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Forest fragments in urban matrices: a conservation network for Atlantic Forest birds

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ABSTRACT. Fauna conservation in anthropic ecosystems is crucial. This study aimed to assess the role of forest fragments in protecting bird communities within the urban matrix of Blumenau, state of Santa Catarina, Brazil. Bird species were identified using visual and auditory methods across five forest remnants from January 2016 to December 2019. Fieldwork began in the early morning and covered both the interior and edges of the areas. The relationship between species richness and land use within the forest fragments and adjacent matrices was investigated to support management actions for expanding urban landscapes. These actions are necessary as habitats and corridors may be eliminated, leading to reduced landscape connectivity. The results indicate an interaction between fragment size and land use, which contributes to the formation of environmental mosaics in the urban landscape. These mosaics may influence bird species richness and composition. Effective public management of legally unprotected forest remnants, regardless of size, along with permanent preservation areas (e.g., riparian forests and urban green spaces) and conservation units, may strengthen a network of green areas for protecting and conserving Atlantic Forest bird species in urban environments.

Keywords: fragmentation; secondary forest; urban ecosystem; Atlantic Forest.

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Introduction

With the expansion of agribusiness and cities, approximately 80% of the remaining Brazilian Atlantic Forest is persisting as fragments smaller than 50 ha (Tonetti & Cavarzere, 2017; Pizo & Tonetti, 2020). Deforestation and fragmentation of tropical forests are indeed regarded as one of the main threats to global biodiversity (Timmers et al., 2022; Kazo, Lovejoy, & Luther, 2022). The Brazilian Atlantic Forest is considered a high priority for conservation and one of the world's 34 biodiversity hotspots owing to its high rates of species endemism and vulnerability to rapid habitat loss (Crouzeilles et al., 2020; Rosa et al., 2021).

The Atlantic Forest serves as habitat for approximately 1020 bird species (Marini & Garcia, 2005). Based on recent taxonomic revisions, 210 species of these species are considered endemic to this biome (Develey & Phalan, 2021). Accordingly, Brazil has the second largest number of globally threatened bird species, reaching up to 166 species, of which more than half occur in the Atlantic Forest (Valls, Rossi, dos Santos, & Petry, 2016; Pizo & Tonetti, 2020).

Bird populations are generally negatively affected by forest fragmentation owing to difficulties in adapting to potentially adverse environmental conditions shaped by these processes (Hanski, Zurita, Bellocq, & Rybiki, 2013). The reduction in the quantity and quality of suitable habitats as a result of increased isolation and the edge effects synergistically affect bird populations (Bierregaard, Lovejoy, Kapos, Santos, & Hutchings, 1992; Anjos, 2006; Barros, Martello, Peres, Pizo, & Ribeiro, 2019). Therefore, planning actions that mitigate the impacts of habitat isolation in fragmented landscapes such as the Atlantic Forest should consider urban expansion. In this regard, an estimated 80% of the world's population between 2025 and 2050 will live in urban areas (Nor, Corstanjea, Harris, & Grafius, 2017). Rapid urbanization can eliminate forests, such as riparian forests, which function as species dispersal corridors connecting small green areas, thereby compromising landscape connectivity and increasing the isolation of forest habitats in urban areas (Kowe, Mutanga, Odindi, & Dube, 2020; Shen et al., 2022).

Planning must also consider the spatial structure of the landscape, which is composed of fragments, corridors, and the matrix as whole, whose porosity can and should be increased (Boscolo & Metzger, 2009; Pizo & Tonetti, 2020). Matrix porosity influences the movement of species over the landscape and minimizes the negative effects of fragmentation (Anjos et al., 2019). In addition, it contributes to habitat connectivity, whose importance for bird species survival may be greater than the total area of forest fragments (Silva Coelho, Marenzi, Iza, Souza, & Longarete, 2018; Timmers et al., 2022). Thus, understanding forest fragmentation processes and evaluating their effects on ecological processes at different spatial scales has become one of the greatest challenges for Conservation Biology (Fahrig, 2017, 2020; Fahrig et al., 2019).

