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ARTICLE

The birds of reminiscent and regenerated Semideciduous Atlantic Forest fragments in southeastern Brazil

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Abstract. The Botucatu Cuesta region in São Paulo, southeastern Brazil, harbors exceptional avian diversity, with 363 species recorded across just two localities – the Lageado (LEF) and the Edgárdia (EEF) Experimental Farms – representing nearly half of São Paulo's avifauna. Our study builds upon historical inventories, documenting 32 new species for LEF (bringing the total to 265) and 84 for EEF (now totaling 351). These additions include boreal migrants, such as the Veery *Catharus fuscescens,* and Atlantic Forest endemics with distributions rarely extending inland, such as the Grey-hooded Attila *Attila rufus.* Notably, 92% of historically recorded species persist since the 1970s, with losses primarily attributed to wetland degradation (*e.g.,* Rosy-billed Pochard *Netta peposaca*) and forest-dependent taxa (*e.g.,* Spot-breasted Antvireo *Dysithamnus stictothorax*). Aquatic species, including the Limpkin *Aramus guarauna* and Anhinga *Anhinga anhinga,* have declined due to land-use changes, while others, such as the Spotted Rail *Pardirallus maculatus,* require further investigation given their likely local rarity. We underscore the urgent need for habitat restoration, particularly wetland management – potentially including the reintroduction of historical rice cultivation – to reestablish suitable habitats for lost species. The Cuesta's avifauna highlights its conservation priority, yet targeted strategies are essential to counter threats from agricultural expansion and hydrological alterations. This study establishes a critical baseline for future monitoring and emphasizes the region's pivotal role in conserving Neotropical bird diversity at the Atlantic Forest-Cerrado transition.

Keywords. Cerrado; Cuestas; Long-term inventories; Species turnover.

INTRODUCTION

The efficacy of conservation and management strategies for natural resources depends on a comprehensive understanding of their biological components across broad temporal scales, enabling comparisons between historical and contemporary data (Moura *et al.,* 2014). Such longitudinal assessments reveal shifts in ecological communities – particularly faunal assemblages – which are highly sensitive to landscape modifications that alter vegetation structure, floristic composition, and resource availability (Dunn, 2004). Given the impracticality of monitoring all ecosystem elements, select biological and physical components can serve as effective indicators of broader environmental conditions (Gregory & Van Strien, 2010).

The avifauna of the Cuesta de Botucatu presents a compelling case study of temporal ecological shifts, serving as both a biological indicator and a conservation priority. Early surveys by pioneering naturalists (Pinto, 1944, 1978; Hempel, 1949; Willis & Oniki, 2003) documented a diverse avifauna that included now-extirpated endemics such as the Purple-winged Ground Dove *Paraclaravis geoffroyi* and the Three-toed Jacamar *Jacamaralcyon tridactyla,* reflecting the region's historical ecological integrity. Contemporary studies (Cavarzere *et al.,* 2013; Neto *et al.,* 2017; Schunck *et al.,* 2022a), however, reveal a significantly altered species assemblage, with most remaining habitat-specialist populations now restricted to the Cuesta's rugged topography. Furthermore, the predominance of grey literature in existing research hinders accurate assessments of species richness and, consequently, the development of targeted conservation strategies for this distinctive avian community.

The environmental significance of the São Paulo Cuesta, including its unique biota and physical attributes, has gained increasing recognition

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since 1983 (São Paulo, 1983). This recognition led to the establishment of the Corumbataí-Botucatu-Tejupá Environmental Protection Area (EPA), spanning 6,492 km². However, the EPA has faced persistent threats from human activities, including deforestation, soil erosion, water depletion, pollution, and arson (São Paulo, 2011). These pressures stem largely from the absence of high-priority conservation zoning and a formal management plan, which remain key challenges for protecting the Cuesta's fragile ecosystems (São Paulo, 2011).

In response, the São Paulo government recently restructured the EPA, dividing it into three distinct administrative units to improve conservation governance (São Paulo, 2024): Cuesta Paranapanema (formerly the Tejupá sector), Cuesta Guarani (formerly the Botucatu sector), and Cuesta Corumbataí (formerly the Corumbataí sector). Today, the most extensive and contiguous forest remnants in central-western São Paulo are found in these areas, largely due to the region's rugged cuesta topography, which has historically limited large-scale land conversion – similar to the protective role of the Serra do Mar massif along the state's eastern coast (Victor *et al.,* 2005). However, unlike eastern São Paulo, which has a higher concentration of strictly protected areas, the central-western region – dominated by seasonal semideciduous forests – remains underprotected, with smaller and fewer protected areas (Cavarzere *et al.,* 2023). Critically, most of the Cuesta's protected areas lack integral protection status, undermining long-term conservation efficacy, particularly in the absence of a management plan (São Paulo, 2011). Consequently, privately protected areas have become essential for safeguarding this unique landscape.

The imperative to protect the Cuesta region is underscored not only by its critical physical attributes – including key recharge zones for the Guarani Aquifer (São Paulo, 1983) – but also by its exceptional biodiversity. This area harbors unique ecosystems at the confluence of two globally threatened biodiversity hotspots: the Atlantic Forest and the Cerrado (Myers *et al.,* 2000). Over the past two centuries, both have undergone dramatic transformation due to anthropogenic activities, particularly land conversion for agriculture and urban expansion. Today, in São Paulo the Atlantic Forest retains less than 21.5% of its original cover, while the Cerrado has been reduced to a mere 1.4% of its historical extent (Project MapBiomas, 2025).

The cuesta region's rugged topography has not only facilitated the preservation of numerous vegetation fragments but also, combined with the historical ornithological collections housed at the Museu de Zoologia da Universidade de São Paulo (MZUSP), makes Botucatu an exceptional case study for avian research. These bird specimens, collected between 1900 and 1904 before widespread deforestation occurred (Willis & Oniki, 2003; Victor *et al.,* 2005), provide crucial baseline data that reveal the local extinction of numerous habitat-specialist species (Nishida *et al.,* 2024). This rare combination – comprehensive pre-disturbance inventories coupled with relatively intact remnant vegetation – represents an unusual scientific opportunity in Brazil, where such conditions are exceedingly uncommon (Silveira & d'Horta, 2002; Moura *et al.,* 2014; Cavarzere *et al.,* 2017).

Given the critical importance of both historical and contemporary data for effective natural resource management at local and regional scales, this study synthesizes five decades of ornithological research from two key sites within the Botucatu cuestas. Our own dataset incorporates both systematic surveys and incidental observations recorded over the past decade.

MATERIAL AND METHODS

Study areas

Cuestas represent distinctive geomorphological formations characterized by asymmetric slopes, a gentle dip slope on one side and a steep escarpment on the other. These landforms develop in areas of tilted sedimentary strata – typically sandstone, limestone, or shale – where differential erosion exposes resistant caprock formations while softer underlying layers weather more rapidly (Stefanuto *et al.,* 2022). In São Paulo state, southeastern Brazil, the cuesta relief extends approximately 600 km along a northeast-southwest axis. The elevation gradient ranges from 210 m in the São Pedro stream micro-basin to 815 m in the Botucatu highlands, reflecting the region's complex geological history and erosional patterns.

