 141) and low strata (n = 40; Fig. 3). In general, birds were most often observed using perches in the higher strata (high = 171, middle = 177), followed by the low stratum (low = 80; Fig. 4). No individuals were seen foraging on the ground. Considering the substrates or perches selected, the A1 and A3 were similar (high = 11 and 8, respectively), (middle = 4 and 8, respectively) and (low = 5 and 5, respectively). While A2 used low perches in most capture activities (low = 33), followed by middle perches (n = 17). Moreover, in a total of 92 records, 84% of consumed food items were arthropods and 16% fruit. Individuals had a clear preference for forest habitats (n = 408) in comparison to open areas with isolated trees (n = 20; Fig. 5). Most observations in areas with isolated trees were of the A2 pair. The members of the pairs remained together during the entire observation period and we observed breeding activities of the A2 pair, which nested and produced three fledglings (Figs. 6A & 6B).

Figure 6. Banded Myiodynastes maculatus solitarius individuals at Parque Ecológico do Tietê, Brazil. (A) Individual A2, and (B) three

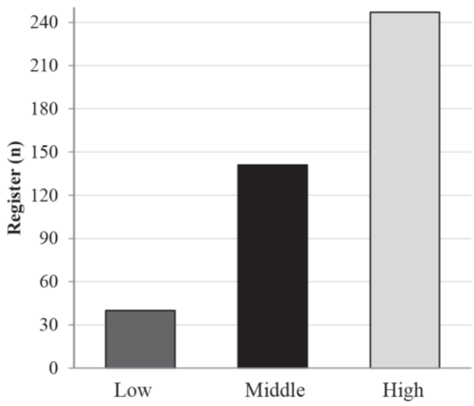

Figure 3. Tree strata used by *Myiodynastes maculatus solitarius* at Parque Ecológico do Tietê, Brazil.

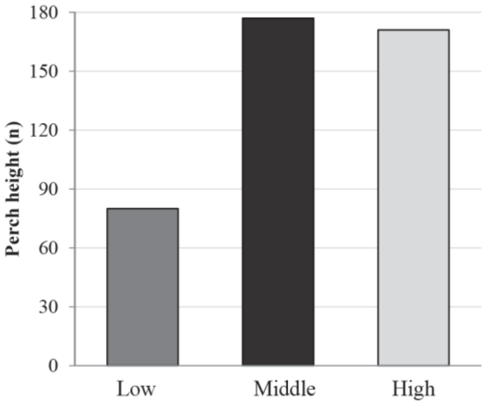

Figure 4. Height of perches used by *Myiodynastes maculatus solitarius* at Parque Ecológico do Tietê, Brazil.

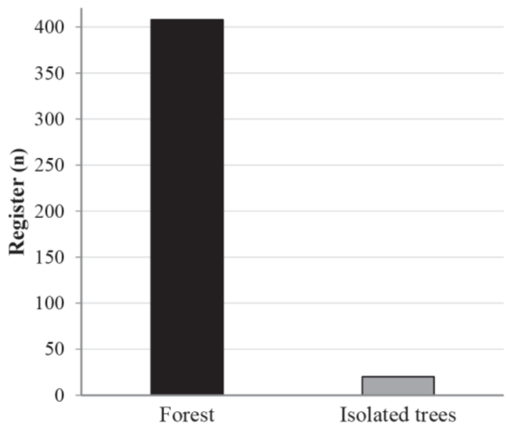

Figure 5. Habitat (forest or isolated trees) used by *Myiodynastes maculatus solitarius* at Parque Ecológico do Tietê, Brazil.

4. Discussion

Information on home range size of birds in South American urban areas are scarce and have been estimated for only a few species (e.g., Marantz et al. 2003, Hansbauer et al. 2008, Hilty 2011). As far as we know, this is the first assessment of the home range and habitat use of *M. m. solitarius* and our findings showed that its home range in an urban area is smaller than those of most Tyrannidae species studied in natural areas (e.g., Ribeiro et al. 2002, Lopes & Marini 2006, Jahn et al. 2010). Additionally, the presence of anthropogenic structures, as well as vegetation homogenization may increase the home range, since we registered M. m. solitarius feeding on fruits and arthropods, and in urban green areas food availability can be affected (Karr 1976, Jokimaki 1999).

Most of the work on home ranges of tyrant flycatchers in South America have been conducted in natural environments. In the rupestrian fields of Minas Gerais, the estimated home range size of *Knipolegus lophotes* (a species smaller than *M. maculatus*), is around 7 ha (Ribeiro et al. 2002) and in the Brazilian Cerrado, two Suiriri Flycatchers (*Suiriri suiriri* and *Suiriri affinis*) have home range sizes of up to 14.0 ha and 11.2 ha, respectively, both species using the canopy more often than other strata in Cerrado forest habitat (Lopes & Marini 2006). Another austral migrant, *Tyrannus melancholicus*, has a home range of 43.0 ± 22.6 ha for males and 45.6 ± 45.5 ha for females in the Bolivian Cerrado (Jahn et al. 2010), and in a mature terra-firme forest in the Peruvian Amazon, the austral migratory species *Legatus leucophaius* has a territory size of ~7 ha (Terborgh et al. 1990). Other studies have found that home ranges in urban environments are smaller than in rural or natural areas (e.g., Roth-II et al. 2008, Chiang et al. 2012) and it can explain the size of home range in our results in comparison with other species of the family. Yet, the underlying mechanisms driving these patterns are still poorly understood, since a variety of interacting factors likely influence home range size in birds, including body size (Terborgh et al. 1990), foraging strategies (Jahn et al. 2010) and food availability (Newton 1979, Chiang et al. 2012), quality and structure of habitat (Chiang et al. 2012), sex and age, breeding period and time of the year (Hansbauer et al. 2008, Jahn et al. 2010).

We detected slight differences between the monitored pairs occupying different habitats, which was reflected in the size of their respective home ranges and in the way individuals used the site. The home range of A1 was more anthropized, and throughout the study this individual increased its home range from 2.31 to 6.84 ha, which is potentially due to its foraging strategy to secure sufficient food (Hansbauer et al. 2008). It was also possibly related to the termination of the reproductive period, after which birds are less restricted to being near the nest site (Hutto 1985). Moreover, the reduced tree cover in A1's home range may have contributed to its larger area. Here, the landscape is partially composed of lawn and buildings near the park entrance, where there is more circulation of people and cars (i.e., the total area of buildings and impermeable anthropic structures occupy 0.81 ha of A1's home range). On the other hand, the landscape in A3's home range was mostly made up of forest with tall trees, including many Eucalyptus and dead trees, with only ~0.24 ha being composed of anthropic structures. In contrast, A2's home range was primarily composed of habitat with higher tree species richness, including native species. Moreover, in this area there are no anthropic structures and the landscape is only composed of forest intersected by a narrow trail, which potentially explains the smaller home range. A2 and its mate were also the only pair that nested and successfully reproduced, producing three fledglings (Fig. 6B).

Studies have shown that breeding birds may reduce their home range size during the egg and nestling stages (Amaral & Macedo 2003, Moraes et al. 2018). Our data refute those results, since in November the area occupied by A2 was larger, when the pair had nestlings and perhaps needed to fly distantly to search for food to feed themselves and their offspring. Although large gaps in information still remain on home range size and habitat requirements of birds in urban parks, most studies to date have found a negative effect of urbanization on breeding birds in urban green spaces, in comparison to those in rural areas (e.g., Bezzel 1985, Jokimaki 1999, Shustack & Rodewald 2010). For example, in an urban park in Ohio, U.S.A., the migratory flycatcher *Empidonax virescens* was negatively affected by urbanization, altering its breeding schedule, such that it nested later and had less time to breed (Shustack &

Rodewald 2010). Insectivorous birds that nest in cavities, such as *M. m. solitarius*, may also be especially affected by the presence of anthropic structures, as shown in a study on two species of the family Muscicapidae: *Ficedula hypoleuca* and *Muscicapa striata* (Jokimaki 1999).

Habitat selection by insectivorous birds is usually related to their ability to find, catch and handle insect prey, activities that can be facilitated in certain types of vegetation structure (Cody 1981). *Myiodynastes m. solita*rius can be found in several different types of habitat, even in more open urban green spaces (del Hoyo et al. 2018). However, the individuals we observed presented a clear preference for forested habitats in our study, since nearly 95% of the records were in places with more tree cover and more complex vegetation structure. On the other hand, the species appears to be adapted to breed in a wide diversity of habitat types, including areas where Eucalyptus is present (Marsden et al. 2001, Pereira et al. 2015). Based on personal observations of other individuals in the study area, we noticed the constant use of Eucalyptus for perching, foraging or nesting by *M. m. solitarius*, normally when the tree is dead and has cavities. In the study area, Eucalyptus are usually taller than other tree species, allowing *M. m. solitarius* that use Eucalyptus to perch and move in higher strata of the vegetation. A1 and A3 showed a clear preference to perch and forage in the middle and higher strata (81% of visualizations), as is typical of the species (e.g., Sick 1997). The complexity of the vegetation contributes to resource availability for birds (MacArthur & MacArthur 1961), especially for insectivorous birds (Karr 1976), with vegetation structure and food supply usually positively related (Karr 1976). In many cases, a species can adapt to characteristics of the landscape changing their behavior and home range (Chiang et al. 2012). Even though *M. m. solitarius* presented some plasticity in terms of its habitat use, our results suggest that the tree cover is important for the species.

The PET is certainly an important breeding habitat for this and other migratory bird species, offering resources absent in other green spaces in São Paulo (Barbosa et al. in prep.). Basic information about a species' ecology, such as home range size and habitat use, provides crucial information to develop effective conservation planning (e.g., Luck 2002, Oppel et al. 2004). Our study contributes to improving our understanding on various aspects of the natural history M. m. solitarius in an urban area in the Atlantic Rainforest, and highlights the importance of urban green spaces such as the Parque Ecológico do Tietê for the conservation of migratory bird species that breed in the region or stopover during migration.

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CAPÍTULO 3

Body condition, sex and urbanization influence breeding-site fidelity of Neotropical austral migrant flycatchers (Tyrannidae) in Brazil

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Body condition, sex and urbanization influence breeding-site fidelity of Neotropical austral migrant flycatchers (Tyrannidae) in Brazil

Abstract

Migratory birds often show high fidelity to their breeding sites, but our understanding of its behavioral and ecological drivers is still lacking, particularly in the case of Neotropical austral migrants, which migrate wholly within South America. We assessed whether breeding-site fidelity is related to sex and habitat type (urban versus rural) in Fork-tailed Flycatcher (nome scientifico pra todos se vai par publicacao) (FtFl) and Southern Streaked Flycatcher (StFl) in Brazil. Between 2013 and 2018, we captured, banded, and made systematic observations of 133 individuals of FoFl and 49 individuals of StFl in different rural and urban areas. Our results revealed higher return rates to breeding-sites in these two species compared to other austral migrants, >23% and >53% in FoFl and StFl, respectively. Return rates were higher in males (FoFl: 37% and StFl: 61%) than in females (23% FoFl and 53% StFl), and were also higher in rural (33% FoFl and 64% StFl) than in urban areas (27% FoFl and 47% StFl). Additionally, we banded a Variegated Flycatcher in an urban green area that returned and nested three times. These results illustrate the influence of demography and habitat on the behavioral ecology of austral migrants. As this field is still poorly understood, we recommend further individual-level ecological and behavioral studies on austral migrants in different habitats, including urban settings. Such research promises a novel perspective on how individual austral migrants perceive their surroundings and can inform conservation initiatives focused on poorly understood migratory species and their habitats.

