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Documenting birds over two centuries of deforestation in an Atlantic Forest region of Brazil

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ABSTRACT

The first ornithological record from Paraná State, Southern Brazil, dates from 1820, when forests covered 83% of the area. There is a lack of studies evaluating how knowledge on species richness increased over time, together with a massive deforestation process. We aimed to describe the changes, by decade, in forest species richness since that time, and to determine how field effort hours were distributed. We reviewed published studies using online databases. We compared forest bird communities between decades with Jaccard Dissimilarity Indices and compared communities' composition among decades with Analysis of Similarity. In 200 years, 421 forest bird species were mentioned. Most of the species were detected until 1980, a likely subset of the avifauna before habitat loss; fewer species (108) were recorded afterward. An increasing number of species (8–20) stopped being recorded by decade from the 1980s. Field effort hours were mentioned in 1984, remaining temporally and spatially uneven. More than 1,000 localities have been inventoried, but most species reports are from Eastern municipalities. Areas within Serra do Mar, Curitiba, and Londrina stand out as protected forests and well-known academic centers. Cerrado endemics corroborated the relevance of exploring different regions, but further studies in this domain are strongly recommended.

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KEYWORDS

Field effort; naturalists; species richness; temporal changes

Introduction


Ornithological studies in Brazil began during colonization but only became more abundant and scientific (specimen collections) during the 19th century, when European naturalists traveled around the country on behalf of natural history museums, during the golden age of zoology (Pinto 1979; Vanzolini 1993, 1996). The most renowned naturalist, the Austrian Johann Natterer, spent 18 years (1817–1835) gathering specimens from the South, Southeast, Midwest, and North regions of Brazil, greatly contributing to Brazilian ornithology (Pinto 1979; Vanzolini 1993). Natterer's journeys included the iron foundry of São João de Ipanema, currently Ipanema National Forest, in the state of São Paulo, Southeast Brazil. Species collected by him in that locality during 1819–1822 contributed to understanding a historical defaunation process after centuries of deforestation and habitat modification of these forests (Cavarzere et al. 2017). Such comparisons, in which community composition can be compared hundreds of years apart, are only possible when extensive work by naturalists is available, which provides

opportunities to evaluate the consequences of anthropic actions on biodiversity (Moura et al. 2014; Machado-Stredel et al. 2022).

Johann Natterer also visited Paraná, in South Brazil, between 1820 and 1821, initiating ornithological surveys in the state (Straube 2012). Almost 100 years later, the birds of the state were studied again, with the important collections by Tadeusz Chrostowski (Straube 2015). Since then, several contributors were responsible for the increase in regional ornithological knowledge (Straube 2013, 2014, 2016, 2020), making this region an ideal case study in which to analyze how research and bird communities changed over time.

Paraná is within the Atlantic Forest and Cerrado biodiversity hotspots (Myers et al. 2000). The Atlantic Forest is the second largest tropical forest in Brazil, stretching from the Northeast to the South, mostly along the coast, with its southernmost portion reaching inner parts of South America in Argentina and Paraguay (Marques et al. 2021). The Atlantic Forest has been severely fragmented in the last centuries, and 28% of its forest remnants persist within

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a landscape of small and isolated patches (Rezende et al. 2018). About 800 species of birds can be found within this domain, with 223 endemic and 66 threatened species (Pizo & Tonetti 2020). The Cerrado is the world's largest savanna, and second domain to the Amazon Forest with respect to size in South America (Silva & Bates 2002). However, half of the Cerrado's natural extent has been lost as agriculture continues to expand, with an increasing threat to its biodiversity (Strassburg et al. 2017). The Cerrado is a species-rich savanna, with >800 species of birds, of which 4% are endemic (Silva 1995; Silva et al. 2005). Because Paraná encompasses several Atlantic Forest habitats and the southernmost limit of the Cerrado, it is of paramount importance for biodiversity in Brazil (Figure 1).

Species richness has been a key ecological component to estimate and compare biological diversity on multiple spatial and temporal scales across different habitat types (Schall & Pianka 1978; Pellissier et al. 2018; Chamberlain et al. 2019; Tu et al. 2020). Because monitoring changes in species richness over time has potential implications, such as detections of cryptic losses in biodiversity and habitat (Pollock et al. 2022) and evaluating distributional patterns (Echeverry-Galvis et al. 2023), we reviewed ornithological published information from Paraná, and compiled records of bird species since the 1800s. We wished to describe the patterns of species richness over time to better understand how sampling effort, field methods,

and habitat loss have influenced the avian community since the 19th century.