The Lageado Experimental Farm (LEF) and Edgárdia Experimental Farm (EEF), owned by São Paulo State University (UNESP), are located in the central-western region of São Paulo, southeastern Brazil (22°47′30″, 22°50′S, 48°22′30″, 48°26′15″W; Fig. 1), situated beyond Botucatu's urban perimeter. This 2,139-ha complex (1.4% of the municipality's area) is embedded within an agricultural matrix dominated by sugarcane plantations, eucalyptus stands, pasturelands, and increasingly urban expansion zones. The Alcides Soares Municipal Road (BTC-010) bisects the study area, demarcating distinct geomorphological units: the LEF (west) occupies the backslope and escarpment zone of the Basaltic Cuesta (580-800 m), while the EEF (east) comprises the cuesta frontslope and peripheral depression (464-775 m). The EEF contains a mosaic of floodplains, cerradão woodland (forested savanna), and secondary forest fragments, whereas the LEF features more anthropogenically modified landscapes, including UNESP campus infrastructure alongside remnant vegetation. Seasonal semideciduous forests – among the most threatened Atlantic Forest formations (Carlucci *et al.,* 2021) – predominate in wooded areas, exhibiting 20-50% canopy deciduousness during austral winter drought periods (IBGE, 2012). Both farms have undergone significant habitat alteration through land-use changes (Jorge & Sartori, 2002; Guerrini *et al.,* 2024). Originally classified as humid subtropical (Cfa in Koppen's climate classification; Alvares *et al.,* 2013), recent climatic shifts suggest a transition toward tropical savanna (Aw) conditions, characterized by hot, wet summers (October-March), cool, dry winters (April-September), a mean annual temperature of 21.3°C, and annual precipitation of 1,500 mm (Franco *et al.,* 2023).

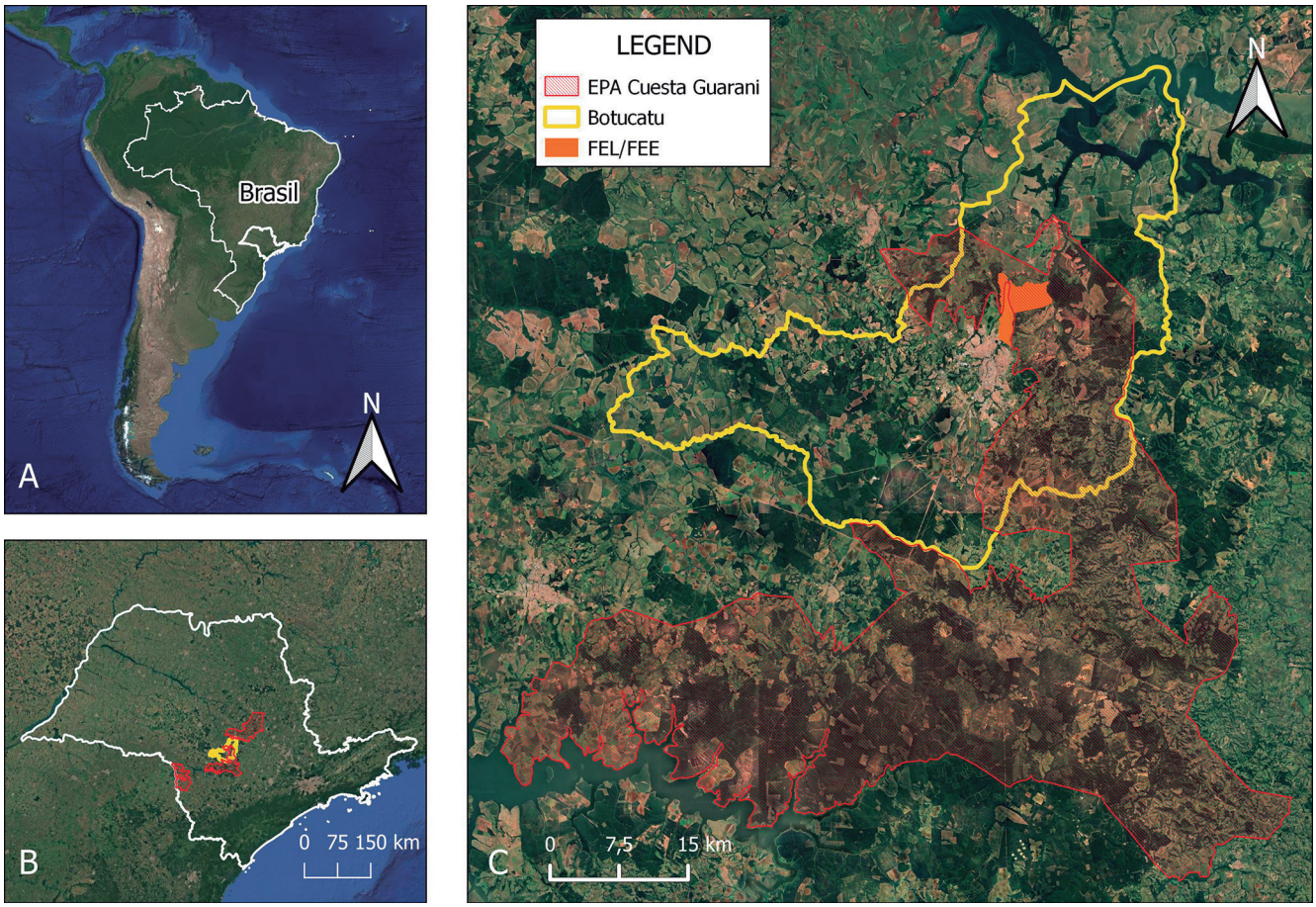

Figure 1. São Paulo state highlighted within Brazil and South America (A). State of São Paulo, highlighting the municipality of Botucatu and the Environmental Protection Areas (B). Botucatu Region, including the Cuesta Guarani Environmental Protection Area and the study areas within Botucatu (C).

Lageado Experimental Farm (LEF)

Originally established in the late 19th century as a significant coffee production hub for foreign trade, the area was later transferred to the federal government to offset debts from the 1929 New York Stock Exchange crisis, becoming the Central Coffee Experiment Station in 1934 (Antonini, 1998). In 1972, the São Paulo State government acquired the land for the establishment of UNESP (São Paulo, 1976). The property is bounded to the west by pasturelands and the Lavapés River channel, to the north by a quarry, and to the east by Alcides Soares Road. Forest cover is predominantly fragmented, with the exception of the Mata da Bica site, which encompasses the Ecological Trail and Timbó Trail fragments – extensions of the Lavapés riparian forest undergoing secondary succession (Guerrini *et al.,* 2024). Anthropogenically modified areas include agroecological zones, water reservoirs, artificial puddles, agricultural fields, and the UNESP campus (Fig. 2).