Keywords: *Empidonomus*, migration, *Myiodynastes*, Neotropical, site-fidelity, *Tyrannus*

1. Introduction

Breeding-site fidelity is a complex and widespread behavior among migratory birds, in which individuals tend to return to the same location every year for breeding (Newton 2008). Along with natal philopatry, adult fidelity to a breeding-site represents a major determinant of the species' geographic distribution and population dynamics (Greenwood 1980), playing a central role in population demographics, social behavior, and mating success (Sedgwick 2004, Brown et al. 2007). It often differs between sexes and ages, usually being more frequent in males and older individuals (Greenwood 1980). Several behavioral and ecological correlates of breeding-site fidelity have been identified, such as habitat quality and reproductive success in the previous season (Greenwood 1980; Bollinger and Gavin 1989; Sedgwick 2004). In general, the main benefit of breeding-site fidelity appears to be an increased familiarity with the physical space and local resources (Brown et al. 2007). Therefore, if a breeding territory contains high-quality resources, it is presumably more advantageous for a bird to reclaim a familiar territory than having to find and defend a new territory (Bollinger and Gavin 1989; Greenwood 1980).

Most current knowledge on breeding-site fidelity in migratory birds is derived from studies on European or North American species and the phenomenon remains poorly documented in the Neotropics. Neotropical austral migration represents an extensive migration system that takes place within South America. About 220 species are known to be part of this migratory system that breed at temperate latitudes, and then migrate north towards the tropics to spend the southern austral winter (Cueto & Jahn 2008). While tyrant flycatchers making up roughly one-third of austral migrants (Chesser 1994), site fidelity has only been documented for a few of them, including *Elaenia parvirostris* in Venezuela (McNeil 1982), *Elaenia albiceps* in Chile (Brown et al. 2007), *Pyrocephalus rubinus* in Bolivia (Jahn et al. 2009), and *Sublegatus modetus*, *Lathrotriccus euleri*, *Phytotoma rutila*, *Griseotyrannus aurantioatrocristatus*, *Knipolegus hudsoni*, *Tyrannus melancholicus* and *T. albogularis* in Argentina (Rumboll et al. 2005, Jahn et al. 2009). Nevertheless, our knowledge on the behavioral and ecological aspects of site fidelity in these species is still lacking.

In this study, based on mark-recapture data we investigated the breeding-site fidelity in three Neotropical austral migratory tyrant flycatchers in Brazil. Our main goals were: 1) to document previously unknown breeding-site fidelity for two species (Southern Streaked Flycatcher and Fork-tailed Flycatcher); 2) to evaluate whether site fidelity is related to individual characteristics, such as sex and body condition, or to habitat type (urban versus rural); and 3) to review information on the behavior and natural history of breeding-site fidelity of three tyrant flycatchers species and propose new avenues for research on site fidelity in the Neotropical austral migrant system. In regard to the second goal, we expect that both individual characteristics (sex and body condition) and habitat type will influence the breeding site fidelity, and that these responses will vary between species.

2. Methods

2.1 Study sites and species

We carried out field surveys in cities of São Paulo State (São Paulo, Guarulhos, Guararema, Jundiaí, Cotia, Marília, Itirapina, and Rio Claro), and in Brasília, Federal District, Brazil (Figure 1). Before extensive land clearing, São Paulo state was covered by several vegetation types of Cerrado and Atlantic Forest biomes. As a result of intensive habitat clearing for agriculture, pasture and urban expansion, the landscapes became highly fragmented, with low natural vegetation coverage, with small, isolated remnants and severe edge effect (Ribeiro et al. 2009). São Paulo city has the highest population in the country, with more than 12 million inhabitants and covers a vast area merging with nearby cities (e.g., Guarulhos and Cotia). Our other study sites, Marília, Guararema, Itirapina, and Rio Claro, are smaller with under 400,000 inhabitants. In Brasília, the landscape is primarily composed of mowed lawns and disturbed Cerrado grassland. The greater Brasília metropolis has almost 2.5 million inhabitants.

We studied three New World flycatchers (Tyrannidae) that are Neotropical austral migrants (Cueto & Jahn 2008): Southern Streaked Flycatcher (*Myiodynastes maculatus solitarius*, StFl), Variegated Flycatcher (*Empidonomus varius*, VaFl) and Fork-tailed Flycatcher (*Tyrannus savana*, FoFl). StFl inhabits semi-open areas and edges of secondary forests, semi-deciduous forest, or clearings with scattered tall trees, where it nests in cavities (Fitzpatrick et al. 2004). It can also be found in urban green areas and has a home range of about 5.4 ha (Vitório et al. 2019). VaFl has a similar habitat requirement and inhabit the edges of primary forests, secondary growth forests and forest clearings, open savanna with scattered bushes and trees, and sometimes urban parks (Fitzpatrick et al. 2004), where they usually build their nests in forks of small branches. Both species has similar plumage, are sexually monomorphic, but differ in body length and mass (StFl: 191 mm, 49g and VaFl: 171 mm, 26 g – Rodrigues, et al. 2019) and have. FoFl (300 mm and 30g) inhabits open terrain, especially pastures and savannas with scattered trees and bushes, lawns, and residential areas (Fitzpatrick et al. 2004). They often nest on small tree branches (Marini et al. 2009). It is one of the most common and widespread flycatchers in Brazil, breeding in the southern parts of the country (Fitzpatrick et al. 2004; Bejarano and Jahn 2018). The species exhibits sexual dimorphism in tail length, with males having longer tails than females.

StFl was studied in two rural and five urban locations within the city São Paulo and five other cities of the state (four rural and an urban), while VaFl was studied in an urban green space in the city of Guarulhos, in the metropolitan area of São Paulo. FoFl was studied at Estação Ecológica de Itirapina (hereafter, Itirapina), a rural, protected area near the small town of Itirapina, state of São Paulo, and in urban green spaces in the city of Brasília.

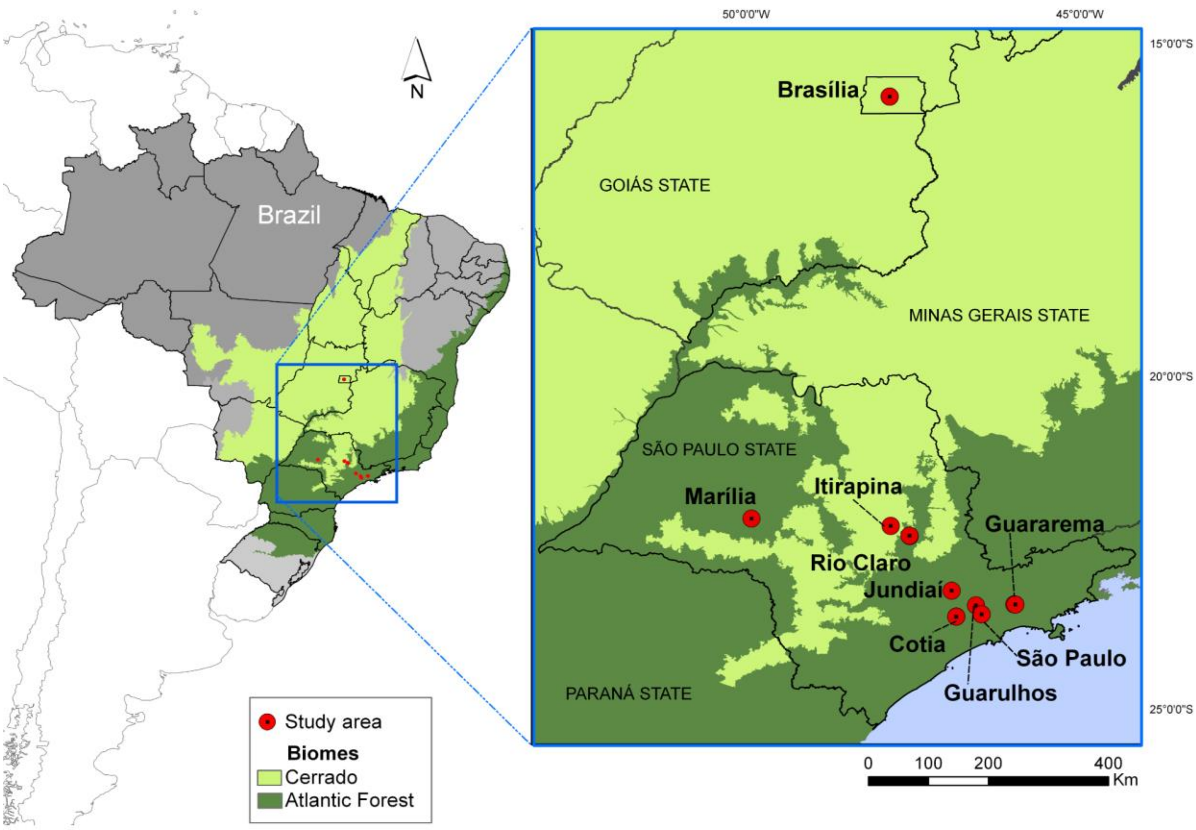

Figure 1: Brazilian cities where the 49 Southern Streaked Flycatchers, 133 Fork-tailed Flycatchers and one Variegated Flycatcher were captured.

2.2 Bird captures and monitoring

We captured birds during the breeding season (August to January) from 2013 to 2018, using nylon mist-nets (12 m and 18 m x 2.6 m, with 36 mm and 38 mm mesh size). We marked the birds with numbered metal bands (CEMAVE) and color Darvic bands for individual identification. We measured culmen and tarsus length, and body mass (data available in Rodrigues et al. 2019). We sexed StFl using DNA collected from blood samples and FoFl based on the shape of the notch of the 8^{th}, 9^{th} and 10^{th} primaries (Pyle 1997).

From 2016 to 2018, we used a portable speaker placed within a meter of the mist net, emitting calls of conspecifics to attract StFl and VaFl to a mist net inside their territory, using a. To increase the chances of attracting and capturing StFl, we set up a mist-net 8 m high and placed a model StFl, along with a portable speaker emitting StFl calls close to the mist net (Barbosa et al. *in prep*). FoFl was captured from 2013 to 2016 using one to three mist nets, set within 2 m of nests.

Banded individuals were searched for up to 300 m from the original point of capture, from sunrise (~6 am) to 10:00 am during the breeding season following the season in which they were originally banded. Searches were made throughout the subsequent breeding season using binoculars, and at times carrying a portable speaker emitting conspecific calls. We visited Each study site at least twice during the breeding season to monitor nests and noted whether both members of the couple were banded. Additionally, we define a return as a bird that was recaptured or observed at least once after initial capture in a subsequent breeding season within 1 km of the original capture site.

3.3 Analyses

We calculated the scaled mass index (SMI – fom here called as body conduction) following Peig and Green (2009) in order to quantify body mass relative to body size, using the equation of the linear regression of log-mass on log-length. For the calculation of this equation, we first tested which measures (tarsus or culmen) have a higher correlation with body mass, by sex. We found that culmen for females and tarsus for males of StFl, and tarsus for both sexes of FoFl had the best fit. Some individuals of FoFl lacking these data were excluded from the analyses (two in Brasília and six in Itirapina) since we have no all measures.

