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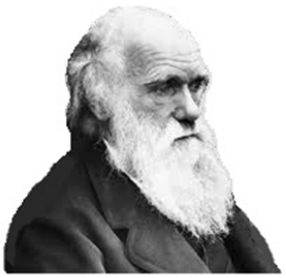

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Spatial distribution and trophic structure of bird's communities of Atlantic Forest fragments in Brazil

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ABSTRACT

We analyzed the differences in composition, richness, and abundance of birds in forest fragments of the Atlantic Forest in the São Paulo State, Brazil, and we demonstrated the variations in richness and abundance of birds between different trophic guilds. We used point counts to characterize the avifauna. Sampling was conducted in two seasons: summer and winter of 2020 in a total of 18 hours distributed in 54 samples. A total of 544 contacts were obtained, belonging to 144 bird species distributed among 22 orders and 45 families and categorized in 18 trophic guilds. The omnivores and insectivores birds composed most of the community, occupying the edge and different strata of the forest such as canopy and understory. For each species, we calculated the abundance index value that showed our study site had a large number of species with low index and few species with intermediate to high index compared to the pattern observed in other surveys. Our study area was characterized by high species diversity for both periods studied. The Shannon-Weaver diversity index for our study areas was 4.62. Equitability was high, 0.92, suggesting the number of species registered in our study site represented the maximum capacity the areas can shelter. Our results show that despite being a secondary and fragmented forest the study area was characterized by a diverse avian community. Although the anthropized forest environments are fragmented and isolated by degraded areas and occupied by pastures, agricultural and urban areas, they are important natural environments to maintain bird diversity.

***Keywords*:** Atlantic forest, avifauna, bird, Brazil, ecology, trophic guild

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1. INTRODUCTION

The Atlantic Forest is one of the most important biodiversity hotspots, originally covering over 1.3 million km^2, distributed along the Brazilian coastal, and is the most threatened Brazilian biome. This important biome harbors a high diversity of bird species, with several endemic and threatened species [1].

The Brazilian Atlantic Forest sensu lato is classified as an area that comprises three types of forests: Ombrophylous Dense forests, Semideciduous and Deciduous Stationary forests from the South and Southern regions, and Ombrophylous Mist forest, also known as *Araucaria* forest from Southern Brazil [2, 3].

During the last 500 years, the Atlantic Forest has been exploited and destroyed, being replaced first by sugarcane in the Northeast region (XVI century), and then later by coffee in the states of Rio de Janeiro and São Paulo (XVIII and XIX century), by cattle ranching in the states of São Paulo and Minas Gerais (XIX and XX century), by cocoa in state of Bahia (XX century), and more recently by *Eucalyptus* forest for cellulose and paper production. The forest was also replaced by cities, being the homeland of about 125 million Brazilians, since all state capitals from the S, SE, and NE region, including Porto Alegre, São Paulo, Rio de Janeiro, Salvador, and Recife, are within the Atlantic Forest domain. Therefore, there is only 7.6%, of the original Atlantic Forest left, and less than 50% of the remnants are protected in conservation Units, according to INPE, the National Institute for Space Research, a research unit of the Brazilian Ministry of Science, Technology and Innovation [4].

The Atlantic Forest has an extremely diverse and unique mix of vegetation and forest types. It has spectacular bird diversity, with over 930 species, about 15 percent of which are found nowhere else [5]. This avifauna is a highly endangered community: 68 % of the species are rare and there are 23 endemic genera [6]. Because most of the region's forests have been cleared during 500 years of exploitation, many species are now threatened, and future extinctions seem inevitable [7, 8].

Among the many factors thought to contribute to the high bird species richness in the Neotropics is the high diversity of habitat and microhabitat types, some of which are unique to tropical regions [9, 10]. The increase in structural complexity of the vegetation on various vertical levels makes new forms of occupancy of the environment possible [11]. The increase in the number of bird species is principally due to the increase of both the new food guilds and the number of species in the existing guilds [12].

The birds are considered the most important bioindicators of the quality of ecosystems because they are sensitive to the alterations of the environment [13]. The birds were group together according to their alimentary diet and to their forest layers, classifying those species that present feeding and similar biotope [14] in distinct ecological groups (trophic guilds).

The biological diversity of tropical forests is seriously threatened by rapid and continuous deforestation. Expanding human populations and attendant land-use changes are the primary factors driving changes in biological diversity [15, 16]. The future scenario of species extinctions appears to hold dramatic changes for the bird communities in the smaller remnants [17]. The main objective of this study was to analyze the groups of birds that were affected by the forest fragmentation in an area fragmented of Atlantic Forest, using birds as an ecological indicator.

2. MATERIALS AND METHODS

The studies were carried out in forest fragments of Ombrophilous Dense Forest at Atlantic Forest, situated in the municipality of Boituva, in the São Paulo State, Southeastern Brazil. It lies between 23°18'S to 23°20'S latitude and 47°39'W to 47°40'W longitude (**Figure 1**), between 530 and 600 meters of altitude. The climate of the region is the Cfa type according to Köppen's classification, humid subtropical climate with hot and humid summers, and cold to mild winters. The annual average rainfall is over 1,100 mm, concentrated in the summer. There are two distinct seasons, a dry season that lasts from April to September, and a humid season that occurs from October to March. The annual medium temperature range is 21.0 °C (69.8 °F).

Different natural environments were studied: forest fragments in medium stage of ecological succession; anthropic areas with pasture and agriculture; and an ecotonal zone between these two environments, that is, the edge of forest fragments. The vegetal community of these fragments is part of a forest subjected to human interference. The forest fragments form in some places riparian forests of streams and swamps.