Edgárdia Experimental Farm (EEF)

It shares a parallel history with LEF, having been established as a Coffee Experiment Station in 1934 before being transferred to the São Paulo State government in 1972. The property is bounded to the west by Alcides Soares Road, to the north and south by private lands designated for agroforestry and urban development, and to the east by the Capivara River. The river's floodplain extends into central portions of the property (Fig. 2), having historically supported rice cultivation prior to UNESP's acquisition. Approximately 65% of EEF's area consists of five Semideciduous Seasonal Forest fragments (Bexiguento, Mata da Bica [homonymous], Mata do IB, Pomar Velho, and Três Barras) and one cerradão woodland (Carmelucho) (Fig. 2). These forest patches represent the product of decades of natural regeneration following historical anthropogenic disturbances including selective logging, fires, cattle grazing, and coffee cultivation between the 1960s-1980s (Ortega & Engel, 1992; Jorge & Sartori, 2002). The remaining floodplain areas have been anthropogenically modified for pasture, livestock, and agricultural use, distinguished from LEF's rural zones by their more developed arboreal stratum, scattered isolated trees, and capoeira (secondary) vegetation. The sole urban elements within EEF consist of zootechnical facilities and buildings concentrated in the central farm area.

Bird censuses

We conducted systematic monthly avian surveys using standardized point count methods (Bibby *et al.,* 2000) from May 2018 to April 2019 across forested do-

mains. Our survey design established: (1) four sampling stations in Bexiguento (EEF), (2) three stations each along the Lavapés riverbanks (LEF) and in Pomar Velho (EEF), and (3) two stations in each remaining study area (Carmelucho, Mata da Bica, Mata do IB, and Três Barras – all within EEF). The Mata da Bica site within LEF was not

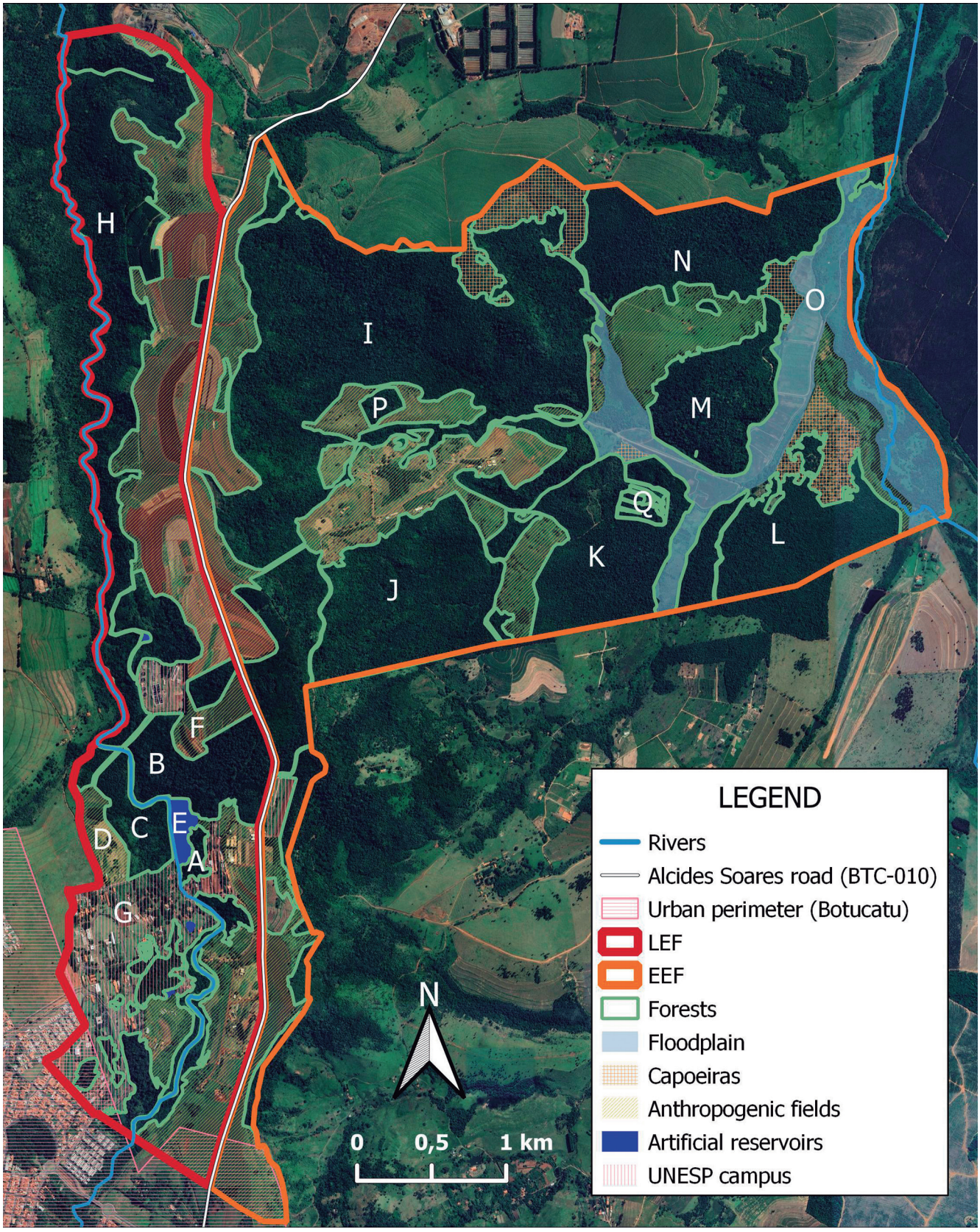

Figure 2. Study sites at Lageado (LEF) and Edgárdia (FEE) Experimental Farms. LEF: (A) Mata da Bica, (B) Trilha Ecológica, (C) Trilha Timbó, (D) Área Experimental da Agroecologia, (E) Setor de Aquicultura, (F) Campos e antiga plantação de café, (G) Campus da UNESP, (H) Mata ciliar do Rio Lavapés. EEF: (I) Mata do Bexiguento, (J) Mata do Três Barras, (K) Mata do Pomar Velho, (L) Mata do Carmelucho, (M) Mata da Bica, (N) Mata do IB, (O) Várzea, (P) reforestation I, (Q) reforestation II.

surveyed. Each station was sampled monthly with three 10-min point counts, spaced 150 m apart, and censused by two observers, yielding 54 point counts monthly (6,480 counts annually; 108 total hours).

In a subsequent study phase (September 2022-August 2023), the same observers resurveyed all original EEF sites while expanding our sampling design to include two additional stations in restoration areas established in the late 1990s. This modified protocol generated 51 monthly point counts, totaling 6,120 additional counts (102 hours). Combined, our systematic observations encompassed 12,600 point counts representing 210 survey hours across both study periods.

Non-systematic observations

We conducted *ad libitum* transect surveys across both farms from January 2015 to August 2024, covering all study sites (Fig. 2) and adjacent areas accessed via existing roads, surveying either on foot or by vehicle at a consistent slow speed (~ 5 km/h). Observations occurred during two daily time windows (05:30-10:30 and 15:30-19:30), totaling over 2,000 h of effort. For both systematic point counts and *ad libitum* surveys, birds were identified visually using 8 × 42 or 10 × 42 binoculars and documented photographically with Canon 60D or 6D cameras equipped with 75-300 mm or 100-400 mm lenses, while audio recordings were obtained using a Tascam DR-05 digital recorder. All observational data including photographs and recordings were archived on ornithological platforms eBird (https://ebird.org), Wikiaves (https://www.wikiaves.com.br), and Xeno-Canto (https://xeno-canto.org), with particular attention given to species of conservation concern or those exhibiting notable distributional patterns. These extensive surveys complemented our systematic point counts by providing broader spatial coverage and additional records of rare or elusive species that might be missed by point counts sampling methods alone. The combination of approaches allowed for comprehensive documentation of avian diversity across varying habitat types and temporal scales throughout the study area.