Materials and methods

Study area

Paraná lies between 22°30'58" S, 52°06'47" W and 26°43'00" S, 51°24'35" W. The region is characterized as humid subtropical with oceanic climate, without dry seasons, and includes two categories according to Koeppen's classification: hot summer with rainfall concentration (Cfa), and temperate summer (Cfb). The first one predominates in the state, mainly across the northern, western, and southwestern regions (Alvares et al. 2013). At the highest elevations in the state, rainfall is homogeneously distributed throughout the year and summers are mild (Cavaglione et al. 2000). In a 30-year interval (1977–2006), the rainfall in the state ranged from 1,134 to 2,702 mm with a mean 1,696 mm (Fritzsons et al. 2011), while minimum and maximum temperatures ranged from −1.3°C to 31.1°C (Silva et al. 2015).

About 83% of the state is Atlantic Forest, followed by the Cerrado and other vegetation types (Maack 2017; Project MapBiomias 2020). The Atlantic Forest formations include eastern Rainforests, Mixed Forests in central higher plateaus, in which araucaria (*Araucaria angustifolia*

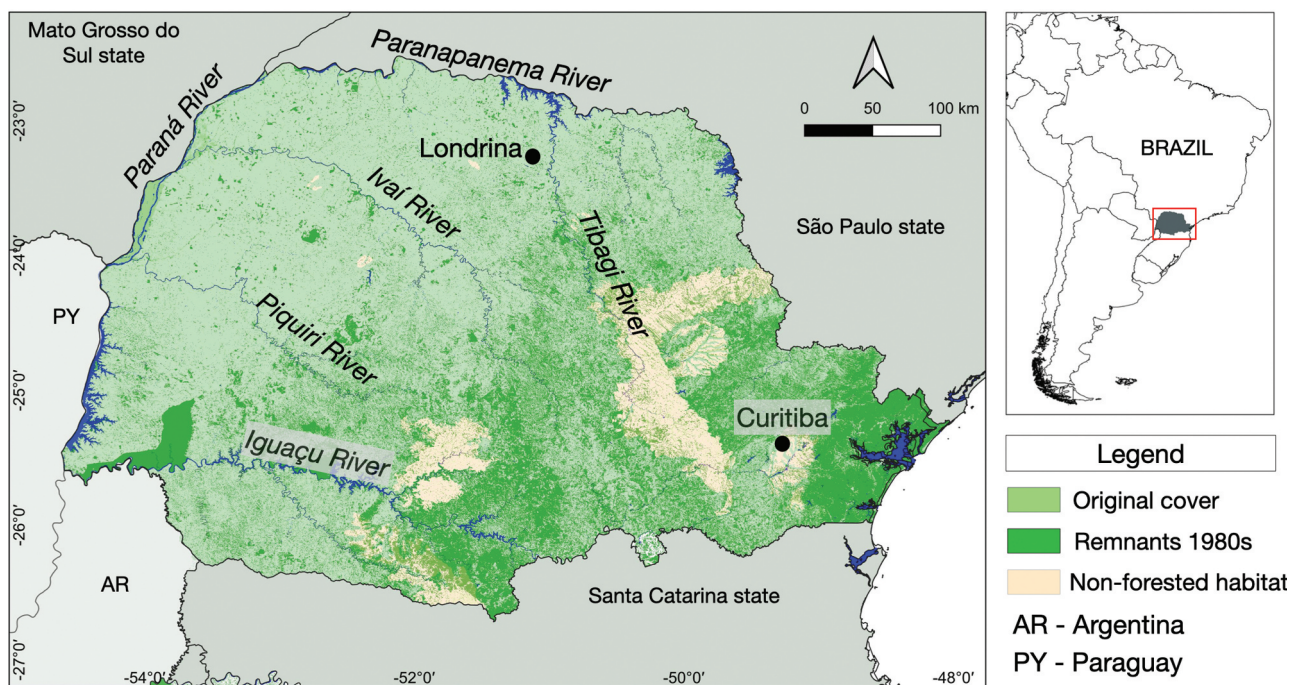


Figure 1. The original cover and the remaining forested vegetation from the 1980s onwards in Paraná State, Southern Brazil. The major rivers and relevant municipalities for the ornithology of the State are indicated.

Mart.) is predominant, and Seasonal Semideciduous Forests, which are found in eastern and western regions, as well as in the valleys of the rivers that compose the Paraná River basin (IBGE 2012; Maack 2017). Cerrado is found to the north and northeast, where the savanna occupies an area of higher altitude in the inland, interspersed with gallery forests (IBGE 2012; Maack 2017).

Bibliographic review

The search for articles, books, and book chapters published in English and Portuguese until 31 December 2022 were conducted in the following databases: Directory of Open Access Journals (<https://doaj.org>), Google Scholar (<https://scholar.google.com>), JSTOR (<https://www.jstor.org>), Scielo (<https://www.scielo.br>), Scopus (<https://www.scopus.com>), and Web of Science (<https://access.clarivate.com>) using the following keywords: ‘avian’ or ‘avifauna’ or ‘bird*’ or ‘ornithol*,’ as well as their Portuguese translations ‘avian*,’ ‘avifauna,’ ‘ave*,’ or ‘ornitol*,’ and ‘Paraná.’ References were then filtered to exclude unrelated topics, those that did not publicly provide species, or those which used previously published databases. Since our aim was to evaluate published and accessible information, we did not personally analyze museum specimens, nor did we search for specimens on the Global Biodiversity Information Facility (<https://www.gbif.org>). Therefore, ancient records of museum specimens were those mentioned in the literature. Our search resulted in 261 references, of which 202 mention forest bird species published between 1937 and 2020 (Supplementary Material S1).