Increased knowledge about ecological processes occurring in urban matrices may support the development of appropriate landscape management policies by public actors. Some examples are the implementation of ecological corridors and the structuring of a network of conservation units and legally established green areas, which would promote the conservation of biodiversity (Shen et al., 2022; Silva, Pena, Viana-Junior, Vergne, & Pizo, 2021). Moreover, such actions may contribute to the development of sustainable cities, as foreseen in the Sustainable Development Goals (SDGs) (Roma, 2019; Kowe et al., 2020; Silva & Savio,2022).

Given the above, the main aim of this study was to characterize and evaluate the potential of fragments of subtropical Atlantic Forest in an urban matrix for protecting bird communities. The premise or hypothesis is that, despite the important relationship between species richness and the total area of forest fragments (species-area relationship), a larger variability of land uses and land cover patterns within and surrounding these fragments positively affects bird species richness.

Materials and methods

Study area

Fieldwork to survey bird species was carried out in five forest remnants in the urban area of Blumenau, state of Santa Catarina, Brazil. The native forest cover consists of remnants of subtropical evergreen rainforest, a forest type within the Atlantic Forest domain (Oliveira-Filho et al., 2015). According to the Köppen classification, climate in the study area is Cfa type or humid subtropical oceanic climate with hot summers. Average annual precipitation is around 1500 mm and average relative humidity is between 75 and 80%, with a period of more intense rainfall in the summer. Average annual temperature is 20.1 °C (Vibrans, Schramm, & Lingner, 2011).

Area selection/mapping

The sample areas were selected based on the available information on the bird community and ease of access for new surveys. The municipal protected areas comprise two areas: (1) São Francisco de Assis Municipal Natural Park, (“PSF”), (2) and Salto Ecological Interest Area, (“ARIE do Salto”). The remaining areas comprise forest remnants on the campuses of the *Universidade Regional de Blumenau*, (3) Campus I and (4) Campus V, and a (5) private green area, (“Goll”) (Figure 1 and 2). Land use was mapped within the limits of the areas and over a 200 m buffer in the adjacent landscape matrix using the software ArcGIS (ESRI), version 10.1. For the legally instated protected areas (called Conservation Units in Brazil), the official perimeters provided by the Municipal Department of Environment and Sustainability of Blumenau were used. Land use classes were defined according to the Technical Manual of Land Use published by the Instituto Brasileiro de Geografia e Estatística [IBGE] (2012), as follows: (a) roads and streets; (b) early successional forest; (c) intermediate/late successional forest; (d) lagoon; pasture and lawn; (e) residential and industrial; and (f) river. These classes were mapped using visual classification of fine resolution aerial photos acquired in 2011 by the State Department of Sustainable Economic Development (SDS); the photos are available at the Geographic Information System of Santa Catarina (SIGSC).

Bird survey

Field recording of bird species was conducted between January 2016 and December 2019, encompassing all seasons, starting before sunrise, which is the period of peak bird activity when nocturnal and crepuscular birds may also be recorded (Valls et al., 2016). Species and individuals were recorded along existing trails both at the edges and inside the areas for a specified period of one hour (sampling unit). Records of species were reset at the beginning of each new sampling unit to prevent duplication. Specific identification was performed using two methods, namely visual identification with binoculars (Zeiss Conquest 10×42) and auditory identification based on the species' vocalizations (Dario, 2012). To prevent double counting, the same individual was not counted more than once (Cavarzere, Marcondes, Moraes, & Donatelli, 2012; Tonetti et al., 2017; Perrella, Ferrari, Katayama, & Vaz Guida, 2018). The threat status of each bird species was retrieved from the List of Endangered Fauna Species of Santa Catarina (Conselho Estadual do Meio Ambiente [CONSEMA], 2011) and from the International Union for Conservation of Nature [IUCN] global list (2017). The adopted taxonomic nomenclature followed the Brazilian Ornithological Records Committee (Pacheco et al., 2021).