Secondary data

We conducted a comprehensive literature review of avian studies from the LEF and EEF by searching Google Scholar (https://scholar.google.com), JSTOR (https://www.jstor.org), Scopus (https://www.scopus.com), SciELO (https://scielo.br), and Web of Science (https://www.webofscience.com) using Boolean operators with the keywords "bird* OR avian* OR ornithol*" and their Portuguese equivalents "ave* OR avian* OR ornitol*" combined with "Lageado OR Edgárdia". For Google Scholar, we examined the first 10 pages of results. This review, completed on 31 May 2025, yielded four peer-reviewed papers, one book, and six institutional documents (Supplementary Online Material 1). We additionally queried the Global Biodiversity Information Facility (GBIF; https://www.gbif.org) and the Brazilian Biodiversity Information System (SiBBr; https://www.sibbr.gov.br), which returned no avian records. Our search identified three voucher specimens from the study areas housed in the didactic collection of UNESP's Zoology section: the Spotted Rail *Pardirallus maculatus,* Common Pauraque *Nyctidromus albicollis,* and Common Potoo *Nyctibius griseus* (Supplementary Online Material 2). Remaining data were obtained from institutional repositories from UNESP (https://repositorio.unesp.br), Campinas State University (https://repositorio.unicamp.br), and University of São Paulo (https://repositorio.usp.br), which provided supplementary records and observational data that complemented our field surveys and literature findings. This multi-source approach enabled a thorough synthesis of both published and unpublished avian records from the study areas across multiple decades.

Analyses

We classified all recorded species according to their conservation status using the most recent threatened species lists at state (São Paulo, 2018), national (MMA, 2022), and global (IUCN, 2025) levels. Species were categorized as endemic to either the Atlantic Forest (Vale *et al.,* 2018) or Cerrado (Silva, 1995; Silva & Santos, 2005). Taxonomic classification adhered to the latest Brazilian Ornithological Records Committee guidelines (Pacheco *et al.,* 2021). Following an adapted version of the classification system proposed by Carlos *et al.* (2010), we organized species records into three distinct categories: primary list (P) comprising species directly observed and properly documented within the study areas; secondary list (S) including species with probable occurrence supported by literature records or verifiable reports on established ornithological platforms but lacking our own documentation; and tertiary list (T) containing species with questionable records, insufficient documentation, or those considered unlikely to occur in the areas based on current distributional knowledge and habitat requirements. This tiered classification system allowed for rigorous evaluation of occurrence data while accounting for varying levels of evidence quality and reliability.

RESULTS

Overall species richness

Our comprehensive 55-year survey period (1970-2025) documented 374 avian species across the study areas (Table 1). Most records derived from conventional research methodologies, supplemented by collector specimens during the 1970s. We revealed 334 species (91.4%) with verified documentation, while the secondary list contained 29 species (7%) supported by reliable external records but lacking documentation. The tertiary list comprised 11 species (1.6%) with questionable or in-

Table 1. Studies conducted in Lageado and Edgárdia Experimental Farms, Botucatu, São Paulo, southeastern Brazil, regarding sites (Figure 2), richness (S), number of Atlantic Forest (AF) and Cerrado (CE) endemics, and forest specialist (Forest) following Stotz *et al.* (1996).

Farm	Site	S	AF	CE	Forest	Source
Lageado	A	58	3	0	34	Guzzi (1999); Guzzi & Donatelli (2003)
	B	130	13	2	112	Castro *et al.,* (2009); França (2013); Antonelli & Fonseca (2019)
	C	39	7	0	35	França (2013)
	D	102	4	1	45	Blanco (2016); Vieira (2016); Vieira *et al.,* (2018); Antonelli & Fonseca (2019)
	E	155	8	2	100	Antonelli & Fonseca (2019)
	F	66	0	1	17	Antonelli & Fonseca (2019)
	G	94	1	1	47	Antonelli & Fonseca (2019)
	H	88	15	1	87	Sivisaca (2020)
	Not informed	95	4	2	49	Spadotto (2012)
	Total	233	18	2	147	
Edgárdia	I	91	16	2	89	Sivisaca (2020)
	J	78	13	0	75	Sivisaca (2020)
	K	85	14	0	82	Sivisaca (2020)
	L	90	17	0	87	Lopes (2000); Sivisaca (2020)
	M	139	20	0	122	Lopes (2000); Giorgetti *et al.* (2004); Fonseca (2005); Neto (2007); Neto (2010); Neto *et al.,* (2017); Sivisaca (2020)
	N	79	13	1	75	Sivisaca (2020)
	O	122	6	0	53	Lopes (2000); Antunes (2003); Tiacineli (2006)
	P	93	9	0	66	Rosa (2003)
	Not informed	214	23	1	121	Ortega & Engel (1992); Lopes (2000); Neto (2010)
	Total	267	29	2	161	

sufficient evidence for confirmed occurrence. The combined primary and secondary lists yielded 363 well-substantiated species records, with 265 species documented at LEF and 351 at EEF (Supplementary Online Material 3). Temporal analysis showed 203 species recorded prior to 2000, including 17 species that have not been observed in recent surveys.

Our analysis revealed 38 Atlantic Forest endemic species (10% of total documented avifauna), with only two Cerrado endemics – the Helmeted Manakin *Antilophia galeata* and Curl-crested Jay *Cyanocorax cristatellus*. Three species are globally threatened: the Endangered Crowned Eagle *Urubitinga coronata,* and Vulnerable Lesser Yellowlegs *Tringa flavipes* and Black-backed Tanager *Stilpnia peruviana*. The Crowned Eagle faces particularly severe conservation challenges, being classified as Endangered nationally and Critically Endangered in São Paulo state. Other state-level threatened species include the Endangered Violaceous Quail-Dove *Geotrygon violacea* and Black-and-white Hawk-Eagle *Spizaetus melanoleucus,* along with Vulnerable species: Long-winged Harrier *Circus buffoni,* Plumbeous Seedeater *Sporophila plumbea,* and Black-backed Tanager *Stilpnia peruviana*.

Our analysis revealed substantial overlap in avian richness between sites, with 253 species (70%) occurring at both experimental farms. However, distinct differences emerged in site-specific occurrences: LEF maintained 12 exclusive species (265 species), while EEF supported 98 unique species (351). EEF contained 96% of all documented species (351 of 363), including all threatened taxa and nearly all Atlantic Forest endemics. The only exceptions were two species exclusively recorded at LEF: the Rufous-capped Motmot *Baryphthengus ruficapillus* and Black-backed Tanager *Stilpnia peruviana*.

Field records

Our comprehensive surveys documented 334 avian species across both study sites, including 34 regional endemics and six threatened species. The species distribution revealed significant overlap between sites, with 247 species (74%) occurring at both experimental farms, while demonstrating distinct site-specific patterns: LEF hosted 10 exclusive species (3%), compared to 77 unique species (23%) at EEF. Fieldwork at LEF recorded 257 species (representing 97% of its total avifauna), with 32 newly documented additions to the farm's inventory. These included 21 endemic species (19 Atlantic Forest and two Cerrado endemics) and one threatened species. EEF exhibited greater diversity, with 324 recorded species (92%), featuring 84 new inventory records. This site supported 33 endemics (31 Atlantic Forest and two Cerrado species) and five threatened species.