In the forest fragments are recognizable three vertical strata of the vegetation: herbaceous stratum, understorey, and canopy stratum. The canopy stratum is composed of the crowns of large-sized trees, with sparse trees varying in average height between eight and 12 meters. The estimated basal area was 16.99 $m^2.ha^{-1}$ and densities ranging from 800 to 1,000 $trees.ha^{-1}$. High species diversity was observed, H = 3.74 nats ind^{-1}. The forest fragments, where bird studies were conducted, are areas that are relatively narrow about 100 meters wide, and suffering an edge effect due to pressure from anthropic areas. The overstorey, the uppermost canopy level of the forest, formed by the tallest trees, is characterized by crowns of large-sized trees varying in average height between 8 and 12 m, proportionating luminosity conditions that benefit the differentiated shrubs herbaceous stratus. Among the most ecological significant species in this forest layer recorded in this study included *Piptadenia gonoacantha*, *Cupania vernalis*, *Anadenanthera colubrina*, *Croton floribundus*, *Tapirira guianensis*, *Pera glabrata*, *Guarea guidonia*, *Alchornea glandulosa*, *Xylopia brasiliensis*, *Copaifera langsdorffii*, *Inga edulis*, *Ocotea puberula*, *Andira fraxinifolia*, *Machaerium villosum*, *Lonchocarpus guilleminianus*, *Cedrela fissilis*, *Myrsine ferruginea*, *Syagrus romanzoffiana*, and *Zanthoxylum rhoifolium*. Most of these trees produce fruit used by local wildlife [18, 19].

The understorey is characterized by the dominance of shrubs between 0.80 and 2.00 meters tall and the outstanding species in this stratum are of the families Melastomataceae, Myrtaceae, Rubiaceae, Fabaceae, and Euphorbiaceae. The herbaceous stratum (generally until 0.80 meters tall) is predominated by terrestrial bromeliads, herbs as heliconias and ferns as *Dycksonia sellowiana*, endemic and threatened with extinction. The trees shelter a higher diversity of epiphytic plants such as bromeliads, orchids, aroids and cacti, mosses, lichens, and vines. This dendricola vegetation is an outcome of a saturated atmosphere of humidity. The marsh vegetation appears on poorly drained soil-forming low terrains and areas dominated by aquatic macrophytes like *Hedychium coronarium* and *Typha dominguensis*.

The method used to sample the avifauna specimens was the technique of observations per point-counts [20]. The location of the points used for this census was randomly chosen and was representative of the whole area: for each sample, the point was sorted independently among previously determined points covering the whole area. The points were marked at least 200 meters apart to avoid over-representation of species with long-range voices [21]. The bird's observations were realized in the first hours after the dawn and during the twilight. The

samplings were accomplished in six days in two seasons: summer and winter of 2020 (in a total of 18 hours distributed in 54 samples). The duration of each point census is 20 minutes [21]. Bird species were identified by vocal recognition and by observations with binoculars. The birds that overflying the areas without to perch on a tree were not analyzed, because their dependence on the places was unlikely. To the scientific nomenclature and taxonomic order was used the new systematic list of CBRO [22]. To determine if the samples were enough were plotted the accumulated number of species against the total number of hours of observation. Since the curve reached a plateau, it was possible to conclude that the samples were enough for the registration of most species existent in the studied forest fragments.

Figure 1. Localization of the studied area. Description: point counts (in red); urban areas; forest fragments (in dark green); pasture and agriculture (in light green)

This study was limited to trace the similar relationships of feeding habitats and preferred foraging strata in the vegetation for the trophic guilds in different environments: open areas (pasture and agriculture), forest canopy, forest edge, riparian woodland, forest understory, swamps, and pond margins. These birds species are classified according to principal food items consumed: insectivores (arthropods), frugivores (fruits), omnivores (arthropods, fruits, and small vertebrates), granivores (seeds), nectarivores (nectar), carnivores (vertebrates captured alive), and detritivores (dead vertebrates) [23].

For each species, we calculated the Point Abundance Index (PAI), by dividing the number of detections for each species by the total number of points sampled [20]. To characterize bird community metrics, we obtained the Shannon-Weaver diversity index (H′), where H' max is the maximum diversity possible in the sample [24], and the equitability index [25].

3. RESULTS AND DISCUSSION

A total of 144 bird species were recorded in our study (**Table 1**). Bird species detected were distributed among 22 orders and 45 families, and categorized into seven alimentary diet

and 18 trophic guilds (**Figure 2**). The total number of detections was 544 and the density of birds in the area was 30.22 individuals/observation-hour. The most representative order was Passeriformes with 77 species which accounted for 53.5% of all species recorded.

Table 1. List of the bird species registered in this study and presented in the taxonomic order by Brazilian Ornithological Records Committee [22] with English names, Trophic Guilds (TG): carnivores (C), detritivores (D), frugivores (F), granivores (G), insectivores (I), nectarivores (N), omnivores (O); Environments (En): forest canopy (C), forest edge (E), open areas (O), riparian woodland (R), swamps and pond margins (S), forest understory (U); Point Abundance Index (PAI).

ORDER **Family** Taxon names	**English names**	**TG**	**En**	PAI
TINAMIFORMES (Huxley, 1872)				
Tinamidae (Gray, 1840)				
Crypturellus parvirostris (Wagler, 1827)	Small-billed Tinamou	O	U	0.0370
ANSERIFORMES (Linnaeus, 1758)				
Anatidae (Leach, 1820)				
Dendrocygna viduata (Linnaeus, 1766)	White-faced Whistling-Duck	O	S	0.0370
Amazonetta brasiliensis (Gmelin, 1789)	Brazilian Teal	O	S	0.0370
GALLIFORMES (Linnaeus, 1758)				
Cracidae (Rafinesque, 1815)				
Penelope obscura (Temminck, 1815)	Dusky-legged Guan	F	U	0.0926
PELECANIFORMES (Sharpe, 1891)				
Ardeidae (Leach, 1820)				
Tigrisoma lineatum (Boddaert, 1783)	Rufescent Tiger-Heron	C	R	0.0185
Butorides striata (Linnaeus, 1758)	Striated Heron	C	R	0.0370
Ardea alba (Linnaeus, 1758)	Great Egret	C	R	0.0741