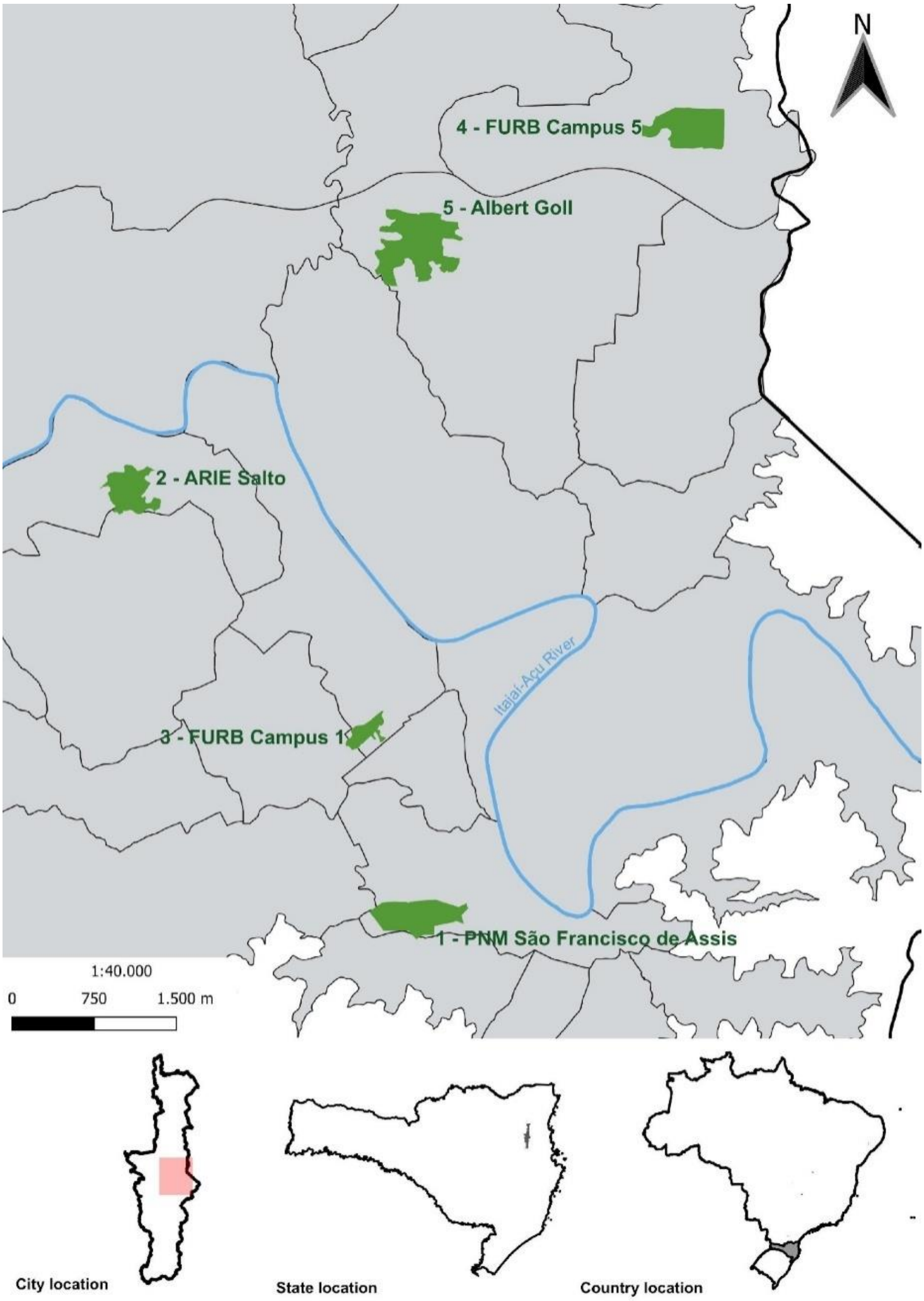

Figure 1. Location of the study areas in Blumenau, SC. Source: Geoprocessing and Remote Sensing Laboratory - LabGEO - DEF/FURB.

Figure 2. Campus V, where the greatest bird species richness was recorded (A1, A2), and Campus I, where the smallest bird species richness was recorded (B1, B2).