Secondary data

Our compilation of historical records revealed that 247 of 294 species (84%) documented between 1992-2020 were reported in published literature, including peer-reviewed articles (Ortega & Engel, 1992; Guzzi & Donatelli, 2003; Neto *et al.,* 2017; Antonelli & Fonseca, 2019) and one book (Vieira *et al.,* 2018). The documentation patterns differed markedly between sites: at LEF, 220 of 233 species (94%) appeared in formal publications, with the remaining records derived from two museum specimens and gray literature sources comprising one conference abstract (Castro *et al.,* 2009), one monography (Spadotto, 2012), three undergraduate theses (França, 2013; Blanco, 2016; Vieira, 2016), and one PhD thesis (Sivisaca, 2020).

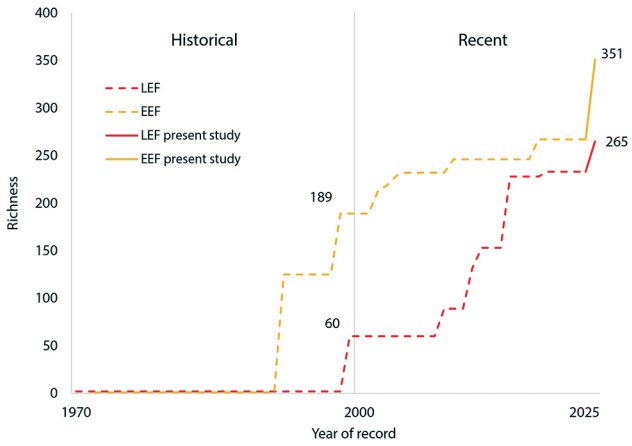

Figure 3. Collector curve indicating how fast the species richness accumulated over the years in Lageado and Edgárdia Experimental Farms, southeastern Brazil.

In contrast, EEF showed substantially lower publication coverage, with only 150 of 267 species (56%) appearing in formal literature. The EEF records were supplemented by one museum specimen and gray literature including one monography (Antunes, 2003), two undergraduate theses (Tiacineli, 2006; Neto, 2007), three master's theses (Lopes, 2000; Rosa, 2003; Neto, 2010), and one PhD thesis (Sivisaca, 2020). This disparity highlights both the uneven documentation history between sites and the critical importance of gray literature for comprehensive biodiversity assessments.

The species accumulation curves revealed distinct temporal patterns in avian documentation across the study sites. At LEF, species richness showed a stabilization trend between 2015-2020, while EEF exhibited a similar plateauing pattern earlier, from 2010-2020. Field-collected data from both sites demonstrated stabilization around 2022 (Fig. 3), suggesting that recent surveys have approached comprehensive documentation of the resident avifauna.

Lageado Experimental Farm

The avian inventory for LEF currently stands at 265 documented species (Table 2), representing a cumulative record spanning five decades. Historical surveys (1970-1999) account for 60 of these species, while subsequent research through 2019 recorded 233 species, including five new additions from the most recent comprehensive study. Our field surveys successfully detected 257 species (97%), though eight species went unrecorded – comprising five historically documented taxa that have not been observed since the 20th century, and three species reported in recent studies but not encountered during our fieldwork.

Edgárdia Experimental Farm

EEF has documented a total of 351 avian species (Table 3). Initial surveys spanning 1972-1998 established records of 189 species. Subsequent investigations through 2019 expanded this inventory to 267 species, with the most recent comprehensive study contributing 21 additional records. During our systematic field surveys, we confirmed the presence of 324 species (92% of the total documented avifauna). The remaining 27 species (7%) were not detected during our surveys, including 18 species exclusively reported in historical records (1972-1998) and nine species documented in post-1998 studies but absent from our observations.

Endemic and threatened species

EEF contained most of endemic and threatened species documented in this study (Table 4). Only two

Table 2. Bird records from the Lageado Experimental Farm, Botucatu, São Paulo, southeastern Brazil. Period refers to the sampling period studies were conducted. Site identifications are cross-referenced with Figure 2.

Time	Source	Richness	Period	Site
Historical	V.C. de Jesus	2	Oct 1970	—
	Guzzi (1999)	54	Oct 1998-Sep 1999	A
	Guzzi & Donatelli (2003)	57	Oct 1998-Sep 1999	A
		60		
Recent	Castro *et al.* (2009)	46	Sep 2009	B
	Spadotto (2012)	93	Aug-Oct 2012	A, B, C, G
	França (2013)	47	Jul-Out 2013	B, D
	Blanco (2016)	65	Jul 2014-2014	D
	Vieira (2016)	54	Not specified	D
	Vieira *et al.* (2018)	65	Jul 2014-2014	D
	Antonelli & Fonseca (2019)	212	Oct 2015-Sep 2016	B, D, E, F, G
	Sivisaca (2020)	88	May 2018-Apr 2019	H
		233		
	Present study	257	Jan 2015-Dec 2024	A, B, C, D, E, F, G, H
Total		265		

Table 3. Bird records for Edgárdia Experimental Farm, Botucatu, São Paulo, southeastern Brazil. Period refers to the sampling period studies were conducted. Site identifications are cross-referenced with Figure 2.

Farm	Author/Collector	Richness	Period	Site
Historical	V.P. Silva	1	1972	—
	Ortega & Engel (1992)	124	Non specified	—
	Lopes (2000)	164	Dec 1997-98	L, M, O
		189		
Recent	Rosa (2003)	93	Apr 2002-Mar 2003	P
	Antunes (2003)	34	Not informed	O
	Giorgetti *et al.* (2004)	42	May-Sep 2004	M
	Fonseca (2005)	44	Aug-Oct 2002	M
			Jan-Mar 2003	M
	Tiacineli (2006)	92	Mar-Oct 2005	O
	Neto (2007)	44	Feb-Mar 2007	M
	Neto (2010)	147	Feb 2009-Jan 2010	M
	Neto *et al.* (2017)	36	Feb 2009-Jan 2010	M
	Sivisaca (2020)	129	May 2018-Apr 2019	I, J, K, L, M, N
		267		
	Present study	324	Jan 2015-Dec 2024	I, J, K, L, M, N, O, P, Q
	EEF	351		

Table 4. Overall bird species richness recorded within the Lageado (LEF) and Edgárdia (FEE) Experimental Farms, Botucatu, São Paulo, southeastern Brazil.

		LEF	EEF	Total
Endemism	Atlantic Forest	21	36	38
	Cerrado	2	2	2
Threat	CR	—	1 (SP)	1 (SP)
	EN	1 (SP)	2 (SP); 1 (BR); 1 (IUCN)	2 (SP); 1 (BR); 1 (IUCN)
	VU	1 (SP); 1 (IUCN)	2 (SP); 1 (IUCN)	3 (SP); 2 (IUCN)
Total		265	351	363

Table 5. Overall bird species richness recorded within Botucatu, São Paulo, southeastern Brazil, according to ornithological online platforms.

		eBird	Wikiaves	Xeno-canto
Endemism	Atlantic Forest	41	32	25
	Cerrado	5	3	1
Threatened	CR	7 (SP)	6 (SP)	3 (SP)
	EN	3 (SP); 2 (BR); 1 (IUCN)	2 (SP); 1 (BR); 1 (IUCN)	2 (SP); 2 (BR); 1 (IUCN)
	VU	8 (SP); 3 (BR); 4 (IUCN)	8 (SP); 2 (BR); 4 (IUCN)	2 (SP); 1 (IUCN)
Forest		240	210	125
Total		420	384	178

Atlantic Forest endemics were not recorded at EEF: the Rufous-capped Motmot and Black-backed Tanager. The latter holds Vulnerable status on both regional (São Paulo, 2018; MMA, 2022) and international (IUCN, 2025) threatened species lists.