Syrigma sibilatrix (Temminck, 1824)	Whistling Heron	I	O	0.0185
CATHARTIFORMES (Seebohm, 1890)				
Cathartidae (Lafresnaye, 1839)				
Coragyps atratus (Bechstein, 1793)	Black Vulture	D	O	0.0926
ACCIPITRIFORMES (Bonaparte, 1831)				
Accipitridae (Vigors, 1824)				
Leptodon cayanensis (Latham, 1790)	Gray-headed Kite	C	E	0.0370
Elanus leucurus (Vieillot, 1818)	White-tailed Kite	C	E	0.0185
Ictinia plumbea (Gmelin, 1788)	Plumbeous Kite	C	E	0.0185
Rostrhamus sociabilis (Vieillot, 1817)	Snail Kite	C	R	0.0185
Rupornis magnirostris (Gmelin, 1788)	Roadside Hawk	C	E	0.0926
Geranoaetus albicaudatus (Vieillot, 1816)	White-tailed Hawk	C	E	0.0185
Buteo brachyurus (Vieillot, 1816)	Short-tailed Hawk	C	E	0.0370
GRUIFORMES (Bonaparte, 1854)				
Rallidae (Rafinesque, 1815)				
Aramides cajaneus (Statius Müller, 1776)	Gray-necked Wood-Rail	O	S	0.0185
Pardirallus nigricans (Vieillot, 1819)	Blackish Rail	O	S	0.0185
Gallinula galeata (Lichtenstein, 1818)	Common Gallinule	O	S	0.0370
CHARADRIIFORMES (Huxley, 1867)				
Charadriidae (Leach, 1820)				
Vanellus chilensis (Molina, 1766)	Southern Lapwing	O	O	0.0926
Jacanidae (Chenu & Des Murs, 1854)				
Jacana jacana (Linnaeus, 1766)	Wattled Jacana	O	S	0.0370
COLUMBIFORMES (Latham, 1790)				

Columbidae (Leach, 1820)				
Columbina talpacoti (Temminck, 1811)	Ruddy Ground-Dove	G	O	0.2593
Columbina squammata (Lesson, 1831)	Scaled Dove	G	O	0.0926
Columba livia (Gmelin, 1789)	Rock Pigeon	G	O	0.0370
Patagioenas picazuro (Temminck, 1813)	Picazuro Pigeon	O	E	0.2963
Zenaida auriculata (Des Murs, 1847)	Eared Dove	G	O	0.1481
Leptotila verreauxi (Bonaparte, 1855)	White-tipped Dove	O	E	0.0556
CUCULIFORMES (Wagler, 1830)				
Cuculidae (Leach, 1820)				
Piaya cayana (Linnaeus, 1766)	Squirrel Cuckoo	I	C	0.0741
Crotophaga ani (Linnaeus, 1758)	Smooth-billed Ani	I	E	0.2222
Guira guira (Gmelin, 1788)	Guira Cuckoo	I	E	0.3148
Tapera naevia (Linnaeus, 1766)	Striped Cuckoo	I	E	0.0185
STRIGIFORMES (Wagler, 1830)				
Strigidae (Leach, 1820)				
Megascops choliba (Vieillot, 1817)	Tropical Screech-Owl	C	E	0.0185
Athene cunicularia (Molina, 1782)	Burrowing Owl	I	E	0.0370
Asio flammeus (Pontoppidan, 1763)	Short-eared Owl	C	E	0.0185
NYCTIBIIFORMES (Yuri et al., 2013)				
Nyctibiidae (Chenu & Des Murs, 1851)				
Nyctibius griseus (Gmelin, 1789)	Common Potoo	I	U	0.0185
CAPRIMULGIFORMES (Ridgway, 1881)				
Caprimulgidae (Vigors, 1825)				
Nyctidromus albicollis (Gmelin, 1789)	Common Pauraque	I	O	0.0185
Hydropsalis parvula (Gould, 1837)	Little Nightjar	I	O	0.0185

APODIFORMES (Peters, 1940)				
Trochilidae (Vigors, 1825)				
Phaethornis pretrei (Lesson & Delattre, 1839)	Planalto Hermit	N	E	0.0741
Eupetomena macroura (Gmelin, 1788)	Swallow-tailed Hummingbird	N	E	0.0185
Colibri serrirostris (Vieillot, 1816)	White-vented Violetear	N	E	0.0370
Aphantochroa cirrochloris (Vieillot, 1818)	White-throated Hummingbird	N	E	0.0370
Leucochloris albicollis (Vieillot, 1818)	White-throated Hummingbird	N	E	0.0370
Chlorostilbon lucidus (Shaw, 1812)	Glittering-bellied Emerald	N	E	0.0185
Amazilia versicolor (Vieillot, 1818)	Versicolored Emerald	N	E	0.0926
Amazilia fimbriata (Gmelin, 1788)	Glittering-throated Emerald	N	E	0.0741
Amazilia lactea (Lesson, 1832)	Sapphire-spangled Emerald	N	E	0.0370
TROGONIFORMES (A. O. U., 1886)				
Trogonidae (Lesson, 1828)				
Trogon surrucura (Vieillot, 1817)	Surucua Trogon	I	U	0.0370
CORACIIFORMES (Forbes, 1844)				
Alcedinidae (Rafinesque, 1815)				
Megaceryle torquata (Linnaeus, 1766)	Ringed Kingfisher	C	R	0.0185
Chloroceryle americana (Gmelin, 1788)	Green Kingfisher	C	R	0.0185
GALBULIFORMES (Fürbringer, 1888)				
Bucconidae (Horsfield, 1821)				
Malacoptila striata (Spix, 1824)	Crescent-chested Puffbird	I	U	0.0185
PICIFORMES (Meyer & Wolf, 1810)				
Ramphastidae (Vigors, 1825)				

Ramphastos toco (Statius Muller, 1776)	Toco Toucan	O	C	0.0370
Picidae (Leach, 1820)				
Picumnus temminckii (Lafresnaye, 1845)	Ochre-collared Piculet	I	E	0.1481
Melanerpes candidus (Otto, 1796)	White Woodpecker	I	E	0.0556
Veniliornis spilogaster (Wagler, 1827)	White-spotted Woodpecker	I	E	0.0370
Colaptes campestris (Vieillot, 1818)	Campo Flicker	I	O	0.1852
Celeus flavescens (Gmelin, 1788)	Blond-crested Woodpecker	I	E	0.0370
Dryocopus lineatus (Linnaeus, 1766)	Lineated Woodpecker	I	E	0.0370
Campephilus robustus (Lichtenstein, 1818)	Robust Woodpecker	I	E	0.0185
CARIAMIFORMES (Furbringer, 1888)				
Cariamidae (Bonaparte, 1850)				
Cariama cristata (Linnaeus, 1766)	Red-legged Seriema	C	O	0.0185
FALCONIFORMES (Bonaparte, 1831)				
Falconidae (Leach, 1820)				
Caracara plancus (Miller, 1777)	Southern Caracara	O	E	0.0741
Milvago chimachima (Vieillot, 1816)	Yellow-headed Caracara	C	E	0.1111
Falco sparverius (Linnaeus, 1758)	American Kestrel	C	O	0.0556
Falco femoralis (Temminck, 1822)	Aplomado Falcon	C	O	0.0370
PSITTACIFORMES (Wagler, 1830)				
Psittacidae (Rafinesque, 1815)				
Psittacara leucophthalmus (Statius Muller, 1776)	White-eyed Parakeet	F	C	0.1111
Forpus xanthopterygius (Spix, 1824)	Blue-winged Parrotlet	F	C	0.2222
Brotogeris tirica (Gmelin, 1788)	Plain Parakeet	F	C	0.0741
Pionus maximiliani (Kuhl, 1820)	Scaly-headed Parrot	F	C	0.0926