Data

Taxonomy follows the Brazilian Ornithological Records Committee (Pacheco et al. 2021). We standardized the data by using forest species only, according to forest dependency categories (letter F in database A) of Stotz et al. (1996). In that procedure, Cerrado endemic species which inhabit forests were included. We also evaluated the distribution of records of endemic species, which were assigned to either the Atlantic Forest (Vale et al. 2018; Pizo & Tonetti 2020) or to the Cerrado (Silva 1995). The total field effort was calculated in hours (when data were available). The percentage of forest coverage within the Paraná was estimated according to deforestation references (Gubert Filho 2010; Project MapBiomias 2020).

No publications mentioned species collected or observed from 1821 to 1900; therefore, the first period of the 13 decades includes the 1820–1900 period. Such

an approach was deemed necessary since it eliminated finer divisions of time for those 80 years as there would be no reports of species in the literature in them. The remaining decades corresponded to that decade plus 1. For example, the 1920s spanned 10 years, from 1921 to 1930.

Analyses

A dendrogram was built using Jaccard Dissimilarity Index with the average method (Krebs 2007) to visually inspect the similarities of species composition between decades. The Analysis of Similarity (ANOSIM) was used to measure the similarity between communities’ composition among decades. Analyses were developed within the R 4.1.3 environment (R Core Team 2022). A heatmap was produced based on counts of species reports by localities from 1937 to 2022 across studies with QGIS software (QGIS Development Team 2019) using the quartic function on the renderer and a 0.5-degree resolution.

Results

Median and standard deviation (SD) of the amount of publications/year were 5.0 and 4.3, respectively. More references ($n = 16$) were published in 2017 than all other years, with 1937, 1938, 1944, 1955, 1982, 1983, 1992, and 1993 only having one each year (Figure 2a). However, the exact years of records spanned a wider range, from 1820–2020 (Figure 2b).

Over the years, we found that forest species mentioned by publication varied from 0 to 400, with a median of 149.0 ± 99.0 (SD). Species reported by year of record peaked in 1903, 1929, 1955, and from 1982 onwards (Figure 3a). Overall, these studies accounted for 421 forest bird species (Supplementary Material S2), which rapidly accumulated from 1903 onwards. However, until 1980, 313 (74%) species were reported in the literature. From 1981–1990, when influential studies (e.g. Karr 1981) encouraged transect counting in Brazil, 80 species were added to the state. In the following decade (1991–2000), point counting was popularized (e.g. Vielliard & Silva 1990), and another 18 species could be recorded in field observations. Only four species were added to Paraná from 2001–2010, while 2011–2020 accounted for another six (Figure 3b). Transect counting was used throughout the years (1991–2022), while point counting was explored from 1999 to 2021; species lists and autonomous audio recorders were only used in the 2020s (Figure 4). The most and least recorded species were mentioned in 77 and one publication,