The studied farms harbor a considerable diversity of forest specialist species (Table 5), predominantly comprised of Atlantic Forest endemics. The only species documented within the municipality but absent from the research area was the Chestnut-headed Tanager *Thlypopsis pyrrhocoma.* Similarly, the sole Cerrado endemic not recorded in the study area was the Black-throated Saltator *Saltatricula atricollis.* Despite this local richness and the presence of numerous threatened species, the majority of critically endangered and vulnerable species were found outside the study area in remnants of the Cerrado biome (Antonelli *et al.,* 2024).

Chronology of records

Lageado Experimental Farm

The earliest ornithological records consist of specimens collected in October 1970 by V.C. de Jesus, housed in the didactic collection of UNESP's Zoology section: a Common Potoo collected on 10 October and a Common Pauraque collected on 12 October. The first systematic inventory of Mata da Bica was conducted by Guzzi (1999) and later published by Guzzi & Donatelli (2003), with fieldwork occurring between October 1998 and September 1999. The undergraduate thesis (Guzzi, 1999) reported 54 species, while the published study, 57 species. Key differences included: the Brown-crested Flycatcher *Myiarchus tyrannulus* appearing only in the thesis, and the Violaceous Quail-Dove *Geotrygon violacea,* Scaled Dove *Columbina squammata,* Campo Flicker *Colaptes campestris,* and House Sparrow *Passer domesticus* being unique to the published version. Both studies shared 53 species, including the Blue Ground-Dove *Claravis pretiosa,* Rufous-capped Motmot, and Common Waxbill *Estrilda astrild,* none observed in subsequent surveys.

Following the 2000s, research efforts primarily focused on Trilha Ecológica, with multiple studies conducted between 2009 and 2016. Castro *et al.* (2009) first documented 46 species during birding events organized by the Nature Conservation Laboratory in 2009. Subsequent work by Spadotto (2012), who surveyed the area from August to October 2012, provided the sole record of Mottled Owl *Strix virgata* for LEF, though species composition data from Trilha Ecológica and Lavapés Riparian Forest were excluded from their analysis. França (2013) then identified 27 species between July and October 2013, including the only record of Dusky-tailed Antbird *Drymophila malura* and the last documented observation of White-browed Warbler *Myiothlypis leucoblephara.* The most comprehensive study was conducted by Antonelli & Fonseca (2019), who reported 125 species detected during systematic surveys from October 2015 to September 2016 throughout the farm.

During the same period, França (2013) recorded 39 species along Trilha Timbó, situated on the western margin of Lavapés River, adjacent to the Experimental Agroecology Area (AEA). Subsequent surveys by Blanco (2016) and Vieira (2016) conducted between July 2014 and 2015 documented 65 and 54 species respectively in this area. The Violet-capped Woodnymph *Thalurania glaucopis* and Chestnut-capped Blackbird *Chrysomus ruficapillus* were absent from Blanco's (2016) observations and likewise not reported in the published version of the study (Vieira *et al.,* 2018), which was based on the first author's inventory data. Antonelli & Fonseca (2019) surveyed all previously mentioned sites except Mata da Bica, along with additional locations including the Aquaculture Sector and agricultural fields, from October 2015 to September 2016, recording a total of 212 species. The most recent LEF inventory by Sivisaca (2020), conducted from May 2018 to April 2019, identified 88 species in the eastern riparian forest of Lavapés River.

Edgárdia Experimental Farm

The earliest ornithological record from EEF consists of a Spotted Rail specimen collected by V.P. Silva on 26 August 1972, currently housed in the didactic collection of UNESP's Zoology section. While the exact collection site is not specified in the records, the species' habitat preferences (typically wetland areas) suggest the specimen was likely obtained from the floodplain areas, as these represent the most suitable habitat for this rail species in the region.

The first comprehensive inventory of EEF was conducted by Ortega & Engel (1992), though the specific

Figure 4. Bird records from Lageado and Edgárdia Experimental Farms, southeastern Brazil. An adult Yellow-billed Cuckoo *Coccyzus americanus* photographed by Victor Antonelli on 03 December 2023 (A); a juvenile Crowned Eagle *Urubitinga coronata* photographed by Guilherme Notari on 06 February 2021 (B); an adult Rufous-breasted Leaftosser *Sclerurus scansor* photographed by Victor Antonelli on 12 April 2023 (C); an adult Lesser Woodcreeper *Xiphorynchus fuscus* photographed by Victor Antonelli on 22 June 2023 (D); an adult Eye-ringed Tody-Tyrant *Hemitriccus orbitatus* photographed by Victor Antonelli on 16 September 2020 (E); an adult Gray-hooded Attila *Attila rufus* photographed by Victor Antonelli on 21 June 2024 (F); an adult Veery *Catharus fuscescens* photographed by Victor Antonelli on 19 February 2024 (G); an adult male Black-backed Tanager *Stilpnia peruviana* photographed by José Carlos on 26 July 2019 (H).

study period was not informed. Their research recorded 190 species, and include the sole and final record of several aquatic species at EEF, including the Least Grebe *Tachybaptus dominicus,* Pied-billed Grebe *Podilymbus podiceps,* and Anhinga *Anhinga anhinga,* as well as the locally uncommon Ferruginous Pygmy-Owl *Glaucidium brasilianum* and Red Tanager *Piranga flava*.

Between 1997 and 1998, Lopes (2000) documented 164 bird species at EEF, with approximately half (123 species) recorded through focal observations across three key habitats: the floodplain (44 species), Mata da Bica (43), and Carmelucho (36). This study provided foundational data on EEF's avian communities, though sampling was primarily conducted along habitat edges. Approximately one-third of the species reported by Lopes (2000) were not detected in our current research, including several considered rare in the Botucatu region: the Pantanal Snipe *Gallinago paraguaiae,* Ochre-breasted Foliage-gleaner *Anabacerthia lichtensteini,* and Buff-browed Foliage-gleaner *Syndactyla rufosuperciliata*. Two species have not been recorded since Lopes' study, the Spot-breasted Antvireo *Dysithamnus stictothorax* and Three-striped Flycatcher *Conopias trivirgatus*.