PASSERIFORMES (Linnaeus, 1758)				
Thamnophilidae (Swainson, 1824)				
Dysithamnus mentalis (Temminck, 1823)	Plain Antvireo	I	U	01111
Thamnophilus doliatus (Linnaeus, 1764)	Barred Antshrike	I	U	0.1296
Thamnophilus caerulescens (Vieillot, 1816)	Variable Antshrike	I	U	0.0556
Conopophagidae (Sclater & Salvin, 1873)				
Conopophaga lineata (Wied, 1831)	Rufous Gnateater	I	U	0.0370
Dendrocolaptidae (Gray, 1840)				
Sittasomus griseicapillus (Vieillot, 1818)	Olivaceous Woodcreeper	I	U	0.0556
Lepidocolaptes angustirostris (Vieillot, 1818)	Narrow-billed Woodcreeper	I	E	0.0185
Xenopidae (Bonaparte, 1854)				
Xenops rutilans (Temminck, 1821)	Streaked Xenops	I	U	0.0185
Furnariidae (Gray, 1840)				
Furnarius rufus (Gmelin, 1788)	Rufous Hornero	I	E	0.0556
Certhiaxis cinnamomeus (Gmelin, 1788)	Yellow-chinned Spinetail	I	S	0.0370
Synallaxis ruficapilla (Vieillot, 1819)	Rufous-capped Spinetail	I	E	0.0926
Synallaxis frontalis (Pelzeln, 1859)	Sooty-fronted Spinetail	I	E	0.0370
Synallaxis albescens (Temminck, 1823)	Pale-breasted Spinetail	I	E	0.0185
Synallaxis spixi (Sclater,1856)	Spix's Spinetail	I	E	0.0370
Tityridae (Gray, 1840)				
Pachyramphus polychopterus (Vieillot, 1818)	White-winged Becard	O	E	0.0556
Pachyramphus validus (Lichtenstein, 1823)	Crested Becard	O	E	0.0185
Rynchocyclidae (Berlepsch, 1907)				
Tolmomyias sulphurescens (Spix, 1825)	Yellow-olive Flycatcher	I	U	0.0370

Todirostrum cinereum (Linnaeus, 1766)	Common Tody-Flycatcher	I	E	0.0370
Tyrannidae (Vigors, 1825)				
Hirundinea ferruginea (Gmelin, 1788)	Cliff Flycatcher	I	E	0.0370
Camptostoma obsoletum (Temminck, 1824)	Southern Beardless-Tyrannulet	O	E	0.0926
Elaenia flavogaster (Thunberg, 1822)	Yellow-bellied Elaenia	O	E	0.0741
Serpophaga subcristata (Vieillot, 1817)	White-crested Tyrannulet	I	U	0.0370
Myiarchus ferox (Gmelin, 1789)	Short-crested Flycatcher	O	E	0.0370
Pitangus sulphuratus (Linnaeus, 1766)	Great Kiskadee	O	E	0.1667
Myiodynastes maculatus (Statius Muller, 1776)	Streaked Flycatcher	O	E	0.0556
Machetornis rixosa (Vieillot, 1819)	Rusty-margined Flycatcher	O	E	0.0556
Tyrannus melancholicus (Vieillot, 1819)	Tropical Kingbird	O	E	0.1667
Empidonomus varius (Vieillot, 1818)	Variegated Flycatcher	O	E	0.0370
Megarhynchus pitangua (Linnaeus, 1766)	Boat-billed Flycatcher	O	E	0.0370
Myiozetetes similis (Spix, 1825)	Social Flycatcher	O	E	0.0556
Tyrannus savana (Vieillot, 1808)	Fork-tailed Flycatcher	O	E	0.0185
Myiophobus fasciatus (Statius Müller, 1776)	Bran-colored Flycatcher	O	E	0.0185
Pyrocephalus rubinus (Boddaert, 1783)	Vermilion Flycatcher	I	E	0.0185
Fluvicola nengeta (Linnaeus, 1766)	Masked Water-Tyrant	I	S	0.0370
Gubernetes yetapa (Vieillot, 1818)	Streamer-tailed Tyrant	I	S	0.0185
Lathrotriccus euleri (Cabanis, 1868)	Euler's Flycatcher	I	E	0.0370
Knipolegus lophotes (Boie 1828)	Crested Black-Tyrant	O	E	0.0370
Satrapa icterophrys (Vieillot, 1818)	Yellow-browed Tyrant	I	E	0.0185
Xolmis velatus (Lichtenstein, 1823)	White-rumped Monjita	I	O	0.0185
Vireonidae (Swainson, 1837)				
Cyclarhis gujanensis (Gmelin, 1789)	Rufous-browed Peppershrike	O	E	0.1296