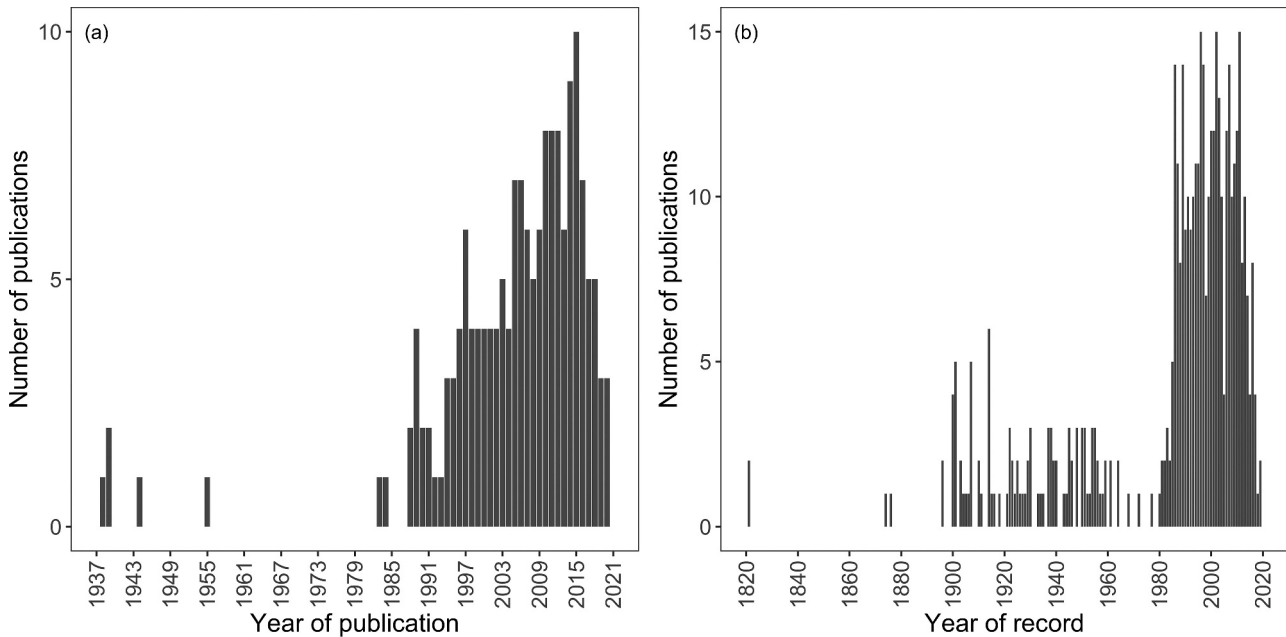


Figure 2. Number of studies published between 1937 and 2021 (a); number of studies mentioning forest bird species by year of record (b).

respectively. While the 10 most mentioned species appeared in 77–64 publications, species cited in ≤ 10 publications summed 155.

We observed the first study mentioning field effort in 1984, based on work developed in 1981. Few publications ($n = 16$; 8%) made their field effort available during the 20th century ($n = 4,725$ h), while such descriptive statistics were available for 84 (42%)

published studies conducted during the 21st century ($n = 34,578.3$ h) (Figure 5a). A total of 313 (74%) species were reported from 1820 to 1980, while the remaining 108 (26%) were only mentioned in publications in the following 40 years. During the last four decades more than 300 species were reported in 10-year intervals. Thus, despite uneven sampling effort dedicated to Paraná's ornithology over the years

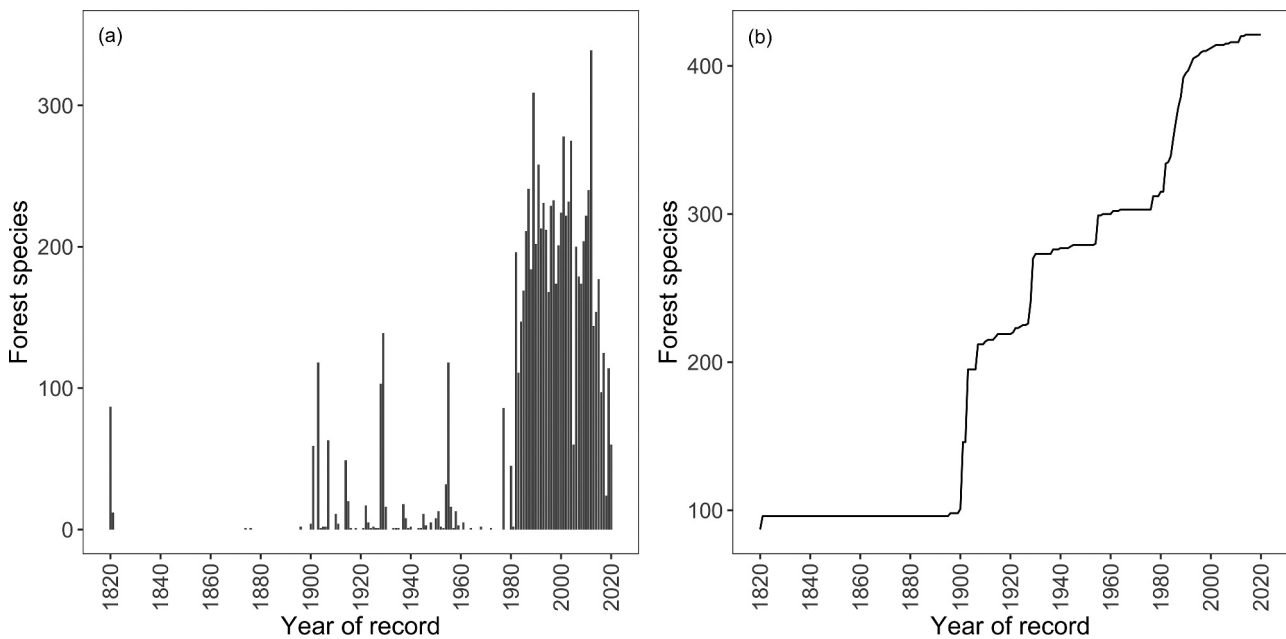


Figure 3. Number of forest bird species reported by year of record based on studies published between 1937 and 2021 (a); Collector curve for forest bird species reported in studies published between 1937 and 2021 (b).