Using R program we used χ^2 test to evaluate differences in return to site according to sex and habitat at the significance level of 0.05. We used a generalized linear model (GLM) for assess if bird returns (0 = no return, 1 = return) to site were related to body condition, sex or habitat, and ANOVA to analyze the differences between groups. When sex was found significant, we fitted independent regression curves to evaluate the influence of body condition (SMI) on the probability of return, also including the confidence intervals of fitted models.

3. Results

We captured and banded 49 StFl (15 females, 23 males, and 11 of unknown sex) and one VaFl of unknown sex in São Paulo State, and 133 FoFl in São Paulo State and Brasília (66 females, 67 males, and one of unknown sex – Figure 1). we did not study breeding behavior, we recorded only opportunistic data from nests that we found. We recorded eight nests of StFl (three with successful fledging), one nest of VaFl (two consecutive years of successful breeding) and 26 nests for FoFl in Itirapina (Table 1).

Table 1: Study sites, site characteristics and migratory birds observed. Biome: AF – Atlantic Forest, C – Cerrado; Sex: F – female, M – male and U – unknown; site-fidelity – 1- returned and 0 - did not return. Species: StFl – Southern Streaked Flycatcher, FoFl – Fork-tailed Flycatcher and VaFl – Variegated Flycatcher

Species	**city**	**state**	**lat**	**long**	**Biome**	sex			habitat		site-fidelity	
						F	**M**	**U**	**R**	**U**	**1**	**0**
StFl	Jundiaí	SP	-23.22354	-46.91776	AF	0	0	1	1	0	0	1
StFl	São Paulo	SP	-23.48587	-46.51888	AF	15	9	8	4	28	16	16
StFl	Rio Claro	SP	-22.39692	-47.54734	C	3	2	2	1	6	4	3
StFl	Guararema	SP	-23.42939	-45.97655	AF	2	2	0	3	0	2	2
StFl	Cotia	SP	-23.60802	-46.84689	AF	1	3	0	0	3	2	2
StFl	Marília	SP	-22.13899	-49.91397	AF	0	1	0	1	0	1	0
FoFl	Itirapina	SP	-22.24960	-47.82818	C	38	37	1	76	0	26	50
FoFl	Brasília	FD	-15.79639	-47.84389	C	25	30	0	0	58	15	43
VaFl	Guarulhos	SP	-23.4428	-46.55327	AF	0	0	1	0	1	1	0

3.1 Breeding-site fidelity

Among 49 banded StFl (15 females; 23males and 11 unknown), 25 (51%) returned in the subsequent years, eight females (53%), 14 males (61%), and 3 unknown, with no significant difference between the sexes (X^2 = 2.61, df = 3, p-value = 0.45 - Figure 2). Among these, two females and one male returned in two different years after banding. One banded female in a rural area was observed two years after banding, 1 km from the capture site. Her partner returned to the original capture site for two years after capture and was seen accompanying other females. We found nests or fledglings at all study sites (13) in São Paulo state, and at least five banded individuals reproduced successfully, including one in Piqueri Park, a small (10 ha) urban green area =.

Among 133 FoFl banded in Itirapina and Brasília (66 females, 67 males and 1 unknown), 41 (30%) returned in the subsequent years. Fifteen of these were females (29%), 25 males (60%), and one unknown, with a significant difference between the sexes (X^2 = 19.34, df = 3, P = 0.0002). Among 75 FoFl banded at Itirapina, 15 of the resighted individuals nested at the site in the previous year, but only four bred successfully.

3.2 Urban versus Rural

We banded 38 StFl in urban green spaces and 11 in rural areas in São Paulo State, of which 18 returned to urban areas (47% return rate), and seven to rural areas (64%), showing a significant difference (X^2 = 13.56, df = 3, P = 0.004 - Figure 2). We banded 68 Fork-tailed Flycatchers in urban green spaces in urban Brasília of which 15 (27%) returned and 75 in rural Itirapina,), with 25 (33%) returned, showing a significant difference (X^2 = 18.09, df = 3, P = 0.0004).

3.3 The effect of body condition on site fidelity

Body condition was not significantly related to the probability of returning to the breeding site in either species (FoFl: deviance = 3.66, df = 123, P = 0.06; StFl: deviance = 0.14, df = 36, P = 0.71). For StFl that returned, body condition was significantly different between the sexes (deviance = 0.24, df = 20, P = 0.02) and significantly related to habitat type (deviance = 7.61, df = 20, P = 0.01). On the other hand, breeding-site fidelity of FoFl was not significantly related to body condition and sex (deviance = 0.08, df = 35, P = 0.77), but it was for body condition and habitat (deviance = 7.91, df = 35, P = 0.01), the body condition of FoFl was higher in Itirapina compared to Brasília (Figure 4).

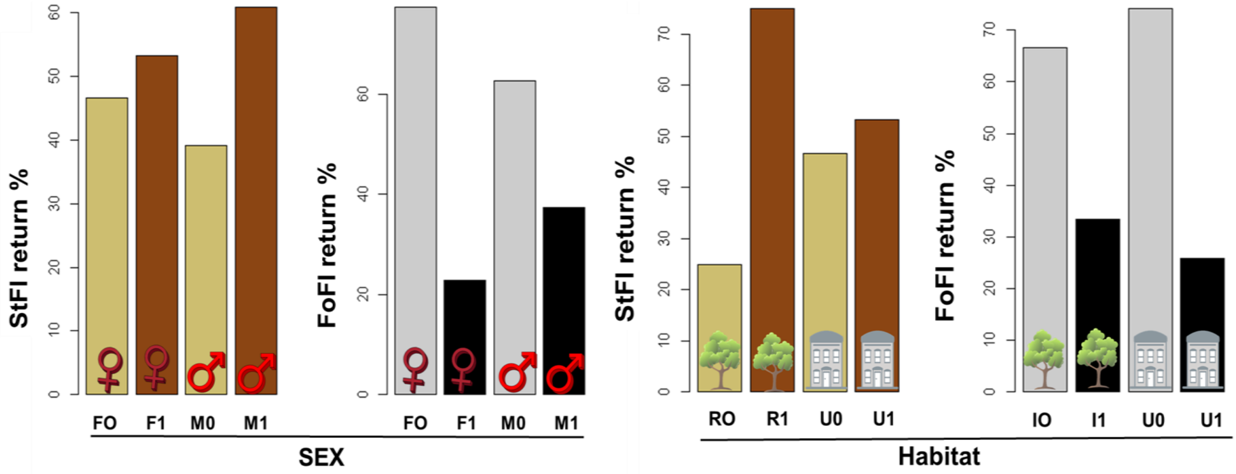

Figure 2: StFl – Southern Streaked Flycatcher and FoFl – Fork-tailed Flycatcher sex (male – M and female – F) and habitat (R/I – Rural/Itirapina Protected area and U – urban area) differences in return rates to the breeding-site: 1 – Return and 0 –

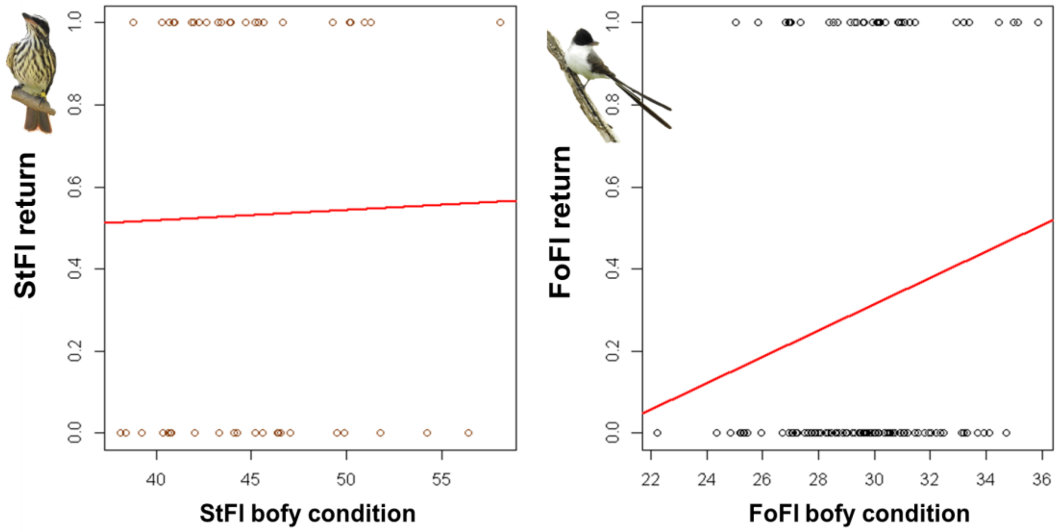

Figure 3: StFl – Southern Streaked Flycatcher and FoFl – Fork-tailed Flycatcher body condition (SMI) in relation to return rates to the breeding-site: 1 – return and 0 – no

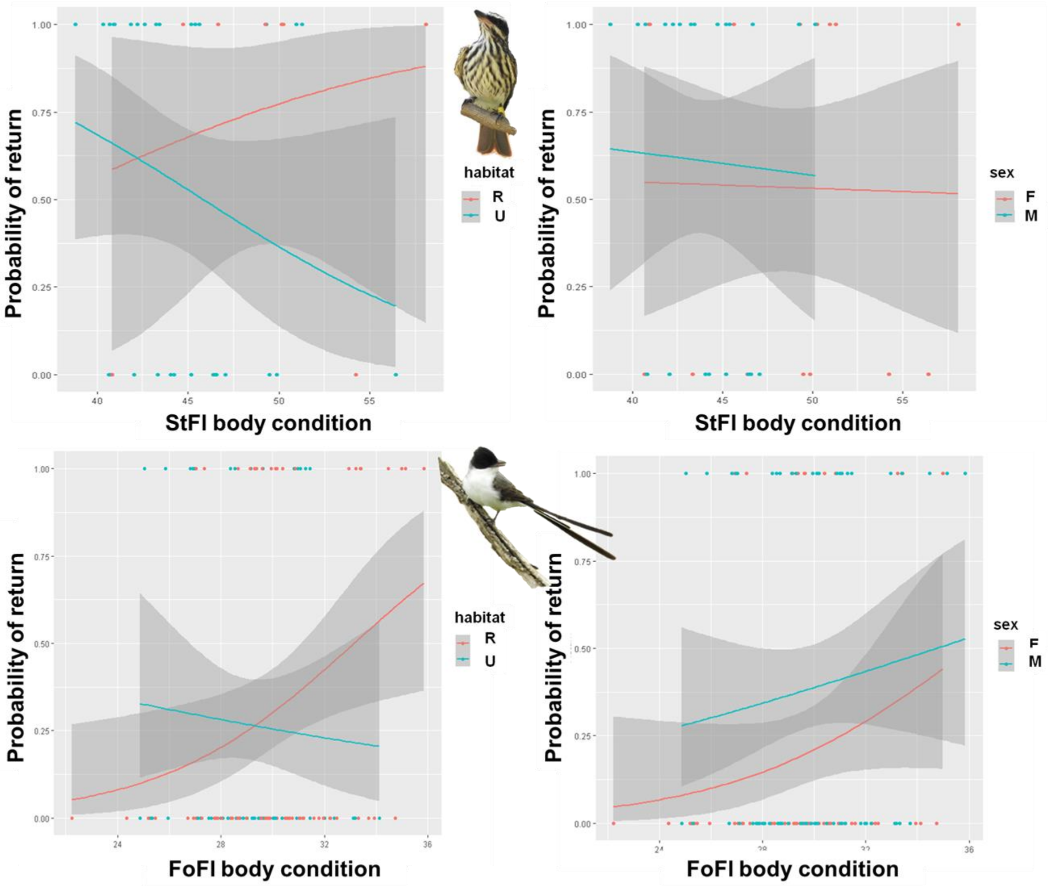

Figure 4: StFl – Southern Streaked Flycatcher and FoFl – Fork-tailed Flycatcher body condition (SMI) relate to return rates to the breeding-site and sex (F – female and M – male) or habitat (R – Rural/Itirapina Protected area and U – urban area)

4. Discussion

Site fidelity (either wintering or breeding fidelity) has been documented for only 10 Neotropical austral migrants (McNeil 1982; Rumboll et al. 2005; Brown et al. 2007; Jahn et al. 2009), even though more than 220 species are known to perform these migratory movements within South America (Chesser 1994, Somenzari et al. 2018). Ours was the first study showing breeding-site fidelity for Fork-tailed Flycatcher and Streaked Flycatcher, and the first evidence of this phenomenon among Neotropical austral migrants in Brazil.