Vireo chivi (Vieillot, 1817)	Chivi Vireo	O	E	0.0370
Hirundinidae (Rafinesque, 1815)				
Pygochelidon cyanoleuca (Vieillot, 1817)	Blue-and-white Swallow	I	O	0.1481
Progne tapera (Vieillot, 1817)	Brown-chested Martin	I	O	0.1111
Progne chalybea (Gmelin, 1789)	Gray-breasted Martin	I	O	0.0556
Troglodytidae (Swainson, 1831)				
Troglodytes musculus (Vieillot, 1808)	Southern House Wren	I	E	0.1296
Donacobiidae (Aleixo & Pacheco, 2006)				
Donacobius atricapilla (Linnaeus, 1766)	Black-capped Donacobius	I	S	0.0370
Turdidae (Rafinesque, 1815)				
Turdus rufiventris (Vieillot, 1818)	Rufous-bellied Thrush	O	E	0.1481
Turdus amaurochalinus (Cabanis, 1851)	Creamy-bellied Thrush	O	E	0.0556
Mimidae (Bonaparte, 1853)				
Mimus saturninus (Lichtenstein, 1823)	Chalk-browed Mockingbird	O	E	0.2222
Passerellidae (Cabanis & Heine, 1850)				
Zonotrichia capensis (Statius Muller, 1776)	Rufous-collared Sparrow	O	O	0.0741
Ammodramus humeralis (Bosc, 1792)	Grassland Sparrow	O	O	0.3333
Parulidae (Wetmore et al., 1947)				
Setophaga pitiayumi (Vieillot, 1817)	Tropical Parula	O	E	0.0370
Geothlypis aequinoctialis (Gmelin, 1789)	Masked Yellowthroat	I	E	0.0185
Basileuterus culicivorus (Deppe, 1830)	Golden-crowned Warbler	I	U	0.0741
Icteridae (Vigors, 1825)				
Icterus pyrrhopterus (Vieillot, 1819)	Variable Oriole	O	E	0.0370
Molothrus bonariensis (Gmelin, 1789)	Shiny Cowbird	O	O	0.1111
Thraupidae (Cabanis, 1847)				

Tangara sayaca (Linnaeus, 1766)	Sayaca Tanager	O	E	0.2963
Tangara palmarum (Wied, 1821)	Palm Tanager	O	E	0.1296
Tangara cayana (Linnaeus, 1766)	Burnished-buff Tanager	O	E	0.0370
Conirostrum speciosum (Temminck, 1824)	Chestnut-vented Conebill	I	E	0.1111
Sicalis flaveola (Linnaeus, 1766)	Saffron Finch	G	O	0.2963
Sicalis luteola (Sparrman, 1789)	Grassland Yellow-Finch	G	O	0.2037
Volatinia jacarina (Linnaeus, 1766)	Blue-black Grassquit	G	O	0.1111
Coryphospingus cucullatus (Statius Muller, 1776)	Red-crested Finch	G	O	0.0185
Tachyphonus coronatus (Vieillot, 1822)	Ruby-crowned Tanager	O	E	0.0370
Tersina viridis (Illiger, 1811)	Swallow Tanager	O	E	0.0185
Dacnis cayana (Linnaeus, 1766)	Blue Dacnis	O	E	0.0370
Coereba flaveola (Linnaeus, 1758)	Bananaquit	O	E	0.1111
Sporophila lineola (Linnaeus, 1758)	Lined Seedeater	G	O	0.0370
Sporophila caerulescens (Vieillot, 1823)	Double-collared Seedeater	G	O	0.0556
Emberizoides herbicola (Vieillot, 1817)	Wedge-tailed Grass-Finch	O	O	0.0556
Cardinalidae (Ridgway, 1901)				
Piranga flava (Vieillot, 1822)	Hepatic Tanager	O	E	0.0185
Fringillidae (Leach, 1820)				
Spinus magellanicus (Vieillot, 1805)	Hooded Siskin	G	O	0.0185
Euphonia chlorotica (Linnaeus, 1766)	Purple-throated Euphonia	O	E	0.1111
Euphonia violacea (Linnaeus, 1758)	Violaceous Euphonia	O	E	0.0741
Euphonia cyanocephala (Vieillot, 1818)	Golden-rumped Euphonia	O	E	0.0370
Estrildidae (Bonaparte, 1850)				
Estrilda astrild (Linnaeus, 1758)	Common Waxbill	G	O	0.0926
Passeridae (Rafinesque, 1815)				
Passer domesticus (Linnaeus, 1758)	House Sparrow	O	E	0.0741

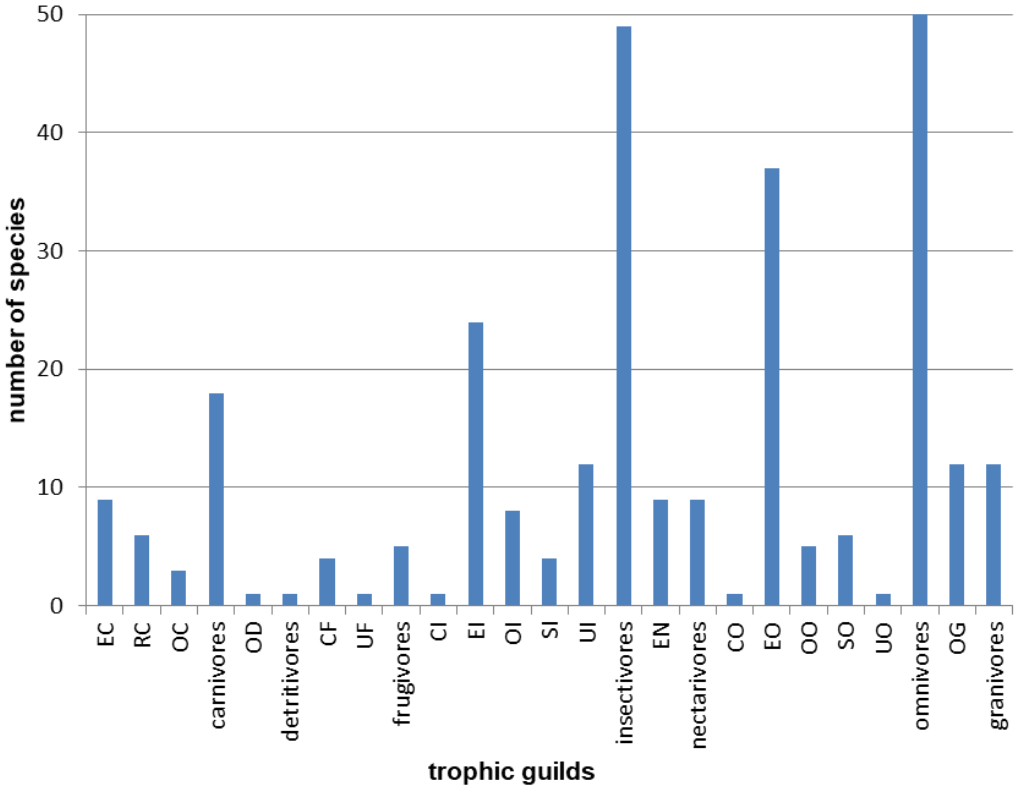

Figure 2. The number of bird species recorded in the area of study according to different trophic guilds. Edge carnivores (EC), riparian carnivores (RP), open-area carnivores (OC), open-area detritivores (OD), canopy frugivores (CF), understory frugivores (UF), canopy insectivores (CI), edge insectivores (EI), open-area insectivores (OI), swamp insectivores (SI), understory insectivores (UI), edge nectarivores (EN), canopy omnivores (CO), edge omnivores (EO), open-area omnivores (OO), swamp omnivores (SO), understory omnivores (UO), open-area granivores (OG).