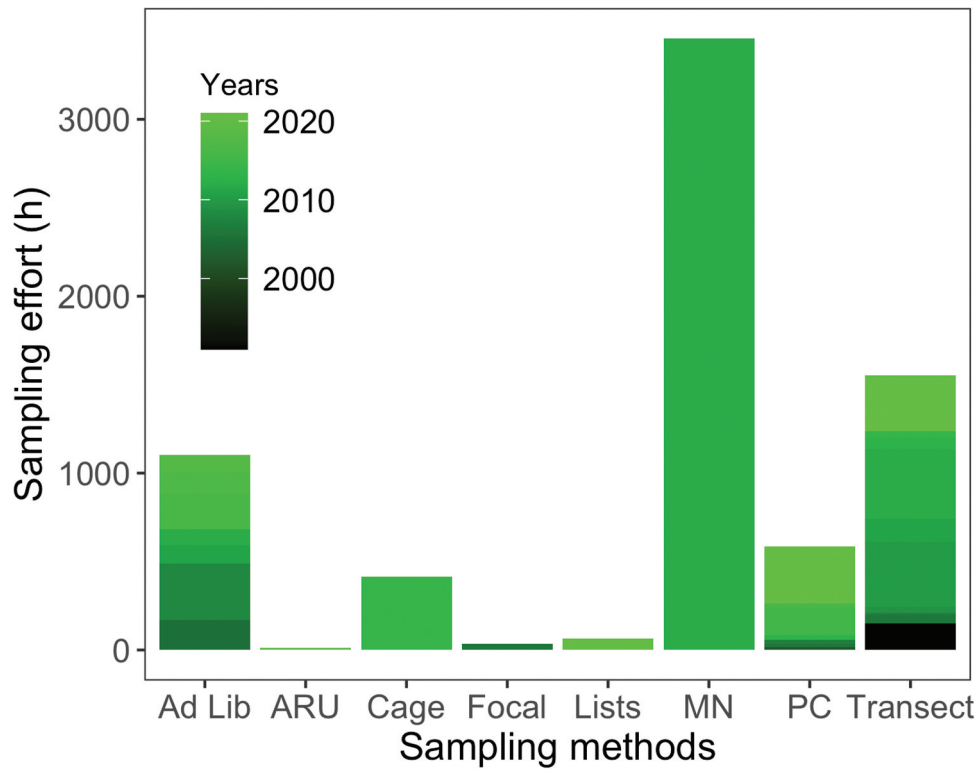


Figure 4. Yearly sampling effort (h) accumulated according to the method used by published ornithological studies conducted in Paraná State, Southern Brazil, from 1991 to 2021. Ad libitum (Ad Lib), autonomous audio recorders (ARU), Mist nets (MN) and point counts (PC).

(Figure 5a), most forest species were reported when the percentage of forest cover in the state was reduced to 5% (Figure 5b).

Over 200 years, we found that not only were the number of effort hours uneven, but the geographical distribution of visited localities greatly varied. Most

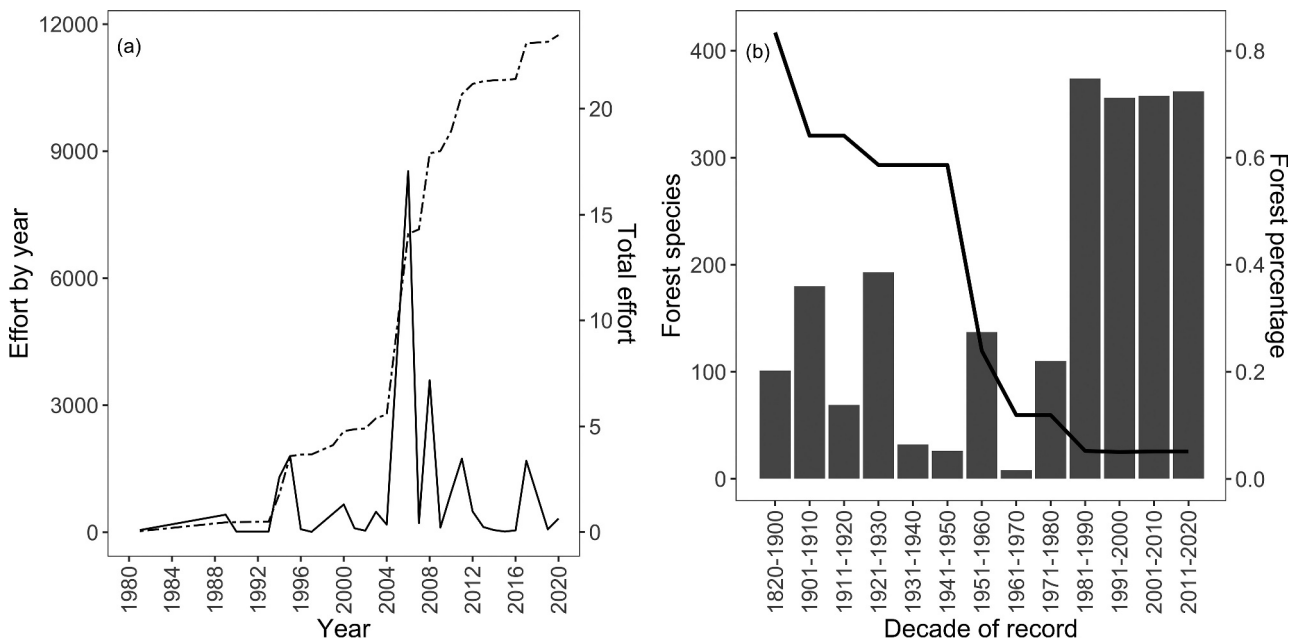


Figure 5. Number of hours spent in ornithological studies per year (continuous line) and number of thousands of hours of overall field effort (dashed line) based on studies published between 1937 and 2021 (a); Number of forest bird species reported by decade (bars) based on studies published between 1937 and 2021 in comparison with Paraná's forest cover percentage (line) (b).