From 2002 to 2004, research efforts focused on three key areas within EEF. Rosa (2003) surveyed Restoration Area I from April 2002 to March 2003, documenting 93 species through mist-netting (76 species) and incidental observations (18 species). Antunes (2003) studied the floodplain habitat, recording 34 species including the only record of Capped Heron *Pilherodius pileatus,* though the exact study period remains unspecified. Fonseca (2005) conducted research in Mata da Bica between August-October 2002 and January-March 2003, identifying 44 species through mist-net captures (35 species) and supplementary observations (9 species). Giorgetti *et al.* (2004) subsequently resurveyed Mata da Bica from May to September 2004, confirming 42 species – all previously reported by Fonseca (2005) except for the Yellow-bellied Elaenia *Elaenia flavogaster* and Surucua Trogon *Trogon surrucura,* while documenting the last observation of White-browed Warbler. Antunes (2003) synthesized data from these and earlier studies in a comprehensive report, creating the first unified avifaunal inventory for both experimental farms and the broader Botucatu region, incorporating additional areas like the UNESP Botanical Garden previously examined by Guzzi & Donatelli (2003).

Between March and October 2005, Tiacineli (2006) conducted avian surveys in the floodplain rice cultivation areas, documenting 92 species across various habitats, including the last recorded observation of Limpkin *Aramus guarauna* at the site. Neto (2007) subsequently surveyed Mata da Bica from February to March 2007, recording 44 species. This same fragment was revisited by Neto (2010) between February 2009 and January 2010, yielding 87 species through systematic mist-netting in forest clearings (36 species) – data later published in Neto *et al.* (2017) – plus an additional 60 species through incidental observations in adjacent areas, totaling 147 species. This comprehensive study represents the last observations of four species at EEF: Rufous-capped Antshrike *Thamnophilus ruficapillus,* Yellow-bellied Seedeater *Sporophila nigricollis,* Rufous-crowned Greenlet *Hylophilus poicilotis,* and Common Waxbill *Estrilda astrild*.

The most recent comprehensive study at EEF, conducted by Sivisaca (2020) from May 2018 to April 2019, systematically surveyed all major forest fragments across the experimental farm. This research documented 129 avian species through standardized sampling in and around six key vegetation parcels: Bexiguento (93 species), Mata da Bica (96), Carmelucho (76), Mata do IB (78), Pomar Velho (85), and Três Barras (79).

DISCUSSION

The combined area of LEF and EEF represents the highest documented avian species richness in Botucatu, with 363 species, or 90% of all recently recorded species within the municipality (Nishida *et al.,* 2024). This total equates to 18% of Brazil's avifauna (Pacheco *et al.,* 2021) and 45% of São Paulo state's bird diversity (Silveira & Uezu, 2011). The richness is comparable to other major seasonal semideciduous forest remnants in inland São Paulo, including Caetetus Ecological Station (346 species; Cavarzere *et al.,* 2024) and Barreiro Rico Ecological Station (359 species; Antunes & Willis, 2003). The patterns of species accumulation curves indicate that EEF's greater species richness was detected earlier in the study timeline, consistent with its larger area and more diverse habitats, while LEF's smaller and more fragmented ecosystems required more intensive sampling effort to fully characterize its avian community. The convergence of both curves by 2022 reflects our systematic survey efforts achieving thorough spatial and temporal coverage across both experimental farms.

The comprehensive species inventory results from both systematic surveys and extensive incidental observations that documented numerous rare species (Fig. 4). Despite inherent challenges in comparing species lists across different sites (Remsen, 1994), the study areas establish a new ornithological benchmark for municipalities within the Cuesta region and the Cuesta Guarani Environmental Protection Area, demonstrating the expected avian diversity in preserved areas with heterogeneous habitats.

The EEF exhibited particularly high avian richness (351 of the 363 total species), attributed to its complex environmental heterogeneity. The extensive wetlands, covering a substantial portion of the terrain, significantly contributed to overall species diversity and particularly enhanced representation of Gruiformes and Pelecaniformes. This habitat supported all known taxa from these orders recorded in Botucatu (Nishida *et al.,* 2024), except for the Plumbeous Rail *Pardirallus sanguinolentus* and Yellow-breasted Crake *Laterallus flaviventer*. The area also maintained diverse Accipitriformes populations, including threatened species such as Long-winged Harrier *Circus buffoni* and Crowned Eagle (São Paulo, 2018), along with water-associated raptors like Black-col-

lared Hawk *Busarellus nigricollis* and Great Black Hawk *Urubitinga urubitinga,* commonly observed along major tributaries of the Tietê River (Nishida *et al.,* 2024). Forest cover, representing 65% of land use, supported numerous forest specialists including Grey-hooded Flycatcher *Mionectes rufiventris,* Eye-ringed Tody-Tyrant *Hemitriccus orbitatus,* and Drab-breasted Pygmy-Tyrant *Hemitriccus diops* – Atlantic Forest endemics. The most preserved remnant, Bexiguento, revealed several species not observed in the previous twenty years: White-throated Woodcreeper *Xiphocolaptes albicollis,* Lesser Woodcreeper *Xiphorhynchus fuscus,* and Grey-hooded Attila *Attila rufus,* species that are absent from most safeguarded seasonal semideciduous forests fragments in the interior of São Paulo (Antunes *et al.,* 2016; Cavarzere *et al.,* 2023).

The avian documentation status differs markedly between the two sites. At LEF, 220 of 233 historically recorded species (94%) appear in published literature, including the most recent inventory (Antonelli & Fonseca, 2019) based on 2015-2016 data. In contrast, EEF – despite its larger size and greater conservation significance for threatened species – has only 150 of 267 historical records (56%) formally published, with the latest comprehensive study (Neto *et al.,* 2017) deriving from 2009-2010. Our surveys substantially expanded both inventories: at LEF, we added 32 new species (increasing the total from 233 to 265), including rare migrants like Peregrine Falcon *Falco peregrinus,* Yellow-legged Thrush *Turdus flavipes,* and Veery *Catharus fuscescens* (Barbosa & Lima, 2025). More significantly, we documented 84 new species at EEF (increasing from 267 to 351 total), comprising: (1) intercontinental migrants like Yellow-billed Cuckoo *Coccyzus americanus;* (2) austral migrants including Rufous-thighed Kite *Harpagus diodon* and Ash-colored Cuckoo *Micrococcyx cinereus* (Cabanne & Seipke, 2005; Schunck *et al.,* 2022b); (3) irregular winter visitors such as Black-backed Grosbeak *Pheucticus aureoventris* (Antonelli & Cavarzere, 2024); and (4) Atlantic Forest endemics typically restricted to eastern São Paulo, such as Rusty-barred Owl *Strix hylophila,* Mouse-coloured Tapaculo *Scytalopus speluncae,* Rufous-breasted Leaftosser *Sclerurus scansor,* and Bare-throated Bellbird *Procnias nudicollis.*

Some 92% of the avian species historically recorded at both experimental farms persist in the area, with wetland-associated taxa showing the most significant declines due to land use modification at EEF. Targeted restoration strategies – including floodplain soil rehabilitation, reintroduction of rice cultivation, and management of invasive aquatic vegetation – could facilitate the recovery of several species which occupy these environments. These include the Rosy-billed Pochard *Netta peposaca,* a partial migrant in Brazil (Nascimento *et al.,* 2000), the Least Grebe, Pied-billed Grebe, Limpkin, Spotted Rail, Pantanal Snipe, Anhinga, and Capped Heron. Conversely, several forest specialists appear locally extinct, including the Plumbeous Pigeon *Patagioenas plumbea,* Spot-breasted Antvireo *Dysithamnus stictothorax,* and Three-striped Flycatcher, with no recent records across Botucatu or neighboring municipalities. The status of Rufous-crowned Greenlet remains uncertain due to historical taxonomic confusion with Gray-eyed Greenlet *Hylophilus amaurocephalus* (Willis, 1991) and lack of contemporary detections.