Data analysis

Cumulative curves of species richness per hour of fieldwork were constructed for each area. A Generalized Additive Model (GAM) was fitted to each curve using the 'mgcv' R package (Wood, 2017) to estimate the expected mean response of species richness accumulated along each curve. In general terms, the GAM is a generalized linear model whereby the linear predictor is the sum of smooth functions (splines) of covariates plus a parametric intercept. Furthermore, the relationship between species richness observed in 100 hours of field sampling (S_{100}) and the area in hectares of each study site (A) was modeled through a power function of the form

$$S_{100} = \gamma \cdot A^{\delta} + \varepsilon$$

where γ is the scale parameter of the function to be estimated, δ is the shape parameter of the function to be estimated, and ε is the random residual. The model parameters were estimated using generalized least squares with the aid of the 'gnls' function of the 'nlme' R package (Pinheiro, Bates, DebRoy, & Sarkar, 2012). The heteroscedasticity of model residuals was accommodated using the exponential function $\mathrm{var}(\varepsilon) = \sigma^2 \cdot \exp(A \cdot 2\delta)$, where σ and δ are parameters to be estimated and A is the area in hectares of each study area. The Shannon Diversity Index (H') was estimated for each sampling unit as

$$H' = -\sum p_i \cdot \ln(p_i)$$

where p_i is the relative abundance of the i-th species. In turn, the equitability index (E), which measures the evenness of distribution of individuals among species in the community, was estimated as

$$E = H'/\ln(S)$$

where S is species richness. These indices were calculated using the statistical package Past (Hammer & Harper, 2001).

For every evaluated area, the frequency of occurrence (FO%), that is, the proportion of number of areas in which the i-th species was observed (Nd_i) in relation to the total number of areas (Nt), was estimated using $FO\% = (Nd_i/Nt) \cdot 100$ (Zimmermann & Branco, 2009). The shape index (IF), which evaluates the geometric shape of the areas, was calculated using the area and perimeter of each study area based on the formula described in Zimmermann, Piazera, Dambrowski, and Silva Junior, (2017):

$$IF = \frac{P}{2\pi\left(\frac{\sqrt{A}}{\sqrt{\pi}}\right)}$$

where P is the perimeter (m) and A is the area of the fragment (m²); values close to 1.00 indicate more regular shapes and, therefore, less influence of edge effects (Silva, Longo, Bressane, & Carvalho, 2019).

Results and discussion

A total of 235 forest bird species (Table S1, Supplementary Material) were observed in the five areas. This richness can be considered high, as it accounts for 33, 3% of the species recorded throughout the state of Santa Catarina (Willrich, da Rosa, & Alves, 2020). The 95% confidence intervals estimated for the species accumulation smooth functions for Arie do Salto and PSF overlapped at 100 hours of fieldwork, thus providing evidence that these areas have statistically equivalent species richness (Figure 3). Goll had a similar species richness to that found for the PSF, albeit without overlap of the 95% confidence intervals for the smooth functions. The greatest species richness after 100 hours of survey was recorded in Campus V, the area with the greatest variety of environments. This pattern of increased richness is expected in landscapes with greater environmental heterogeneity, where a correlation among heterogeneity, biodiversity and flow of organisms has been observed (Marenzi & Roderjan, 2005; Reis, Bechara, & Tres, 2010).