Omnivores included 50 species occupying the edge and different strata of the forest such as canopy and understory. The great abundance of omnivores birds may be directly related to the abundant fruit resources. These results suggest the sensitivities of bird species to vegetation are associated with their dependence on a fruit diet [26]. Insectivores and nectar-feeders were represented by 49 species also as large distribution on the edge and inside the forest. The avian community in our study was similar to other Atlantic Forest fragments studied [27-31] with a predominance of omnivores and insectivores species.

Abundance index values (PAI) showed our study site had a large number of species with low PAI and few species with intermediate to high PAI compared to the pattern observed in other surveys [32-34]. The PAI varied from 0.0185 (two contacts) to 0.3333 (22 contacts).

The most abundant species (Table 1) were *Ammodramus humeralis* (0.3333), *Guira guira* (0.3148), *Patagioenas picazuro* (0.2963), *Tangara sayaca* (0.2963), and *Sicalis flaveola* (0.2963), all synanthropic species and well adapted to the conditions of degraded environments.

These species have increased their populations due to the expansion of forest degradation, which provides a favorable environment for them.

Among the fifty species with the highest abundance, only three are understory insectivores. It is a group very affected by forest fragmentation. The decline in abundance of species less suited to anthropogenic disturbance, like frugivores and insectivores understory birds is a hallmark in fragmented areas [35, 36].

In tropical forest areas, communities of understorey birds are very dependent on forest environments and rarely move between forest patches in fragmented areas [38], and the composition and diversity of the understorey bird should vary mostly in response to fluctuations in the supply of food [38]. Insectivores birds usually have greater spatial stability and are more site-attached than frugivores ones [39], but this does not mean that fluctuations do not occur, since forest insectivores birds may have spatial distribution related to the availability of arthropods [40, 41].

The omnivores and the insectivores are the trophic guilds predominant at small remains forest [42, 43]. However, in general, populations of insectivore bird species are lost or tend to decline following forest isolation [44], which is affected mainly by the reduction of invertebrates in fragmented areas [45].

Habitat specialization is the major determinant factor of the vulnerability of the birds. Birds' sensitivity to changes in forest structure involves reduced food categories, habitat reduction, understory changes, edge effects, and increased exposure to predators [46]. Studies carried out in tropical forests indicate that more than 40% of all bird species are associated with gaps, edges, upper canopy emergent trees or natural openings [47, 48].

Therefore, a more permeable matrix may facilitate the species dispersal through the landscape, helping them find resources in other areas [49]. Similarly, as in this study, some studies obtained smaller abundance for frugivores, in landscapes tropical, fragmented, and anthropized [50, 51], maybe because there are not fruits during all the year and, certain species present a specialized diet, being more vulnerable to anthropic alterations and food availability [52]. The carnivores species also showed low representativeness, because they have a population with lower density, have a lower survival rate, and need a larger area to survive [53].

Some signs of good habitat conditions include the occurrence of mixed-species flocks [54] and army-ant swarm following birds, commons and confiding birds of primary and secondary forest that forage for small insects and other arthropods taken from twigs and foliage in the lower branches of trees. Among tropical forest birds, understory insectivores, such as some furnarids and formicarids, are particularly sensitive to habitat disturbance and fragmentation [55], and some of these important species were absent or rare in this study.

Mixed-species groups of these understory birds congregate around ant swarms, where they forage on insects flushed by the ants. Obligate ant-followers have specialized behaviors to track ant swarms and may serve as information sources for facultative ant-followers [56].

Mixed-species flocks are common in many tropical forests and have been well described in the Neotropics. Mixed-species flocking birds may increase foraging efficiency [57, 58] and protection from predation [59]. Mixed-species flocks in tropical forests are maintained throughout the annual cycle despite seasonal differences in resource availability, breeding seasons, and ecological requirements of individual species [60]. However, we observed few mixed-species flocks which suggest that the habitat conditions at the study area were no adequate for many bird species.

The studied area was characterized by high species diversity. The Shannon-Weaver diversity index was 4.62. Equitability was high, 0.92, suggesting the number of species registered in our study site represented the maximum capacity the areas can shelter.

Many of the species registered in this study were edge species (e.g., *Crotophaga ani*, *Guira guira*, *Patagioenas picazuro*, *Pitangus sulphuratus*, *Coereba flaveola*, *Tyrannus melancholicus*, *Turdus rufiventris*, *Mimus saturninus*, and *Tangara sayaca*), that represent 61.1% of all species recorded.

Most of these birds species, because prefer to visit the forest edge, are less affected by forest fragmentation, especially when we consider that the anthropic transformations caused in natural environments produce environments favorable to the development of pioneer vegetation, which is characterized by great production of fruits, increasing the availability of food for many of these birds that have in them the base of the feeding [61].

The occurrence of many species commonly found in human-altered habitats reflects the continuing degradation of the Atlantic Forest as more and more of these sites disappear. Some changes in vegetation structure and composition caused by deforestation may disrupt those interactions and change bird community composition [62, 63]. The conservation, restoration, and ecological studies of the Atlantic Forest represent important actions for conservation in this biome.