sampled sites came from eastern Paraná, such as the Serra do Mar continuous Rainforests, Curitiba (the state's capital), and Ponta Grossa and Londrina regions (high and low Tibagi River basins). Only recently were western portions represented in publications, such as the Iguaçu National Park and surroundings (Figure 6a).

Differences in field effort, both hours and localities, defined the status of occurrence of Cerrado and Atlantic Forest endemic species. Cerrado birds were primarily known from Jaguariaíva, and only by expanding geographical coverage, such species were also acknowledged along the margins of the Paraná River (Figure 6b). Atlantic Forest endemic species were known to occur on easternmost borders with the state of São Paulo, coinciding with the most visited localities in Paraná (Figure 6c).

The composition of species among decades was quite dissimilar. Whereas the most similar decades included 1981–2020, there were no obvious clusters when all 13 decades were considered. Except for the 1950s, when more than 100 species were reported in the literature (Figure 5b), the dissimilarity of species composition among the 1930s, 1940s, and 1960s stood out (Supplementary Figure S1).

Ten species were exclusively recorded until 1980, while 105 were only registered from 1981–2020; 306 are common to both periods. The Analysis of Similarity between communities' composition among the decades resulted in $R = 0.041$, $p = 0.034$, indicating a significant and highly different species composition among decades (Supplementary Figure S2). Nine species were recorded only until 1980 (Table 1), and an increasing number of species stopped being detected in the following decades: 12 (1981–1990), 14 (1991–2000), and 20 (2001–2010). The remaining species have records from 2011–2020.

Discussion

We found that most bird species of Paraná were recorded until 1980, overlapping the period when forest cover had already been reduced to 5% of its original area. The low similarity between bird composition before and after 1980 may also be due to species which stopped being recorded from this decade onwards. In addition, this period showed studies with non-standardized surveys, given that field effort was first specifically mentioned in 1984. Since then, it has been uneven across sites and decades. Although most of the state territory has at least one bird record, ornithology in Paraná proved largely based on data from Eastern territories, a sampling bias also detected

for small non-volant mammal surveys in Paraná (Pereira et al. 2021).

Evident patterns regarding sampling effort were: (1) no sampling effort was provided in earlier studies since they involved collecting activities by naturalists, indicating only number of days, if that; (2) few studies provided sampling effort during the 20th century, which was expected since standardization was generally not properly addressed before the 1980s (James & Rathbun 1981); and (3) few studies provided proper sampling effort in more recent studies. In the latter case, we could not retrieve sampling effort from studies which mentioned the number of field days without specifying the number of hours spent during standardized methods. Thus, the total effort in hours dedicated to the study of birds within Paraná is considerably underestimated. Moreover, the dissimilarity of species composition among decades may be related to the great amount of standardized field work conducted during those years, reflecting the changing methods of ornithological sampling over time.

In 40 years (1981–2020), more records of birds were published compared to the preceding 160 years, a similar pattern observed for other taxa (Pereira et al. 2021). Portions which had not been visited, such as the central (Straube & Urben-Filho 2005b) and western (Straube & Urben-Filho 2004, 2008; Lindsey et al. 2019) regions of the state were now represented in studies. However, most species reports came from the Serra do Mar region (Hasui et al. 2018; Rodrigues et al. 2019), with contributions from the surroundings of Londrina (Anjos 2006) and Foz do Iguaçu (Hasui et al. 2018; Oliveira & Anjos 2022). Although the reports of species currently cover most of the state, field effort in the last 200 years has been geographically uneven and biased toward the easternmost regions of Paraná. The regions of Curitiba and Serra do Mar stand out for their continuous blocks of remaining forests (Rezende et al. 2018) and, along with Londrina, regions with the best-preserved protected areas (Pereira et al. 2021), where ornithologists (academic biologists or autonomous researchers) have regularly published their results since the 1980s (Anjos et al. 2011).