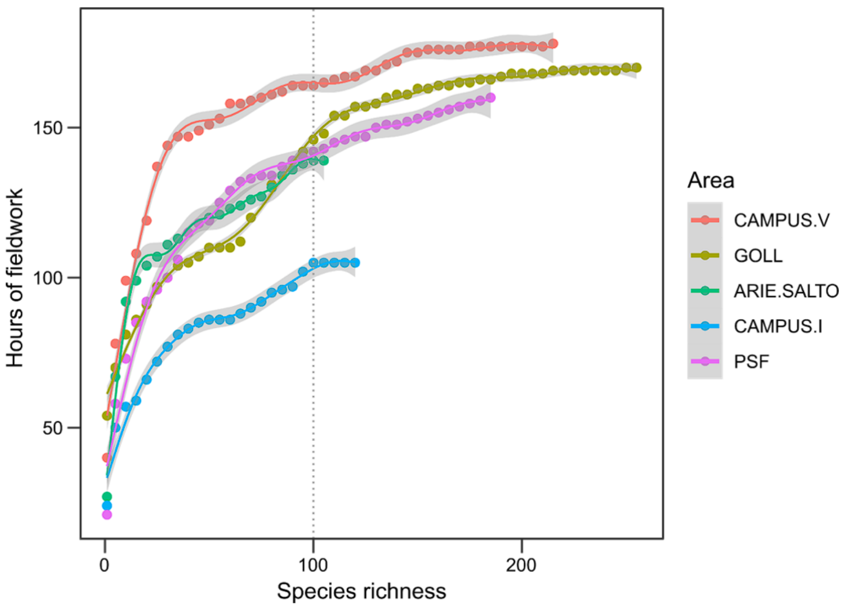

Figure 3. Accumulation curves of species for each study area. Gray regions delimit 95% confidence intervals for the smooth functions.

The increased sampling effort in some areas led to an increase in the number of observed new species after a long monitoring period, reinforcing the role of forest fragments as places of passage, rest, and feeding (Pizo & Tonetti, 2020). It may also indicate that forest remnants serve as discontinuous corridors (ecological stepping stones) and contribute to enhancing bird community connectivity and conservation in urban ecosystems (Herrera, Sabatino, Jaimes, & Saura, 2017).

Studies have indicated the negative effects of urbanization on bird species richness and composition, especially during the breeding season (MacGregor-Fors, González-García, Hernández-Lara, & Santiago-Alarcon, 2018). The urban matrix is generally hostile to bird movement, and ecological stepping stones may reduce the effects of species isolation in these forest fragments (Pereira, Oliveira, & Torezan, 2013; Sacco, Rui, Bergmann, Müller, & Hartz, 2015; Barbosa, Knogge, Develey, Jenkins, & Uezu, 2017; Silva Coelho et al., 2018). The hypothesis that urban forest fragments function as discontinuous corridors or ecological stepping stones is better understood with longer monitoring periods, as in the case of the Goll fragment. The Common Pauraque (*Nyctidromus albicollis*) and the White Woodpecker (*Melanerpes candidus*) are typical examples. They were recorded after 135 and 250 hours of sampling effort, respectively, thereby suggesting a recolonization of the area, as predicted by the metapopulation theory (Hanski & Simberloff,1997).

Species richness was greater in larger fragments, as indicated by the estimated power model (Figure 4), whose parameters were significantly different from zero at the significance level of 0.05. The model highlights the classic relationship between species richness and area described by the theory of island biogeography, where larger areas would harbor greater species richness (MacArthur & Wilson, 2001; Willis, 1979). A similar relationship was found in several studies carried out in the Amazon rainforest (Bierregaard, et al., 1992; Laurance, et al., 2002; Stouffer, 2020), Minas Gerais (Marini, 2000), São Paulo (Uezu, Metzger, & Vielliard, 2005; Martensen, Pimentel, & Metzger, 2008; Boscolo & Metzger, 2009, 2011), and Paraná (Anjos, Bochio, Campos, McCrate, & Palomino, 2009).

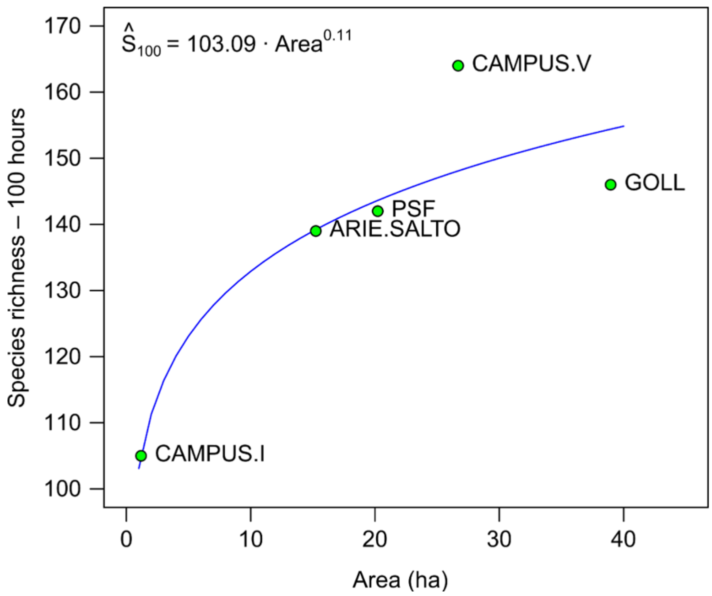

Figure 4. Mean response of the power model relating species richness in 100 hours of field survey and forest fragment size.