The guilds obtained for birds were grouped into seven broader groups based on diet (**Figure 3**), as follows: **Carnivores**: *Edge carnivores:* birds of prey, such as hawks and owls, that feed on a wide variety of vertebrates (birds, mammals, reptiles) that they capture on the ground, e.g., *Rupornis magnirostris* (Roadside Hawk) and *Buteo brachyurus* (Short-tailed Hawk) and species active mainly at night as owls that hunt several species of vertebrates, e.g., *Megascops choliba* (Tropical Screech-Owl); *Riparian carnivores*: species that feed mainly on fish and a large number of aquatic invertebrates caught in rivers or lakes, e.g., *Butorides striata* (Striated Heron), *Ardea alba* (Great Egret), and *Chloroceryle americana* (Green Kingfisher); *Open-area carnivores*: species that specialized in hunting prey in the air, and their main food item is other birds and bats. Representative species of this guild are falcons, e.g., *Falco femoralis* (Aplomado Falcon), and we also consider the *Cariama cristata* (Red-legged Seriema) for this group, a large terrestrial predator, it catches all kinds of prey even poisonous snakes and also steals nestlings and eggs from other bird's nests.

Detritivores: *Open-area detritivores*: necrophagous birds, who eat animals that have been run over on roads, or drowned in the rivers. In this study they are represented by the *Coragyps atratus* (Black Vulture), the most common species of vulture in Brazil.

Frugivores: *Canopy frugivores*: birds foraging on fruits mainly in the upper parts of trees, such as parrots, macaws, and parakeets, e.g., *Pionus maximiliani* (Scaly-headed Parrot), *Psittacara leucophthalmus* (White-eyed Parakeet), and *Forpus xanthopterygius* (Blue-winged Parrotlet)*; Understory frugivores*: the cracids, main representatives of that group, comprise essentially forest birds, from medium to large sizes that forage on the ground and in the lower parts of trees or shrubs, e.g., *Penelope obscura* (Dusky-legged Guan).

Granivores: *Open-area granivores*: these birds glean seeds principally on the ground and shrubs and rarely forage in trees. In the first category, the seed dispersers, such as pigeons and doves, e.g., *Columbina talpacoti* (Ruddy Ground-Dove), *Columba livia* (Rock Pigeon), and *Zenaida auriculata* (Eared Dove), and in the second category, the seed predators, that have

large bills, which are specially adapted to open the hard seeds of graminoids, e.g, *Sporophila caerulescens* (Double-collared Seedeater), and *Sicalis flaveola* (Saffron Finch).

Insectivores: *Canopy insectivores*: birds feeding mainly on insects and caterpillars mostly under the canopies of trees, e.g., *Piaya cayana* (Squirrel Cuckoo); *Edge insectivores*: (**Figure 4**) this group includes woodpecker species that feeds on caterpillars and insects caught on the internal side of tree bark, thanks to their capacity for perforating hard tree timber, e.g., *Veniliornis spilogaster* (White-spotted Woodpecker), and *Campephilus robustus* (Robust Woodpecker), also includes species that feed on insects caught on the foliage, foraging from the middle to high parts of trees, e.g., *Guira guira* (Guira Cuckoo), *Furnarius rufus* (Rufous Hornero), *Synallaxis spixi* (Spix's Spinetail), *Lathrotriccus euleri* (Euler's Flycatcher), and *Knipolegus lophotes* (Crested Black-Tyrant); *Open-area insectivores*: species feeding mainly on insects caught in the air above the tree canopy, such as swallows, which pursue winged insects flying in various flocks, e.g., *Pygochelidon cyanoleuca* (Blue-and-white Swallow), and species feeding on insects at night in mid-flight, e.g., *Nyctidromus albicollis* (Common Pauraque); s*wamp insectivores*: includes species that feed primarily on insects caught on the ground, near streams and flooded areas, e.g., *Fluvicola nengeta* (Masked Water-Tyrant); *Understory insectivores*: species that feed on insects caught on the foliage, foraging from the lower to middle parts of trees, e.g., *Dysithamnus mentalis* (Plain Antvireo), and *Thamnophilus doliatus* (Barred Antshrike), known for follow army ants and feeding off insects flushed out by the vast ant legion in the understory, and the woodcreepers, e.g., *Sittasomus griseicapillus* (Olivaceous Woodcreeper), their feet are syndactyl, and are used to explore vertical perches, their tails are provided with stiff "thorns" formed by elongation of their rectrices rachis, which are used to support their body's weight on tree trunks when climbing, in the same manner as the woodpeckers, however, unlike them, woodpeckers possess a delicate bill, which does not serve to excavate wood, but only to capture arthropods in the bark cavities.

Nectarivores: *Edge nectarivores*: species whose main food item is nectar from flowers, and they complement their diet by capturing small insects and spiders, such as hummingbirds *Phaethornis pretrei* (Planalto Hermit), *Eupetomena macroura* (Swallow-tailed Hummingbird), and *Amazilia versicolor* (Versicolored Emerald).

Omnivores: this group included species that cannot be differentiated by any type of food, because they feed on a wide variety of foods (insects, vertebrates, seeds, fruits, parts of plants), but yet they can be distinguished by their foraging habits such as *Canopy omnivores*, whose food is obtained from the canopy of trees, e.g., *Ramphastos toco* (Toco Toucan); *Edge omnivores*: are more frequent at the edges of forests, e.g., the thrushes *Turdus rufiventris* and *Turdus amaurochalinus*, the flycatchers *Tyrannus melancholicus*, *Pitangus sulphuratus*, and *Megarhynchus pitangua*, the tanagers *Tangara sayaca*, *Tachyphonus coronatus*, and *Dacnis cayana*; *Open-area omnivores*, e.g., *Vanelus chilensis* (Southern Lapwing), *Zonotrichia capensis* (Rufous-collared Sparrow), and includes species that forage on several types of food, including carrion, mainly on the ground, e.g., *Caracara plancus* (Southern Caracara); *Swamp omnivores*: ducks and teals that live in aquatic environments at rivers edges, swamplands and wet grasslands, e.g., *Dendrocygna viduata* (White-faced Whistling-Duck) and *Amazonetta brasiliensis* (Brazilian Teal), and rails like *Aramides cajaneus* (Gray-necked Wood-rail); *Understory omnivores*: tinamous, are terrestrial birds which have gallinaceous features, live in the countryside or semi-open areas, but the majority of them have forest habits, roaming timidly throughout the understory of forests, like the *Crypturellus parvirostris* (Small-billed Tinamou).