The return rates observed in our study species (StFl 53-61%, FoFl 29-60%) were higher than those reported for other austral migrants. In a study conducted in Argentina, the return rates for seven migrant species were <10% (Jahn et al. 2009). Other studies also showed lower return rates in comparison to our results, 11.41% for White-crested Elaenia (*Elaenia albiceps*, Brown et al. 2007) at a breeding site and 9.3% for Small-billed Elaenia (*E.*

parvirostris, McNeil 1982) at a wintering site. The relative high return rates of StFl and FoFl in Brazil presented here may be due to fact that few previous studies used color marking and in this study, we intensively searched for the color-banded individuals in subsequent seasons.

In studies conducted in the north-temperate region, the breeding-site return rates of flycatcher species were higher and in some cases, similar to those of our study. In North America, 52.0% of Willow Flycatcher (*Empidonax traillii*) males and 51.3% of females returned (Sedwick 2004), whereas in Spain, the return rates of European Pied Flycatchers (*Ficedula hypoleuca*) were 53% for males and 42% for females (Kern et al. 2004). Return rates of other families of Nearctic-Neotropical migrants varied between 30 and 40% (Wunderle Jr. and Latta 2000). These high rates could be explained by higher site faithfulness, however they could also be related to the high searching effort.

For most migratory passerines, return rates are positively age dependent (Gauthreaux 1982), possibly due to the high mortality of juveniles, or even competition with adults, or more likely, high rates of juvenile dispersal (Greenwood 1980). The fact that none of the three juvenile StFl we banded returned to their hatching site suggests a similar high juvenile dispersal and/or mortality rate, which calls for further research.

4.1 Males vs. females and nesting behavior

We found that breeding-site fidelity was higher in males than females, and although for StFl the difference was not statistical significant, the percentage of males was higher than females, similar to other passerines (Bollinger and Gavin 1989; Hoover 2003; Sedwick 2004). The proximate causes of sex-dependent differences in return rates are mostly unknown, but are likely associated with the different roles of males and females during the breeding season. Males defend and establish territories, while females are often more flexible in their selection of breeding-sites and mates (Greenwood 1980). Nonetheless, females can return to the same nest site, even when their previous social mates are currently paired with another female (Sedwick 2004). None of the five pairs of StFl we banded remained together for subsequent seasons.

We found only eight nests of banded StFl, and for three of them belonged to parents that returned after successfully breeding in previous years. We also observed the breeding behavior of FoFl with possible importance for their population dynamics. Among the five FoFl that reproduced successful in the previous season, four returned to the same nesting area and kept their social mate. We also observed that those that returned after a reproductive failure in the previous season (mostly males) moved to a different breeding territory and paired with a different mate.

Overall, our results suggest that breeding success is not a determining factor driving the return rate of FoFl, and site fidelity could be an adaptive response (e.g., Sedgwick 2004). Previous studies show that breeding-site fidelity is higher for Willow Flycatchers that successfully reproductively previously (61.9%) compared to unsuccessful individuals (38.5%) (Sedgwick 2004). Similarly, in Ovenbirds (*Seiurus aurocapillus*), return rates of males are not due to previous reproductive success (Porneluzi, 2003). However, future research should consider sex-related breeding outcomes as the responses in terms of site fidelity could be sex-dependent (Šimek 2001; Sedgwick 2004).

4.2 Habitat quality

In general, habitat quality affects if an individual is going to return to a breeding site (Bollinger and Gavin 1989). For StFl, return rates were higher in rural as opposed to urban areas, similar to FoFl. A potential explanation for this is that urban green spaces may be less connected and are often located within a matrix that is less permeable compared to surrounding rural areas (Shimazaki et al. 2016). Thus, unless an individual enjoys high breeding success in a small urban green space, which typically have low-quality habitat (Bollinger and Gavin 1989), it may be disadvantageous to return to such a site, with fewer options in terms of foraging and nest defense compared to a rural territory. Second, urban sites may fill up more quickly than rural sites. For example, Piqueri Park, located in São Paulo city is 10 ha large, and we found only two pairs of StFl there during three years of monitoring, supporting previous research showing that StFl requires 5.4 hectares of habitat to breed (Vitorio et al. 2019; Barbosa et al. *in prep*). These urban birds may therefore be more limited than rural birds in their ability to acquire potential breeding-sites. This could influence return rates, especially if all potential territories are already occupied.

Migratory species that breed in urban areas may have a different set of decision rules about returning than those in rural areas, especially if nest predation levels are higher in urban sites (Rodewald and Shustack 2008). Protected areas, such as Itirapina or Parque da Cantareira, may provide better breeding conditions, given a presumably lower predatory pressure compared to small urban parks, where domestic cats and other invasive predators are prevalent.

4.3 Body condition

We found that body condition is a key factor determining return rates of migratory birds, and can be related to sex and habitat. Individuals in rural areas (including protected sites) had higher body condition than those in urban areas. Additionally, FoFl females that returned were in significantly better body condition, whereas in StFl there was no significant difference between sexes. In a North American study, female were also in marginally better condition than males, but their condition was not related significantly to urbanization or interaction between urban habitat and sex (Rodewald and Shustack, 2008).

In Costa Rica, mass and body condition were positively related with the return rates in the wintering area of the Northern Waterthrush (*Parkesia noveboracensis)*, a Nearctic-Neotropical migratory songbird; (Warkentin and Hernández 1996), suggesting that individuals that are in better condition have higher interannual survival rates and a higher chance to return to maintain their winter territories. Species with high interannual site fidelity may be less able to adapt to habitat degradation and loss (Warkentin and Hernández 1996). As the distance between patches of suitable habitat continues to increase, these species tend to decline more. Even returning to the same general region may not lead to the discovery of new, suitable habitat, resulting in decreased survival, particularly among habitat specialists. Better body conduction in rural areas may be related to adequate food resources, and the previous "familiarity" with a place saves on unnecessary reproduction costs (Switzer 1993).

4.4 Natural history notes

This study contributes new information about the natural history of three poorly studied Neotropical austral migratory flycatchers. Both sexes of StFl and VaFl defend their territory aggressively from conspecifics, which facilitated our ability to capture birds. We developed a novel way to capture StFl (Barbosa et al. *in prep*), which allowed banding nearly equal numbers of males and females (23 vs 15, respectively).

We also banded a Variegated Flycatcher (*Empidonomus varius*) in Guarulhos city (São Paulo State) that nested in the same tree for three years (including the year we banded it). The flycatcher built the nest in the tree on the sidewalk and bred successfully. Urban green areas can provide habitat for many resident and migratory species (Barbosa et al. 2020) and this species has been observed using small urban green areas (5 hectares) even in cities as big as São Paulo (Barbosa et al. *Chapter 4*). However, urban parks usually have a reduced number of old or dead trees that can provide nesting cavity for StFl potentially decreasing their breeding success (Cockle et al. 2017). Streaked Flycatcher can nest in a wide variety of cavities, including those in palm trees and gourds (Cucurbitaceae), in nests built by Rufous Hornero (*Furnarius rufus*), as well as in artificial nests offered by people.

We also found FoFl nesting on a lamp post near train tracks. Although we do not know their breeding success and cannot rule out the possibility that these urban sites represent an ecological trap, these preliminary observations suggest that these species are flexible in adapting to urbanization. Indeed, numerous other bird species are found within green spaces of the mega-city of Sao Paulo, especially near water, suggesting that certain components of that urban landscape are more favorable to birds (Barbosa et al. 2020).

Additionally, we observed a pair of FoFl which, after failing to breed, separated and appeared to seek new territories and new mates to breed with. Such records are rare for passerines, as the separation of a pair generally occurs because of the death of an individual (Beheler et al. 2003). Future studies with regard to the dynamics of monogamy vs. polygamy in Neotropical austral migrants are needed.

5. Conclusions

Two Neotropical austral migratory flycatchers showed breeding-site fidelity, with higher rates in males vs. females. Moreover, individuals with better body condition and those in rural areas had a higher return rate. Such results provide useful information to improve the management of urban parks by making them more bird-friendly. Systematic studies of Neotropical austral migrant species in the future will go a long way to improve our understanding of the patterns and underlying drivers of return rates in this system.

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CAPÍTULO 4

The potential for citizen science to contribute to research and conservation of birds in Brazil