Regarding diversity and equitability indices, the averages exceeded than 3.00 nats ind^{-1}. and 0.90, respectively. These values align with expectations for tropical environments and heterogeneous communities, where non-dominant bird species are not prevalent (D'angelo Neto, Venturin, Oliveira Filho, & Costa, 1998) (Table 1). Comparable values were also found in urban fragments in Blumenau, where the Shannon Diversity Index ranged from 2.94 to 3.39 nats ind^{-1}. (Guztzazky, Cruz, Rupp, & Zimmermann, 2014).

Table 1. Physical and biological parameters of the studied urban forest remnants.

Study area	SaE	S; S_{100}	H' (sd)	E (sd)	Mean sp. h^{-1} (sd)	Mean ind. h^{-1} (sd)	AS (ha)	P (m)	SI	TA (ha)
Arie do Salto	100	138; 138	3.37 (±0.43)	0.94 (±0.11)	36.11 (±7.9)	83.19 (±22.9)	15.2	1,873	1.35	61.7
Campus I	105	105; 105	3.20 (±0.23)	0.93 (±0.05)	31.21 (±3.9)	75.82 (±15.4)	1.2	807	2.1	30.1
Campus V	215	178; 165	3.58 (±0.24)	0.96 (±0.02)	40.81 (±8.2)	87.61 (±19.2)	26.7	4,322	2.4	92.6
São Francisco Park	179	159; 142	3.41 (±0.24)	0.97 (±0.02)	34.24 (±6.8)	69.65 (±14.9)	20.2	2,246	1.4	76.6
Albert Goll	261	170; 146	3.42 (±0.24)	0.96 (±0.03)	35.64 (±6.7)	76.87 (±20.1)	38.9	6,014	2.7	112.5

* SaE - sampling effort in hours; S - Richness; S100 - Richness with 100 hours of sampling effort; H' - Diversity Index (Shannon); E - Evenness Index; AS - area without the 200 m buffer; P - Perimeter; SI - Shape Index; TA - total area with the 200 m buffer. (sd) – Standard deviation.

Unlike other areas, the PSF is shielded by an adjoining Environmental Protection Area. Alongside the 200 m buffer zone around the park, an area of 76 ha was sampled, of which 60.6 ha (79%) is composed of conserved forest environments (Table 2). Interestingly, this area is the most pristine among those evaluated in this study, yet it did not exhibit the greatest richness of bird species (Table 2). The greatest species richness was observed in Campus V, where 52% of its area is covered by non-forest environments. This underscores the relevance of environmental complexity or heterogeneity (mosaic) in the urban ecosystem for the coexistence, movement, and permanence of a greater number of bird species in forest remnants (Boscolo & Metzger, 2009; Reis et al., 2010; Boscolo & Metzger, 2011).

Despite not having the greatest species richness, the officially protected areas, namely PSF and ARIE do Salto, had the smallest values for the shape index, 1.41 and 1.31, respectively. This suggests that these areas have high conservation value, as values close to 1.00 indicate more regular shapes and, therefore, less influence of edge effects (Silva, Longo, Bressane, & Carvalho, 2019). Species such as the Ruddy Ground-Dove (*Columbina talpacoti*) may often be observed because they are favored by increased forest edge area, which creates habitats for granivorous and habitat-generalist birds (Poletto et al., 2004).

The greatest forest cover found in PSF is another feature that adds conservation value, as it promotes the occurrence of birds associated with more conserved forests. A typical example is the Rufous-capped Antthrush (*Formicarius colma*), which was not recorded in any of the smaller fragments since it depends on a developed forest understory. Species such as the Red-crowned Ant Tanager (*Habia rubica*), the Least Pygmy-Owl (*Glaucidium minutissimum*), and the Pale-browed Treehunter (*Cichlocolaptes leucophrus*) were found only in PSF.

Table 2 Area (in hectares) of land use classes including the 200 m buffer.