Several species widely-ranged in São Paulo state – including the Capped Heron and Sombre Hummingbird *Aphantochroa cirrochloris* – persist only in historical records from the study area. Others, such as the Glittering-throated Emerald *Chionomesa fimbriata* and Common Waxbill, remain undocumented both in Botucatu municipality and surroundings. The Common Waxbill, introduced to inland São Paulo during the late 19th century (Sick, 1997), was last recorded at LEF in 1999 and EEF in 2010, with no subsequent observations in our study, suggesting its populations may not have become as firmly established as those in eastern portions of the state. Conversely, recent surveys in the Botucatu Cuesta region have detected several unexpected species, including Rosy-billed Pochard, Mottled Owl *Strix virgata,* Ochre-breasted Foliage-gleaner, and Buff-browed Foliage-gleaner (Wikiaves, 2025).

The absence of water-dependent species in EEF appears linked to land-use changes in the floodplain, particularly the discontinuation of rice farming in favor of non-irrigated crops. Most of these species require clean water for foraging – a condition already degraded when our study began. Historical records show the Limpkin persisted from early surveys (Ortega & Engel, 1992) through 2005 (Tiacineli, 2006), coinciding with the final years of rice cultivation. Nearby Tietê River tributaries (< 30 km north) continue to support populations of all these species, demonstrating the habitat requirements absent from our study area (*e.g.,* Koury *et al.,* 2019).

Several additional species absent from recent surveys are characteristic of Cerrado ecosystems, including the White-tailed Goldenthroat *Polytmus guainumbi,* White-eared Puffbird *Nystalus chacuru,* Rufous-capped Antshrike *Thamnophilus ruficapillus,* White-lined tanager *Tachyphonus rufus* and Cinnamon Tanager *Schistochlamys ruficapillus.* These resident species remain well-documented in Cerrado habitat mosaics within Botucatu's backslope of the cuesta (Antonelli *et al.,* 2024). Other locally rare species show limited distributions: the Ferruginous Pygmy-Owl *Glaucidium brasilianum* is known from a single location < 9 km north of the study area along the Tietê River margin. Non-resident species like the Hepatic Tanager *Piranga flava* and Yellow-bellied Seedeater *Sporophila nigricollis* appear subject to seasonal movements, with only sporadic records in the region (Nishida *et al.,* 2024).

Two forest-specialist species show concerning distribution patterns in the study area. The Rufous-capped Motmot is known from only a single location in Botucatu, < 10 km north of the experimental farms along the Tietê River margin (Nishida *et al.,* 2024). The White-browed Warbler, while historically widespread in the municipality's riparian forests (including peri-urban areas), has not been recorded at EEF since 2004 (Giorgetti *et al.,* 2004) nor at LEF since 2012 (França, 2013). This extended ab-

sence suggests either local extinction or severe population decline. Field observations indicate an inverse relationship between White-browed Warbler occurrence and that of its congener, the Flavescent Warbler *Myiothlypis flaveola,* though this pattern requires further investigation.

Tertiary list

The tertiary list comprises a total of 11 species whose presence in the LEF and EEF should initially be disregarded (see below). Most of these represent extralimital occurrences that fall outside the documented distribution ranges of the respective taxa, with no verified records to support their presence. Assessments regarding the erroneous inclusion of these species took into account at least four determining factors.

Criterion A: Extralimital records from beyond the state. Three species meet this criterion: the Brown-and-yellow Marshbird *Pseudoleistes virescens,* the Blue-chinned Sapphire *Chlorestes notata,* and Reiser's Tyrannulet *Phyllomyias reiseri.* Their documented geographic distributions preclude any plausible occurrence within the state boundaries (Billerman *et al.,* 2025). The records of the Brown-and-yellow Marshbird and Blue-chinned Sapphire most probably represent misidentifications. In contrast, Reiser's Tyrannulet may be considered erroneous due to taxonomic revisions. This species was previously classified as conspecific with both Urich's Tyrannulet *Phyllomyias urichi,* which occurs outside Brazil, and the Greenish Tyrannulet *Phyllomyias virescens,* an Atlantic Forest endemic present in the study area.

Criterion B: Extralimital records beyond the established domain. Four species satisfy this criterion: the Green-crowned Plovercrest *Stephanoxis lalandi* and Oustalet's Tyrannulet *Phylloscartes oustaleti,* which are restricted to eastern São Paulo in the Serra do Mar region, as well as the Brazilian Tanager *Ramphocelus bresilia* and the Azure-shouldered Tanager *Thraupis cyanoptera.* Although the latter two species have been recorded inland in the municipalities of Bauru and Piracicaba (inland São Paulo state), they may also be classified as escapees from captivity, given their status as commercially traded species.

Criterion C: Erroneously reported data. Only the Lesser Kiskadee *Philohydor lictor* qualifies under this criterion. Although the species was recorded during the initial study conducted in the LEF, its occurrence was incorrectly attributed to a different location in the subsequent publication by the same author (Guzzi & Donatelli, 2003).

Criterion D: Misidentifications. Three species satisfy this criterion: the Planalto Slaty-Antshrike *Thamnophilus pelzelni,* though present in the cerradão woodlands of Botucatu, was misidentified in a previous study (Antonelli & Fonseca, 2019); the Fork-tailed Woodnymph *Thalurania furcata* and Crimson-crested Woodpecker *Campephilus melanoleucos* have been reported in central to southern São Paulo state. However, the authors did not account for the Violet-capped Woodnymph *Thalurania glaucopis,* a regionally abundant species whose females closely resemble *T. furcata,* suggesting a likely identification error. While the Crimson-crested Woodpecker has been cited in multiple locations across Botucatu's Cuesta region (São Paulo, 2021; Schunck *et al.,* 2022a), no verifiable documentation exists. The sole supporting record from Barreiro Rico Ecological Station (São Paulo, 2021) refers to the Robust Woodpecker *C. robustus* (F. Schunck, pers. com.).

Despite limited sampling effort in the 1990s – when the forest fragments remained isolated – nearly all forest-specialist species were subsequently rediscovered in studies conducted from the 2000s onward. Historical records from the early 20th century (prior to large-scale vegetation degradation from coffee cultivation) confirm that habitat-specialist species were originally present. However, following clear-cutting, these species were extirpated, demonstrating the irreversible impact of deforestation (Brooks *et al.,* 1999).

CONCLUSION

LEF and EEF support the highest avian diversity in Botucatu, exceeding that of protected areas in central-western São Paulo. Our findings indicate that 92% of historically recorded bird species persist in the area after three decades. Among the species no longer detected, half remain common and resident in other parts of Botucatu. The most significant taxonomic losses are linked to environmental degradation of EEF's wetland habitats, particularly due to alterations in hydrology and vegetation structure. Restoration measures – such as floodplain soil recovery, reintroduction of traditional rice farming, and control of invasive aquatic vegetation (*e.g.,* cattails) – could reestablish critical wetland microhabitats and facilitate the return of floodplain species. This study underscores the importance of long-term monitoring in the same localities to inform effective, evidence-based conservation strategies.

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