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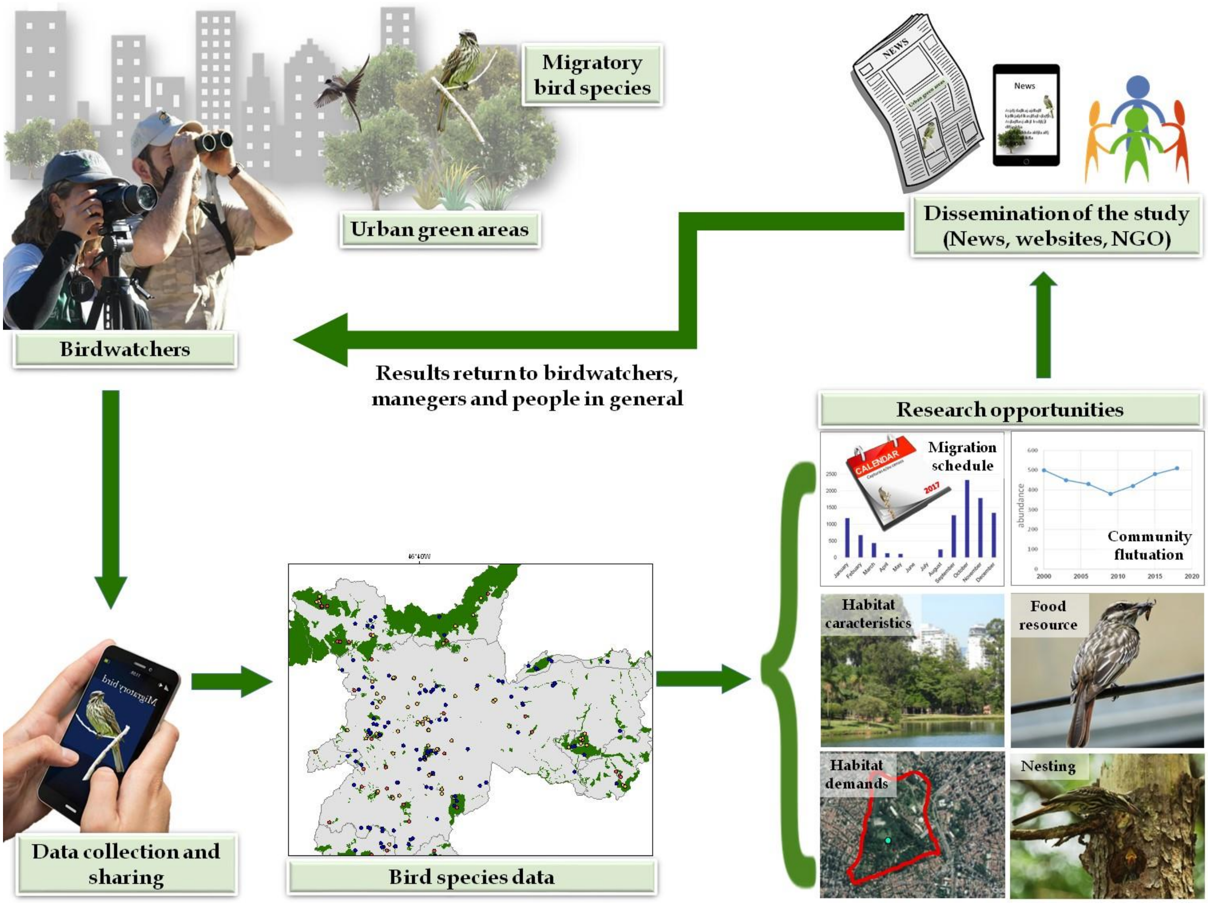

The potential for citizen science to contribute to research and conservation of birds in Brazil

Abstract

For ages, the wide variety of colors, shapes, and behaviors in birds have attracted the attention of professional ornithologists and nature observers alike. Birdwatching represents a potential source of data on many aspects of bird biology in Brazil, a highly biodiverse country. We reviewed the current state of citizen science with regard to Brazilian birds by evaluating where, how much, and what kind of data is collected by birdwatchers. To highlight the potential of such data, we used citizen science data to evaluate the migration timing and habitat occupancy of four migratory bird species whose movements are still understudied. We also suggest new avenues for citizen science-based research on migratory bird ecology in Brazil. Finally, given that the urban ecology of numerous Brazilian birds is still poorly understood, we highlight how this can be remediated through the efforts of birdwatchers, 73% of which are concentrated within or nearby large urban centers in the southern and southeastern Brazil. Our results show that data generated by citizen scientists can be useful for a suite of applications, such as habitat use and migration patterns of Brazilian birds. We conclude that citizen science can be a useful tool to improve our knowledge about Brazilian birds and promote their conservation in an era of rapid change. Nevertheless, its impact in the long term will depend on improving the quality of the data and involvement of more birdwatchers.

Keywords: Birdwatching, *Empidonomus*, *Myiodynastes*, *Pyrocephalus*, *Tyrannus*, Tyrannidae.

1. Introduction

Birds are one of the most-visible and best-studied taxonomic groups on the planet. Their wide variety of colors, shapes, and behaviors have long attracted the attention of both ornithologists and nature observers. Given the rapid growth of birdwatching as a hobby, especially in Latin America and Asia, data from birdwatchers have the potential to substantially contribute to ornithological research across various habitats and regions over long timespans (Bhattacharjee 2005). Citizen science can also contribute to advance the engagement of laypeople with the environment, and citizen scientists can serve as a remarkable resource, especially where ornithologists are scarce and field research is costly (Hurlbert and Liang 2012; La Sorte et al. 2017; McKinley et al. 2017). Bird occurrence data from citizen science websites, such as eBird, can be as valuable as that collected by professional ornithologists and can help identify new avenues for research (Coxen et al 2017).

Data collected by birdwatchers have been used across the globe to understand biological and ecological patterns, such as species distribution and abundance patterns (Hochachka et al. 1999), impacts of human activities (La Sorte et al. 2017), migration patterns (Hurlbert and Liang 2012; Tryjanowski et al. 2013; La Sorte et al. 2017; Gillings et al 2019), to evaluate the impacts of conservation actions (Sullivan et al. 2017; McKinley et al. 2017), and the effects of urbanization on birds (McCaffrey 2005; Tejeda and Medrano 2018). In general, birdwatchers collect data in areas that are easy to access, such as urban green areas (Tulloch et al. 2013). Notably, large cities concentrate a higher number of birdwatchers, who can contribute to a better understanding of how bird species respond to constantly changing urban environments (Ryder et al. 2010; Callaghan et al 2017). Citizen-science data can also aid urban wildlife managers identify important sites for birds within cities (McCaffrey 2005).

Neotropical cities are growing rapidly, invading native habitats and generally conserving only small green areas. Brazil is the largest and most biodiverse country in the Neotropics, with almost 200 migratory bird species (Somenzari et al 2017). Most of Brazil's 211 million inhabitants live in the southern and southeastern regions of the country, where urbanization, economic growth and educational resources are concentrated (Almeida dos Reis and Paes de Barros 1991). In particular, the state of São Paulo, which is home to more than 20% of Brazilians, ranks as the state with the highest population (IBGE 2019). The state's capital, São Paulo, is a highly urbanized megacity, but holds hundreds of small parks and large blocks of native forest (Barbosa et al. 2020). Here, urban green spaces offer resources for resident and migratory birds (Barbosa et al, 2019). Nevertheless, only few studies (Amaya-Espinel and Hostetler 2019) currently focus on the ecology and behavior of tropical urban bird communities.

1.1 An overview of birdwatching in Brazil

Birdwatching in Brazil is a relatively new activity in comparison to that in other countries in the Americas or in Europe; however, it has grown considerably in recent years. Since 2005, nationwide initiatives have been created to engage Brazilian citizen scientists. Most notably, the growth of birdwatching as a hobby in Brazil was propelled by the creation in 2006 of "Avistar", the Brazilian bird fair, held annually in São Paulo city, attracting 5,000 to 7,000 people (Carvalho, G. – Avistar organizer, *pers. comm.*). As a result, new birdwatching clubs have formed, and new citizen science initiatives have started (e.g., *WikiAves*, *Taxeus*, *Sistema Urubu*, *Cidadão Cientista,* SIBBr). Currently, *WikiAves* is one of most popular websites used by Brazilian birdwatchers, with nearly 35,000 users and 270,000 bird records, including photographs and sounds, and with more than 12,000 visitors per day (WikiAves 2019). Another platform, eBird, is the world's largest biodiversity-related citizen science project, to which birdwatchers from around the world continuously contribute data (eBird 2019). Created by the Cornell Lab of Ornithology in 2002, it was translated to Portuguese in 2015, contributing to increased use by Brazilians. With over 10,000 users in Brazil (eBird 2019), it has the potential to produce a substantial amount of new data about Brazil's >1900 bird species.

Here, we review the current state of ornithological citizen science in Brazil by evaluating where birdwatchers reside within the country and the amount and type of data that has been gathered. Through a case study, we demonstrate the potential of using citizen science data to describe the timing of migration and habitat use of four migratory bird species. Finally, we propose ways to improve the quality of information on bird biology generated with citizen science in Brazil and suggest new avenues for research on urban birds.

2. Methods

2.1 Study region

We collected data on citizen science birdwatchers from across Brazil, to understand where birdwatchers reside within the country and to evaluate which types of data they collect (Fig.

1). To evaluate migration timing and habitat use of four focal species, we used citizen science data from the state of São Paulo (Fig. 1 – SP and Fig. 2), since it is the state with the largest amount of data collected by citizen scientists.

2.2 Data collection and analysis: citizen science platforms

We obtained the number of users per state from WikiAves and eBird, the two most popular citizen science platforms used by Brazilian birdwatchers. A list of WikiAves users per state is available in the WikiAves website, under "*estatisticas por estado*" (WikiAves 2019). A list of eBird users is not currently available online, so we requested it from the developers.

WikiAves and eBird users are those listed up to December of 2019. To identify the location of users, we added the number of users per state for each platform, and created a ranking of users by state (see supplementary material). Although most birdwatchers have accounts in both platforms, our intent was to evaluate the regions where they are most concentrated, such that use of both platforms by users did not affect our results.

2.3 Data collection and analysis: citizen science-based research in Brazil

We searched in Google Scholar for publications based on studies conducted in Brazil that had cited these platforms and produced original results about birds based on citizen science data. We choose Google Scholar because it also includes "gray literature" - publications that have not passed through the peer-review process. To conduct this search, we used the following keywords: "eBird" and "Brazil", and "WikiAves" and "Brazil". Although WikiAves was launched in 2009 and eBird in 2002, we searched for publications using data from both platforms from 2010 to 2019, since it was when birdwatching started to grow most rapidly in Brazil.

We organized the publications by type ["gray literature", which include theses and dissertations, conference proceedings and reports from local agencies, papers in Brazilian-based journals that publish on in-country research, and papers in international journals, including Brazilian-based journals that publish international research. We also categorized publications by the focus of the study (e.g. behavior, range extensions, migration, ecology, inventory, natural history), language, year of publication, and which platform the data came from (eBird, WikiAves or both). We used this information to understand the drivers of the increase in the use of citizen science data in Brazil and the type of results produced using citizen science data.

2.4 A case study of migratory birds: data acquisition and analysis

As a case study, we evaluated the migration timing and habitat use of four New World flycatchers (Tyrannidae) that occur in Brazil: Southern Streaked Flycatcher (*Myiodynastes maculatus solitarius*), Fork-tailed Flycatcher (*Tyrannus savana*), Variegated Flycatcher (*Empidonomus varius*), and Vermilion Flycatcher (*Pyrocephalus rubinus*). These species were chosen because they are highly abundant across different regions and are relatively easy to identify, such that there is a large amount of citizen-collected data on their occurrence in time and space. All four are Neotropical austral migrant species, breeding in temperate South America and spending the austral winter closer to the Equator (Cueto and Jahn 2008). The Southern Streaked Flycatcher, Fork-tailed Flycatcher and Variegated Flycatcher breed in southeastern and southern Brazil, and Vermilion Flycatcher breeds south of Brazil (primarily in Uruguay, Paraguay and Argentina) and overwinters in southeastern Brazil (Del Hoyo et al. 2004; Somenzari et al. 2017).

We downloaded the eBird Basic Dataset in the eBird website (eBird 2019) and requested data from WikiAves (2019). We conducted an extensive search within the digital vouchers and user comments archived in eBird and WikiAves, since comments in the lists or with photos can give more information about bird records, helping identify user mistakes. We also included data from *Aves da Cidade* (created by KVCB, to obtain data on the occurrence of migratory birds - https://avesdacidade.wordpress.com/).

Although these websites were launched after the year 2000, users are allowed to upload previously records (lists, sounds or pictures); nevertheless, we only analyzed data from São Paulo city beginning in January 2000 to minimize the influence of temporal changes in the urban landscape on the results (i.e., urban areas are constantly changing and green areas can be created or removed). If a longer period were considered, regional changes in bird abundance could be influenced by changes in the local landscape that we cannot directly account for.