Specimens collected by naturalists accounted for earlier species records, when visual or aural detections corresponded to very few of these reports (Straube 2015). Most specimens came from Curitiba and its surroundings, while the only Cerrado species collected by naturalists, *Taoniscus nanus* (Temminck, 1815), was known from Jaguariaíva (Straube 2012, 2015). Another important historical region is the northern region of *Norte Pioneiro*, around

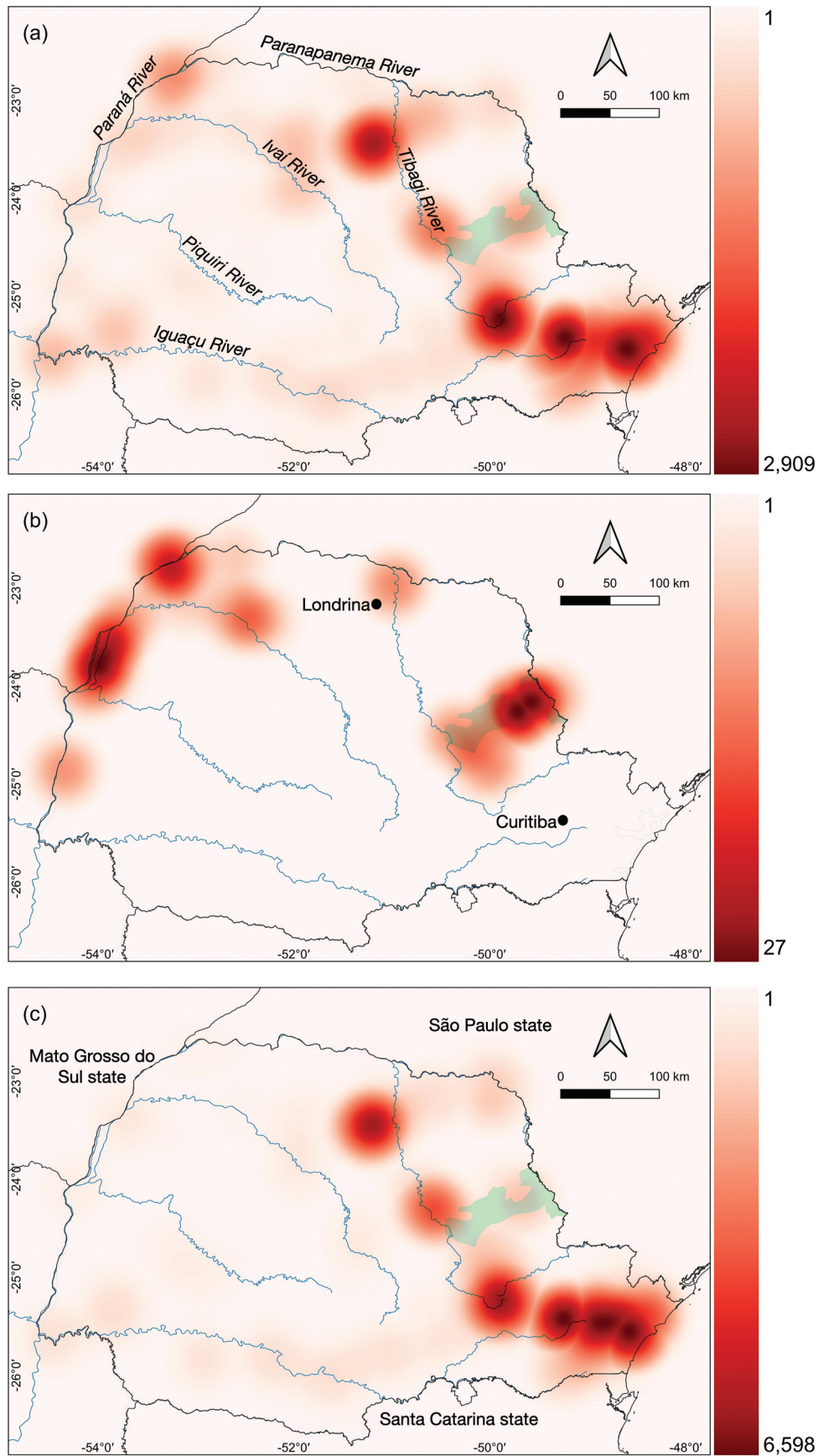


Figure 6. Number of times species were mentioned according to localities by studies published between 1937 and 2021 (a); Number of times Cerrado endemic species were mentioned by studies published between 1937 and 2021 (b); Number of times Atlantic Forest endemic species were mentioned by studies published between 1937 and 2021 (c). The light green shading indicates the southernmost extent of the Cerrado.

Table 1. Forest species which have not been recorded in the literature since the 20th century. Publication refers to the number of references in which each species was mentioned.* = species recorded until 2011.