Study areas	Land use class (ha)						
	Roads	Early successional forest	Intermediate/ Late successional forest	Lagoon	Pasture	Residential Industrial	Total
ARIE do Salto	4.96	3.61	29.08	0.00	1.32	22.65	61.63
Campus I	4.22	0.00	9.27	0.00	0.39	16.23	30.11
Campus V	4.82	13.61	30.99	0.79	15.29	27.11	92.61
São Francisco Park	1.89	6.44	54.09	0.00	0.00	14.21	76.64
Albert Goll	7.69	7.59	49.41	0.79	10.73	37.07	113.3
TOTAL	23.59	31.26	172.84	1.58	27.73	117.27	374.2

This study highlights an intriguing interaction between area size and land use heterogeneity, exemplified by Campus V, which exhibited the greatest richness of bird species (Table 2). Land use heterogeneity can create a more permeable matrix due to the mosaic of contact zones and/or edges between habitats, thus facilitating a smoother transition from a forested area to an urbanized landscape (Marenzi & Roderjan, 2005). Additionally, it can enhance landscape connectivity and species movement (Uezu et al., 2005; Barbosa et al., 2017; Timmers et al., 2022). Heterogeneous landscape matrices have garnered increased attention not only as corridors for bird species to traverse between forest fragments but also for their potential to create suitable habitats for some species (Stouffer, 2020).

In light of the global increase in urban expansion, fragmentation, and isolation of habitats (Nor et al., 2017), this study highlights the importance of conserving all forest remnants within an urban matrix. This can be effectively achieved by monitoring the frequency of bird species occurrence (Table S1, Supplementary Material). In this regard, 81 species (34.5%) were recorded in all five evaluated areas. In contrast, 54 species (22.9%) were recorded in a single fragment. For the remaining species, 28 (11.9%) occurred in four areas, 26 (11.1%) occurred in three areas, and the remaining (19.6%) occurred in two areas. Species occurring in more than one fragment are less threatened of becoming locally extinct (Fahrig, 2020), as they can occupy a larger number of forest remnants regardless of their size. For example, the Golden-crowned Warbler (*Basileuterus culicivorus*) and the Lesser Woodcreeper (*Xiphorhynchus fuscus*) are resilient to fragmentation and persist even in small fragments (Poletto et al., 2004; Boscolo, Candia-Gallardo, Awade, & Metzger, 2008). Both species are forest insectivores and were recorded in all areas (100%). For these species and others with occurrence frequency greater than 60%, forest remnants also appear to function as habitats, allowing for the presence of resident populations.

Species with conservation interest

This study emphasizes the importance of forest remnants within the urban matrix by documenting the presence of species with conservation interest. Notably, 73 species considered endemic to the Atlantic Forest were observed, including the White-necked Hawk (*Amadonastur lacernulatus*). Endemic species naturally have reduced populations and may experience population decline as a result of forest fragmentation, which can lead to extinction (Ribon, Simon, & Mattos, 2003). Species observed and considered vulnerable (VU) in the state of Santa Catarina include the Black Hawk (*Spizaetus tyrannus*), the Yellow-throated Woodpecker (*Piculus flavigula*), the Tanager (*Ramphocelus bresilia*), and the Black-fronted Seedeater (*Sporophila frontalis*) (Table S1, Supplementary Material). The Kaempfer's Tody-Tyrant (*Hemitriccus kaempferi*) and the Yellow-legged Tinamou (*Crypturellus noctivagus*), deemed endangered (EN), were recorded in the non-legally protected area of Campus V. It merits noting that the most endangered species in Santa Catarina is the Blue-winged Macaw (*Primolius maracana*), deemed critically endangered (CR) (CONSEMA, 2011).

Conclusion

The key findings of this study are (a) the vital role of these forest fragments in sustaining bird populations; (b) the notable richness found in these areas; (c) and that fragments can protect bird species with conservation interest, including endemic species and those threatened with extinction.

Considering the loss of habitats, this study recommends (1) prioritizing the protection of remnants regardless of size; (2) developing integrated conservation strategies; (3) and implementing actions that enhance connectivity of the urban landscape. Managers should include permanent preservation areas in urban areas such as riparian forests and green areas as an approach to create a network of small protected areas.

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