To quantify the amount and location of green areas in the city, we used a classified land cover maps made available by Laboratório de Silvicultura Urbana (2010), which were generated from satellite imagery (infrared orthophotos with 5-m resolution) from 2010

(UTM-WGS84 zone 23S), and supported with a Google Earth image., we then correlated the observations of citizen scientists with the classified map using ArcMap version 10.2.1 to identify the size of the green areas where birds were present.

We evaluated bird occurrence data from a specific region or habitat (e.g. urban green spaces) to eliminate double-counts within the same or different platforms. Records from the three databases (eBird, WikiAves and Aves da Cidade) were checked to eliminate duplicates and errors regarding the location of observations, for example by checking the list comments against the location on the map where birds were stated to be observed. We then sorted the records by date to identify the first records of each species in the state and in the city of São Paulo.

3. Results

3.1. Citizen science to research database

We found the total of 672 publications that used citizen science data to increase the birds knowledge, eBird (55) and/or WikiAves (651). Concerning the publications in university studies, meetings and local documents ("grey literature") 21 used eBird data and 191 used WikiAves data; in Brazilian journals were 15 in eBird and 279 in WikiAves, and in international publications 20 used eBird data and 179 publications used WikiAves data. The number of studies have increased since 2010 specially "grey literature" using WikiAves.

The most publications have the mainly focus in species range extension (173), inventory of birds in a region (168), bird behavior (64), natural history (42), ecology (20), vocalization analysis (20), bird modeling distribution (6), habitat (6) and bird hybridism (6). Regarding the publications that used citizen science data to understand migratory bird patterns were 12 publications, seven of them in international journal reach, and the studies in urban areas were 14, four in international journal reach.

3.2 Wikiaves and eBird users in Brazil

Most WikiAves users (73% of 32,597 birdwatchers) and eBird users (54% of 10,071 birdwatchers) reside in southern and southeastern Brazil. Moreover, the highest number of birdwatchers in WikiAves (9,372 users) and eBird (1,872) come from São Paulo state, most in urban areas (Fig.1; see numbers by state in Supplementary Material).

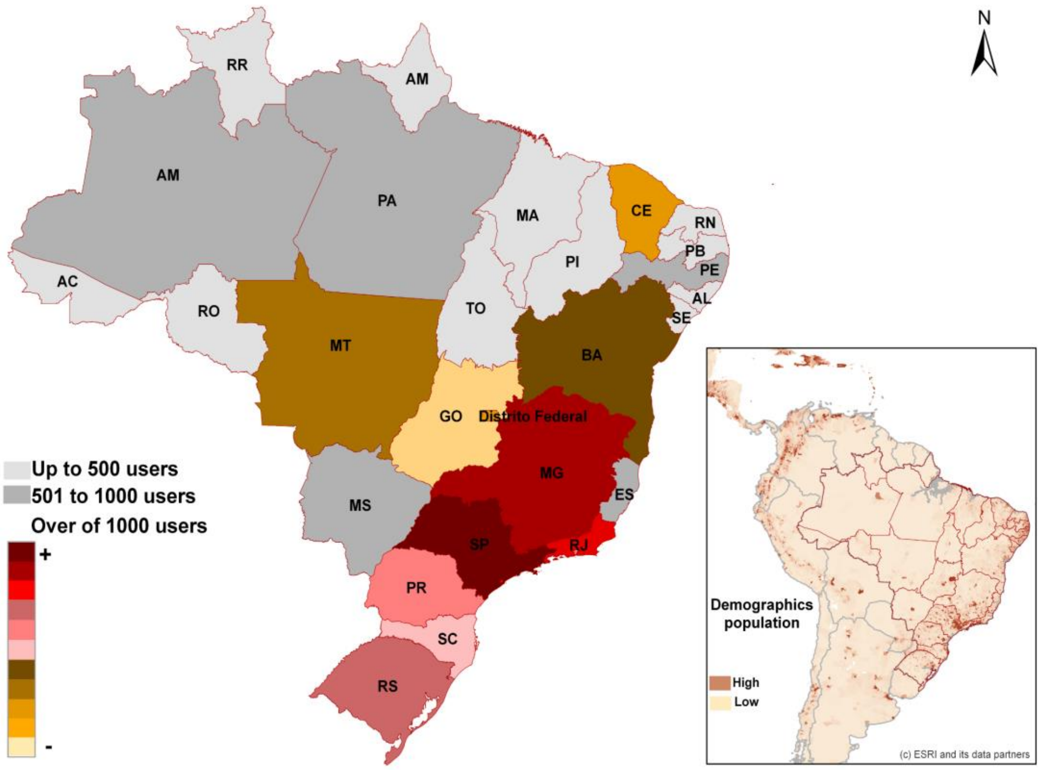

Figure 1: Map of the distribution of Brazilian birdwatchers, according eBird and WikiAves. The red to pink colors represent the most populous regions (southern and southeastern regions, which includes the state of Espirito Santo).

3.3 New World flycatchers as models

Searching the three databases for records of four widespread migratory New World flycatchers (Tyrannidae), we found 652 and 8,357 records for Southern Streaked Flycatcher, 616 and 5,319 for Variegated Flycatcher, 375 and 3,707 for Fork-tailed Flycatcher, and 27 and 662 for Vermilion Flycatcher in São Paulo city and state, respectively. All four species were observed in urban parks across the city. Nevertheless, the timing of migration was unique for each species (Table 1; Fig. 2).

Table 1: Arrival and departure dates of four New World migratory flycatchers (Tyrannidae) in both the state and city of São Paulo, based on records from Wikiaves, eBird and Aves da Cidade. Arrival date is defined as the first day that a species was registered and departure date corresponds to the last date that a species was registered.

species	Arrival		Departure	
	São Paulo state	São Paulo city	São Paulo state	São Paulo city
Southern Streaked Flycatcher (*M. maculatus solitarius*)	10 August	10 September	30 May	20 May
Variegated Flycatcher (*E. varius*)	10 August	30 August	15 May	10 April
Fork-tailed Flycatcher (*T. savana*)	25 July	20 August	30 May	10 March
Vermilion Flycatcher (*P. rubinus*)	20 March	20 April	20 November	10 November

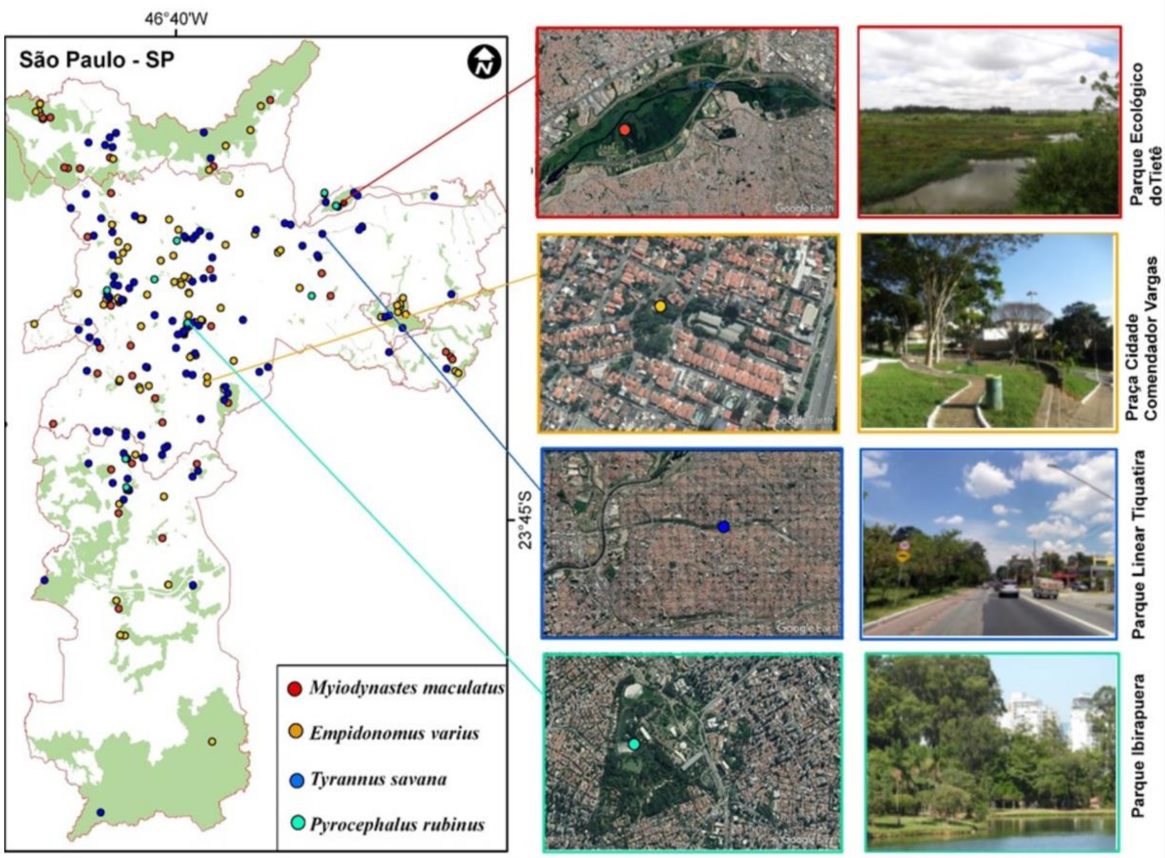

Figure 2: Locations of observations by birdwatchers of four migratory bird species in the city of São Paulo, Brazil and examples of urban green areas in the city.

Results indicate that Southern Streaked Flycatcher and Variegated Flycatcher appear in São Paulo state in early August, after earlier records in the northwestern parts of the state, with consequent observations towards the southeastern part of the state for about a month, when they appear in the city of São Paulo. The first records of these species in the state of São Paulo were after 10 August. On the other hand, the last records were 30 May and 10 May for Streaked Flycatcher and Variegated Flycatcher, respectively with a few days difference in their date of arrival in the city of São Paulo (Table 1). It can take approximately 20 days after the first observation of Variegated Flycatcher in São Paulo state to be recorded in the city of São Paulo. Vermilion Flycatcher uses urban areas in the state of São Paulo during the non-breeding period and is observed in São Paulo city from April to September. Nevertheless, it is found in the state throughout the year, although more frequently in May to July, during winter (Fig. 3).