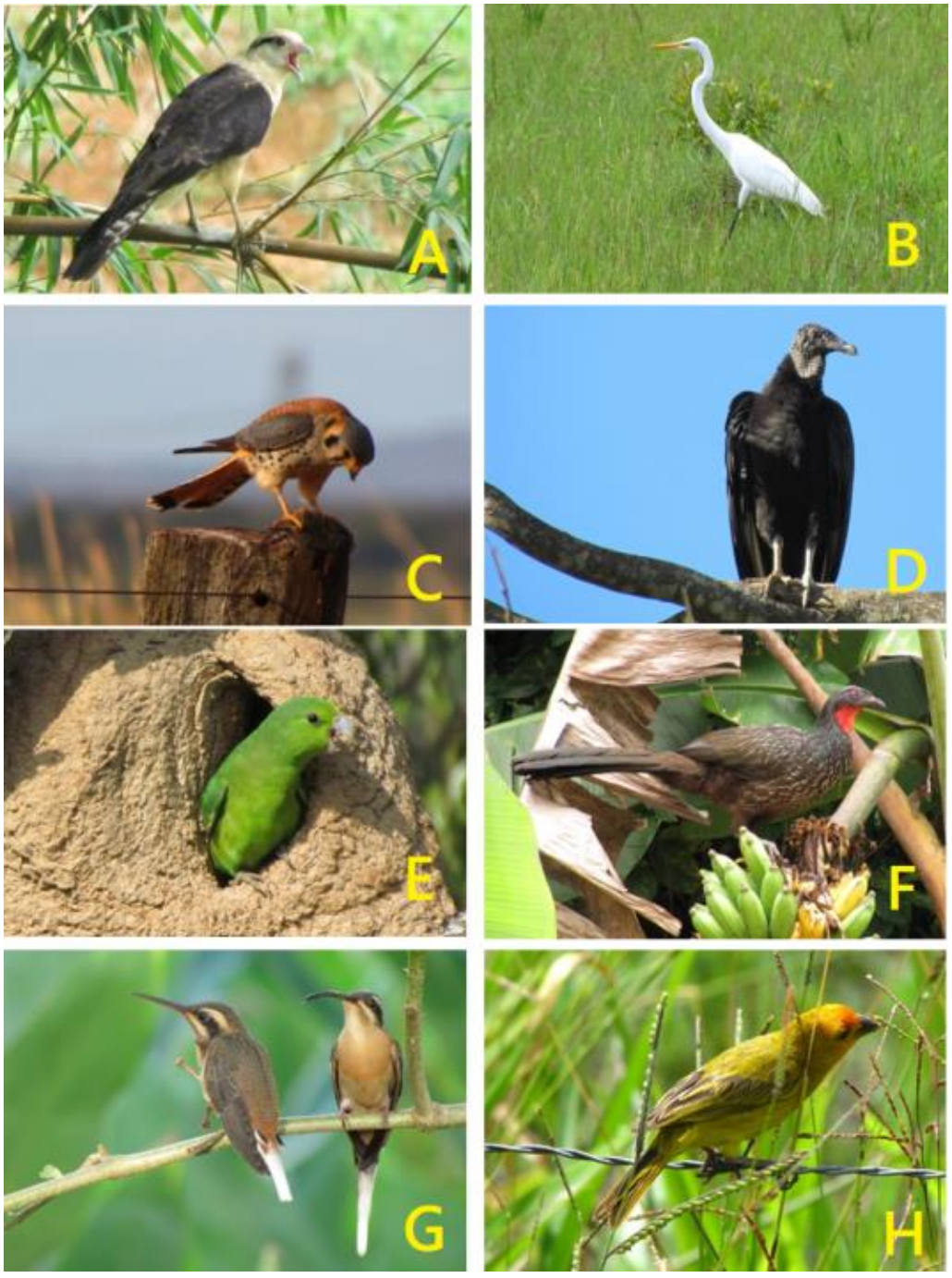

Figure 3. Examples of birds registered in this study: (A) edge carnivore *Milvago chimachima* (Yellow-headed Caracara), (B) riparian carnivore *Ardea alba* (Great Egret), (C) open-area carnivore *Falco sparverius* (American Kestrel) eating a mouse, (D) open-area detritivore *Coragyps atratus* (Black Vulture), (E) canopy frugivore *Forpus xanthopterygius* (Blue-winged Parrotlet) occupying the abandoned nest of a *Furnarius rufus*, (F) understory frugivore *Penelope obscura* (Dusky-legged Guan), (G) edge nectarivore *Phaethornis pretrei* (Planalto Hermit), and (H) open-area granivore *Sicalis flaveola* (Saffron Finch). Photos by Fabio Rossano Dario.

Figure 4. Examples of birds registered in this study: (A) edge insectivore *Athene cunicularia* (Burrowing Owl), (B) open-area insectivore *Colaptes campestris* (Campo Flicker), (C) swamp insectivore *Fluvicola nengeta* (Masked Water-Tyrant), (D) understory insectivore *Thamnophilus doliatus* (Barred Antshrike), (E) canopy omnivore *Ramphastos toco* (Toco Toucan), (F) edge omnivore *Mimus saturninus* (Chalk-browed Mockingbird), (G) open-area omnivore *Zonotrichia capensis* (Rufous-collared Sparrow), and (H) swamp omnivore *Amazonetta brasiliensis* (Brazilian Teal). Photos by Fabio Rossano Dario.

4. CONCLUSIONS

The impacts of forest fragmentation, even for a group with a notorious dispersion power such as that of birds, cause a territorial decrease, thus influencing a series of blocks to the interactions that this group presents concerning the environment. One of the greatest threats to biological diversity is the loss of habitats, due to fragmentation, which changes the dynamics of the area by increasing its amount of border.

Among the trophic guilds analyzed, understory insectivores are particularly sensitive to habitat disturbance and fragmentation. Bird species less affected by forest fragmentation are, in general, the omnivores and those that use the forest edge.

Analyzing the fragmentation and the size of the forest fragments existing in the study areas, the lack of connection between them, and the degree of anthropism, it is likely that the population dynamics of many bird species recorded in this study is already seriously compromised. However, the results of this study showed evidence that forest fragments, even in highly anthropized areas, are significantly important as an available habitat for birds.

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