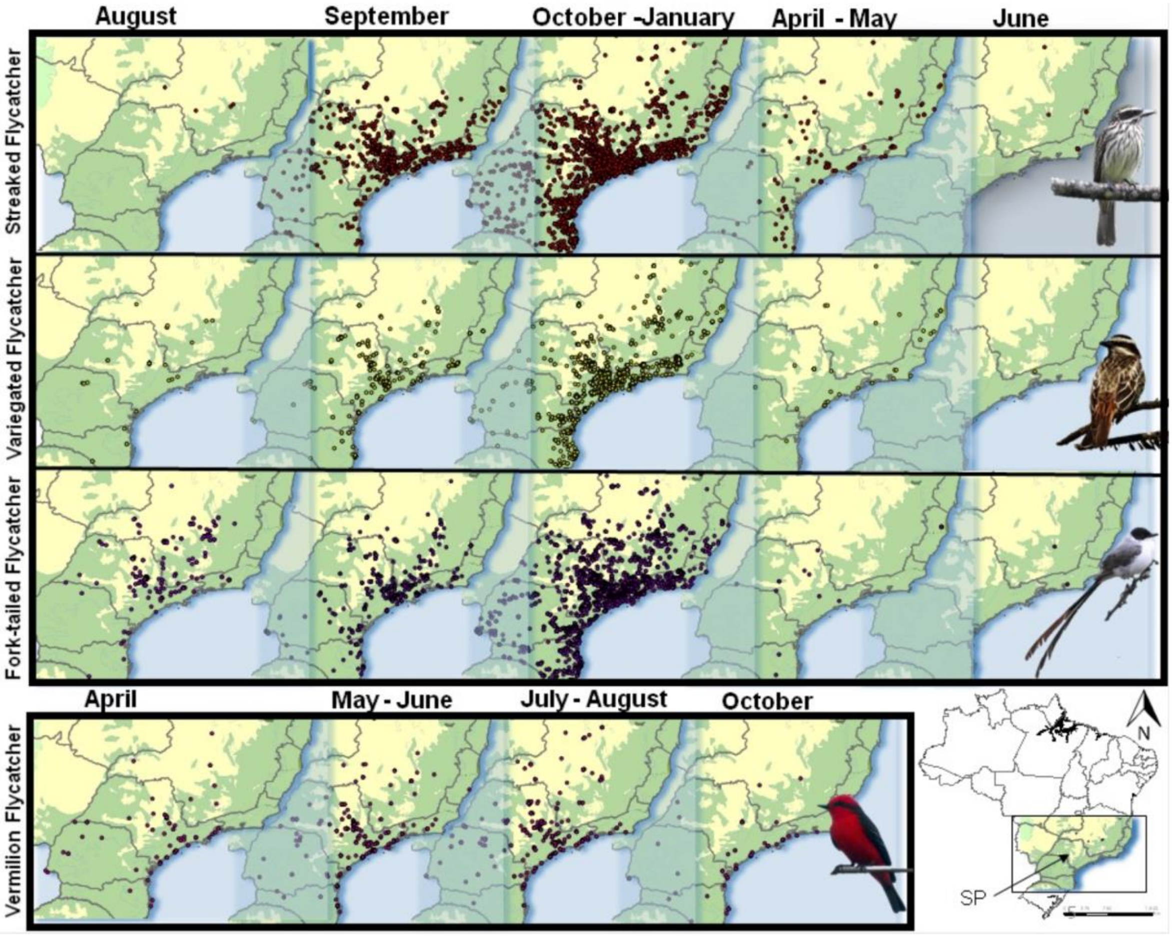

Figure 3: Maps of southeastern Brazil depicting the occurrence of the four Tyrannidae species in the state of São Paulo throughout the year, based on citizen science data – WikiAves, eBird and Aves da Cidade (2000 - 2019).

Southern Streaked Flycatcher has only been observed in green spaces larger than 10 ha in the city of São Paulo. In contrast, Variegated Flycatcher has been observed in small (<1 ha) urban green spaces (locally called *praças*); however, this species has only been observed nesting in urban parks over 10 ha. Fork-tailed Flycatcher has been observed perched in trees along streets or in small green urban spaces. It sometimes places its nest in anthropic structures, such as steel structures (Fig. 4 – B1). During a short period in winter, Vermilion Flycatcher is regularly recorded in urban parks larger than 5 ha in the state of São Paulo.

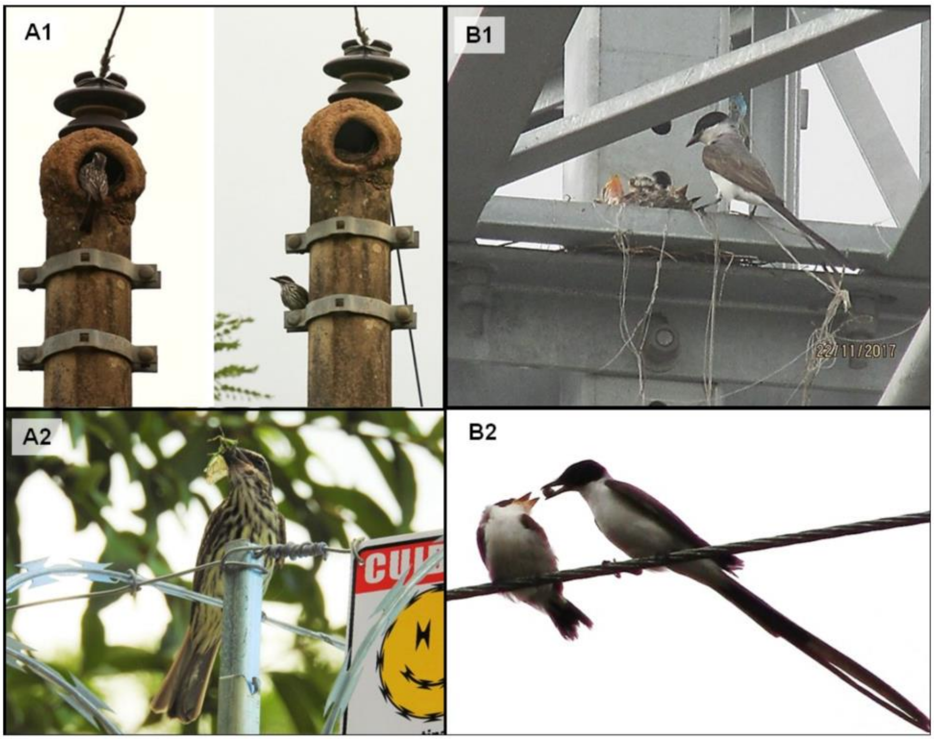

Figure 4: Examples of nests of migratory species (A1, B1), a Southern Streaked Flycatcher with food (A2), and an adult Fork-tailed Flycatcher feeding a juvenile (B2) in Brazilian cities. Photographs are by the following birdwatchers (source: Aves da Cidade): A1 – Juliana Lima; A2 – Dirceu; B1- Beatriz Gianiselle; B2 - Adolf Kruger.

4. Discussion

The use of citizen science data for ornithological research is rapidly growing, and has already been used in over 490 peer-reviewed studies in Brazil. Although data are concentrated in the most urbanized regions, only in 13 studies have data come from Brazilian urbanized areas, and none have focused on urban migratory birds. Our results suggest that citizen science can play an important role in providing new information about departure and arrival dates of migratory bird species in urbanized regions of Brazil, and future studies should tap into this rich source of data to evaluate such patterns across species.

Published ornithological studies that have used citizen science data in Brazil are primarily in the gray, non-peer reviewed literature and local journals. However, more than 200 ornithological studies have been published in peer reviewed literature. Examples include studies on climate and land use changes (Miranda et al 2019), taxonomy and conservation (Ubaid et al 2018), species distributions (Klemann-Junior et al. 2017, Silveira et al. 2017), migration (Lees 2016; Lees and Martin 2014; Schubert et al. 2019), and nesting behavior (Ferreira et al. 2019). These studies show that citizen science can contribute significantly to ornithological knowledge in Brazil, since they convey important natural history information useful to researchers, educators, managers and conservationists.

Most birdwatching activity in Brazil is concentrated in the southern and southeastern regions of country, reflecting the general population density in the country (IBGE 2019). The level of education and salaries are also highest in southern Brazil (Almeida dos Reis and Paes de Barros 1991) and many environmental conservation institutions are based there, all of which translates into a higher rate of uploads to online platforms from this region. Our results also show that most birdwatchers are active in or nearby large cities, reflected in the number of bird sightings registered near São Paulo and other large cities. A similar pattern was found for data in WikiAves in another study (Alexandrino et al. 2019a).

4.1. New World flycatchers as models

Citizen science data provided new information about habitat use and migration timing of four migratory bird species. Fork-tailed Flycatcher was observed by birdwatchers in highly urbanized areas, such as tree-lined streets, as found in other studies (Pena et al. 2017), while Southern Streaked Flycatcher was detected in urban parks with a higher percentage of tree cover. The timing of migration also differs among these closely related species, corroborating the findings of other studies that migratory species have different habitat requirements and timing of migration in urban vs. rural green spaces (Rodewald et al. 2013; Møller et al. 2015).

In general, avian species richness in cities is often positively related to tree cover, and many species are absent from small urban green spaces (Chace and Walsh 2006; MacGregor-Fors 2008; Pena et al. 2017; Barbosa et al. 2020). The Southern Streaked Flycatcher was regularly observed by birdwatchers in isolated, >10 ha large green areas in São Paulo (although it was also occasionally observed in green spaces as small as 3 ha; pers. obs.). Our results are corroborated by the study of Vitorio et al. (2019), which suggests a home range size for this species of 5.4 ha in an urban park. Likewise, Vermilion Flycatcher, which spends the non-breeding season in São Paulo, has only been observed by birdwatchers in urban green spaces of >5 ha in the city of São Paulo. In contrast, Variegated Flycatcher and Fork-tailed Flycatcher appear to use smaller patches than Southern Streaked Flycatcher, which may be related to their nesting requirements (Gussoni & Guaraldo 2009). Fork-tailed Flycatcher inhabits open areas in the Cerrado ecoregion, often placing its cup-shaped nest in isolated trees, in contrast to Southern Streaked Flycatcher, which nests in tree cavities.

Urban green spaces in the megacity of São Paulo are usually located several km apart and are often surrounded by numerous human-made structures, such as tall buildings and impervious surface. In general, maintaining urban green spaces larger than 10 ha can contribute to providing habitat for a variety of migratory bird species. Although tree cover is essential for many species, other factors also need to be considered when managing for avian richness and abundance in urban parks, such as ambient noise levels, presence of water bodies and percentage of impervious surface (Fontana et al. 2011; Pena et al. 2017; Barbosa et al. 2020). Citizen science can provide vital information about bird distributions and migration patterns (Coxen et al 2017; Gillings et al 2019), and on the potential impacts of such factors on birds, to those in charge of managing urban greenspaces (Callaghan et al. 2017).

4.2 Challenges and recommendations to improve the quality of citizen science data

Given the size of Brazil, monitoring birds outside of urban areas is costly (Tulloch et al 2013); therefore, citizen science can be a valuable and inexpensive source of a wide range of data on birds (Tulloch and Szabo 2012). For birdwatchers, uploading their data to these platforms is not only an opportunity to share their data with the larger birdwatching community, but also to participate in the scientific process and contribute to the growth of ornithological knowledge.

However, some citizen science records can be inaccurate and therefore of little use for fine-scale studies. For example, records can be submitted with the wrong coordinates, an error that can originate from the recording device or by transcribing errors. While this might not cause problems for data-rich, large scale-studies, such as evaluations of regional distributions or abundances, it can be a problem for research on micro-habitat use, for example. In in this study, we found five records of Southern Streaked Flycatcher that did not correspond to the eBird list location; however, we were able identify the mistake and verify in the comment section of that record the location where the bird was seen, thereby excluding it from our analysis. Researchers should therefore be careful in vetting the data prior to analyses (Tulloch and Szabo 2012; Tulloch et al 2013).

By providing more detailed information on each record, birdwatchers can also facilitate the detection of outliers or errors. Training citizen scientists on how to provide more detailed and accurate information, as well as about the birds themselves (e.g., behavioral observations or uploading photographs, sound recordings and videos), will also go a long way to helping birdwatchers contribute more precise data to citizen science platforms.

Additionally, researchers could provide information about announce the gaps in information about, for example, species distributions or habitat use that could be made publicly available on the data platforms, so that birdwatchers know where what types of data are most needed. Furthermore, understanding the population trends of species (e.g., Red List classifications) is crucial for effective conservation planning, so reporting the number of individuals when uploading records provides valuable information. Finally, online and especially in-person contact between birdwatchers and researchers could enable birdwatchers understand the importance and data needs of research projects, and help researchers understand the challenges and interests on the part of birdwatchers.

4.3 Recommendations for future research using citizen science data

Because citizen science data can provide novel information on a wide range of topics related to bird biology (e.g., phenology, breeding behavior, food resource availability, short term and along term population trends), we suggest several avenues of potential citizen science research on Brazilian birds.

Migration phenology: Individual birds benefit from early arrival to their breeding site: males acquire higher quality territories and females are able to begin egg laying early, which can lead to higher productivity (Smith and Moore 2005). Yet, our knowledge about the effects of climate change and urbanization on migration timing of Neotropical austral migrants is still lacking. Fork-tailed Flycatcher is one of a handful Neotropical austral migrants whose migration has been described in detail (Jahn et al. 2019). Citizen science can play an important role in filling the large gaps in our knowledge about various aspects of Neotropical austral migration, including timing of departure and arrival, migratory routes and overwintering localities, therefore contributing to a better understanding about the way migratory birds are affected by rapid climate change and urbanization.

Habitat quality: Even though habitat quality can influence various aspects of bird community dynamics (Chace and Walsh 2006; Pena et al 217; Barbosa et al 2020), it can also affect individual behavior, such as the arrival date of migratory birds to their breeding site (Norris et al. 2004). However, given the large number of bird species and habitat diversity within Brazil, there is relatively little detailed information about micro-habitat use of Brazilian bird. Gathering such data across a wide range of taxa and habitats would require a lot of effort and time for scientists using traditional methods (e.g., point counts and bird banding; Tulloch and Szabo 2012). Our results show that the data available on citizen science websites could be a major contribution to our knowledge on habitat use by Brazilian birds.

Urban bird ecology: Although urbanization is generally thought to decrease avian abundance and richness (Loss et al. 2009; Husté and Boulinier 2011; Evanset al. 2018), urban green spaces can also offer shelter and resources for birds (Barbosa et al., 2020). Urban birdwatchers have a unique opportunity to provide large amounts of data to advance our understanding about the impacts of the rapidly changing urban environment on birds (McCaffrey 2005; Tejeda and Medrano 2018), especially in the tropics, where information about the ecology, behavior and diversity of urban birds is lacking (Amaya-Espinel and Hostetler 2019; Barbosa et al. 2020). To date, only two studies have been published in international journals that used citizen science data on urban birds in Brazil (Souza et al 2019; Alexandrino et al. 2019b), and citizen science can provide a large amount of data from urbanized areas (Callaghan et al 2017)

5. Conclusions

One the most important current challenges for urban planners is to strike a balance, maintaining a landscape mosaic that offers a sustainable environment for both urban development and the conservation of biodiversity. Urban green spaces not only offer resources for many birds, but also provide multiple social and psychological benefits for humans (Heerwagen 2009), as well as environmental services such as air purification, regulation of microclimate, and noise reduction (Bolund and Hunhammar 1999; Chiesura 2004). Given that it can provide information on key indicators of urban ecosystem health, citizen science has a central role to play in urban planning that provides benefits for both wildlife and humans.

Birds face many threats in our rapidly changing world, and citizen scientists have a key role to play in conserving birds, and in the quest to increase our understanding about various aspects of bird biology. With further support and training, their data can become even more important for guiding future studies and conservation actions in Brazil and other countries across the globe.

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Supplementary material

Table with the number of Brazilian users in WikiAves and eBird citizen science platforms.

	Wikiaves	eBird	Total	mean		
Brazil states					South and Southeast (SP, RJ, PR)	
São Paulo (SP)	9372	1872	**11244**	5622	23783	Wikiaves
Minas Gerais (MG)	3876	759	**4635**	2317.5	73%	
Rio de Janeiro (RJ)	3230	1253	**4483**	2241.5	5476	eBird
Rio Grande do Sul (RS)	3109	427	**3536**	1768	54%	
Santa Catarina (SC)	2186	448	**2634**	1317		
Paraná (PR)	2010	717	**2727**	1363.5		
Bahia (BA)	1091	426	**1517**	758.5		
Ceará (CE)	878	244	**1122**	561		
Distrito Federal	799	275	**1074**	537		
Goiás (GO)	796	244	**1040**	520		
Espírito Santo (ES)	773	202	**975**	487.5		
Pernambuco (PE)	529	217	**746**	373		
Mato Grosso (MT)	504	847	**1351**	675.5		
Mato Grosso do Sul (MS)	481	490	**971**	485.5		
Rio Grande do Norte (RN)	426	99	**525**	262.5		
Pará (PA)	387	274	**661**	330.5		
Amazonas (AM)	346	526	**872**	436		
Paraíba (PB)	323	84	**407**	203.5		
Maranhão (MA)	295	64	**359**	179.5		
Piauí (PI)	224	43	**267**	133.5		
Alagoas (AL)	180	123	**303**	151.5		
Rondônia (RO)	176	74	**250**	125		
Tocantins (TO)	148	81	**229**	114.5		
Acre (AC)	141	55	**196**	98		
Sergipe (SE)	116	66	**182**	91		
Roraima (RR)	87	105	**192**	96		
Amapá (AM)	61	56	**117**	58		
	32544	**10071**	**42615**			

CONSIDERAÇÕES FINAIS

Os resultados obtidos nesse estudo aumentaram nosso entendimento de quais características da paisagem urbana, na Mata Atlântica brasileira, têm maiores impactos nas aves migratórias e residentes, bem como revelaram informações inéditas sobre espécies de aves migratórias neotropicais austrais. As análises mostraram que o uso de áreas verdes urbanas pelas aves migratórias e residentes são afetadas negativamente pelo alto índice de ruído e a distância dos corpos d'água (Capitulo 1). Os efeitos da urbanização também dependem das características ecológicas da espécie, como a área de vida ou suas demandas de habitat, e dados provenientes de ciência cidadã podem nos ajudar a conhecer melhor esses efeitos.

A composição da paisagem é importante preditor do uso das manchas verdes pelas aves, sendo que em paisagens urbanas o índice de ruído e a distância dos corpos d'água mostraram ter efeitos mais forte nos padrões de riqueza das aves, do que outras cobertura arbórea, áreas impermeáveis e densidade populacional humana. Quando observado separadamente a riqueza de espécies migratórias foi mais fortemente afetada pelo nível de ruído urbano, enquanto que as residentes pela distância de corpos d´água. Além disso, diferente do que é encontrado no Hemisfério Norte, aves migratórias e residentes foram afetadas de maneira similar aos efeitos da urbanização na Mata Atlântica. Essa diferença pode se dar potencialmente devido à baixa especificidade ao habitat que caracteriza os migrantes neotropicais. Em contraste ao que ocorre com muitas aves migratórias que se reproduzem em latitudes temperadas do Norte, que ocupam as florestas, a maioria das espécies de aves migratórias neotropicais austrais usa mais frequentemente habitats abertos e bordas de mata e, portanto, pode ter mais propensão a se adaptarem a ambientes urbanos.

Para os tiranídeos migratórios neotropicais austrais, a fidelidade de sítio reprodutivo, tamanho da área de vida e demanda de habitat também podem ser afetadas pela urbanização (Capitulo 3). Indivíduos que estão em ambientes rurais apresentaram maiores taxas de retorno para uma mesma área em comparação com aqueles que estão na área urbana. Adicionalmente, a fidelidade de sítio parece estar relacionada a outras características das aves, tais como condição corpórea e o sexo do indivíduo. Os machos de *Tyrannus savana* parecem ser mais fiéis a um local de reprodução do que as fêmeas, fator que provavelmente é devido a uma maior familiaridade com o espaço físico e os recursos locais. Além disso, quanto mais estruturas urbanas são encontradas na área verde onde essas aves reproduzem, maior poderá ser sua área de vida. Existe uma demanda mínima de habitat, como por exemplo para o bem-te-vi-rajado (*Myiodynastes maculatus solitarius*), apesar de sua área de vida ser de em média de 5,4 hectares, ele não é encontrado em áreas verdes menores do que 10 hectares na cidade de São Paulo. Já espécies como o príncipe (*Pyrocephalus rubinus*) precisam de uma área de 5 hectares, o peitica (*Empidonomus varius*) 1 hectare e a tesourinha (*Tyrannus savana*) pode ser encontrada mesmo em ruas mais arborizadas. Essas informações sobre demanda de habitat, assim como data de chegada e partida das aves migratórias, foram possíveis através de dados de ciência cidadã.

No Brasil a ciência cidadã tem sido notavelmente bem-sucedida no avanço do conhecimento científico sobre as aves e artigos científicos diversos estão sendo gerados (Capitulo 4). Para as aves migratórias, esses dados ainda podem contribuir para o conhecimento de suas necessidades de habitat ou mesmo dados ecológicos e de história natural, como região de nidificação, agenda migratória e itens alimentares. A ciência colaborativa pode ser uma importante ferramenta para contribuir com nosso entendimento sobre diversos aspectos biológicos e ecológicos das aves migratórias, principalmente em áreas urbanas onde grande parte dos observadores de aves estão concentrados.

Esse trabalho veio para contribuir com o aumento do conhecimento sobre as aves migratórias no Brasil, fornecendo dados sobre história natural e ecologia de algumas espécies em áreas urbanas. Muitos estudos ainda são necessários para que possamos entender a migração das aves neotropicais, inclusive estudos de monitoramento das espécies, uma vez que muitas espécies consideradas residentes podem ser migratórias totais ou parciais. Áreas urbanas estão mais susceptíveis a alterações rápidas em comparação com áreas de floresta, e as aves migratórias estão mais sujeitas a essas mudanças, pois podem se deparar com a perda de habitat logo após voltarem de migração. Por exemplo, espécies que usam cavidades para nidificar, como o bem-te-vi-rajado, têm que procurar um novo local quando uma árvore que era utilizada como ninho é retirada deliberadamente por ação humana, acarretando atraso ou até mesmo perda do período reprodutivo.

Ainda que a urbanização elimine espécies de aves mais sensíveis a urbanização, as pequenas manchas verdes podem servir de abrigo, refúgio ou mesmo local de passagem para aves dentro da matriz urbana, particularmente a espécies são menos sensíveis às perturbações humanas. Essas manchas podem abrigar espécies nativas e representar um habitat, temporário ou permanente, devendo ser vistos como elementos fundamentais para conservação da biodiversidade. Portanto, com o intuito de implementar iniciativas de conservação de modo mais efetivo, é necessário um maior foco nos diferentes componentes do mosaico da paisagem urbana e não apenas nos remanescentes de floresta. Sob esse aspecto, a gerência e manejo dos parques urbanos devem ainda levar em conta características como baixo ruído, oferta de recurso hídrico e cobertura arbórea para um ambiente saudável e equilibrado para as aves e mesmo para os seres humanos.