Species	Publication	Year of last record	Decade	Species richness
<i>Ibycter americanus</i>	2	1903	until 1980	9
<i>Thalurania furcata</i>	1	1937		
<i>Antilophia galeata</i>	1	1955		
<i>Herpsilochmus atricapillus</i>	1	1955		
<i>Syndactyla dimidiata</i>	1	1955		
<i>Morphnus guianensis</i>	2	1964		
<i>Myiothlypis leucophrys</i>	1	1907–1914		
<i>Ara ararauna</i>	1	1921–1968		
<i>Harpia harpyja</i>	2	1925–1934		
<i>Neopelma chrysolophum</i>	1	1988	until 1990	11
<i>Poecilatriccus latirostris</i>	3	1989		
<i>Atticora tibialis</i>	2	1989		
<i>Heliomaster longirostris</i>	2	1989		
<i>Momotus momota</i>	2	1990		
<i>Piprites pileata</i>	5	1820–1990		
<i>Jacamaralcyon tridactyla</i>	6	1901–1985		
<i>Lophornis magnificus</i>	6	1907–1987		
<i>Clibanornis rectirostris</i>	2	1955–1989		
<i>Laniisoma elegans</i>	3	1982–1983		
<i>Cyanocorax cyanomelas</i>	4	1982–1989		
<i>Cyanerpes cyaneus</i>	2	1991	until 2000	14
<i>Neopelma pallescens</i>	2	1993		
<i>Bubo virginianus</i>	1	1993		
<i>Saltator aurantirostris</i>	2	2000		
<i>Nyctibius aethereus</i>	5	1900–1993		
<i>Pulsatrix perspicillata</i>	3	1903–1996		
<i>Cantorchilus leucotis</i>	5	1955–1991		
<i>Strix huhula</i>	3	1982–1998		
<i>Myiobius atricaudus</i>	6	1985–1994		
<i>Dacnis nigripes</i>	2	1989–1993		
<i>Chrysolampis mosquitus</i>	2	1992–2000		
<i>Chlorestes cyanus</i>	3	1995–1999		
<i>Crax fasciolata</i>	4	1996–1997		
<i>Gampsonyx swainsonii</i>	1	1996–1997		
<i>Sublegatus modestus</i>	2	2006	untill 2010	20
<i>Leptasthenura striolata</i>	9	1820–2010		
<i>Accipiter bicolor</i>	4	1821–2001		
<i>Hemitriccus nidipendulus</i>	8	1903–2004		
<i>Urubitinga coronata</i>	5	1907–2009		
<i>Patagioenas speciosa</i>	9	1929–2006		
<i>Anrostomus sericocaudatus</i>	3	1940–2004		
<i>Spizaetus melanoleucus</i>	5	1944–2009		
<i>Coccyzus euleri</i>	7	1955–2008		
<i>Nyctiphrynus ocellatus*</i>	2	1961–2011		
<i>Patagioenas maculosa</i>	6	1984–2007		
<i>Paraclaravis geoffroyi</i>	2	1985–2001		
<i>Aramides mangle</i>	2	1986–2001		
<i>Conirostrum bicolor</i>	2	1989–2001		
<i>Chondrohierax uncinatus</i>	3	1989–2009		
<i>Polioptila lactea</i>	6	1991–2010		
<i>Heliomaster squamosus</i>	4	1992–2002		
<i>Buteo nitidus</i>	3	1993–2003		
<i>Buteo albonotatus</i>	3	1999–2009		
<i>Spizaetus ornatus</i>	2	2002–2004		

Jacarezinho, where the first deforestation fronts occurred inland during the beginning of the 20th century to pave way for coffee monocultures (Straube et al. 2002; Gubert Filho 2010).

Ecological and zoological studies which produced species lists in the form of inventories or surveys predominated during the late 20th century, expanding the ornithological knowledge of the state. Collection of specimens was still being gathered until 1950 by naturalists such as T. Chrostowski and several workers

from Museu Paulista (currently Museum of Zoology of the University of São Paulo) (Pinto & Camargo 1955; Straube 2016, 2017). From 1980 onwards, contemporary ornithologists also greatly contributed to expand studies throughout Paraná. Curitiba continued to stand out as an important locality (Straube et al. 2014), but hundreds of others were added, such as Serra do Mar (Straube & Urben-Filho 2005a), Ponta Grossa (Scherer-Neto et al. 2011), the middle and lower Tibagi River basins (Anjos et al. 1997), and the

upper Paraná River on the borders of the states of São Paulo and Mato Grosso do Sul (Gimenes & Anjos 2006; Straube et al. 2012).

We determined that four of the most mentioned forest species in Atlantic Forests studies published after 1970 were also among the most reported in Paraná: *Pitangus sulphuratus*, *Turdus amaurochalinus*, *Thraupis sayaca*, and *Basileuterus culicivorus* (Hasui et al. 2018). Several species are absent from our analyses if compared to a critical review of the birds of Paraná (Scherer-Neto et al. 2011). This should be expected as the previous authors listed as many specimens (including non-forest species) as they could from private and public museum collections worldwide (Scherer-Neto et al. 2011). Moreover, we did not consider the gray literature (reports and annals), most of which are impractical to find and do not contain entire species lists, or online ornithological platforms, such as eBird and Wikiaves; our forest species richness does not coincide with the most recent review of the birds of Paraná (Klemann-Junior et al. 2017). Finally, the few studies early on were isolated, and so it was impossible for them to have similar species richness values as more recent studies.

Atlantic Forest endemic species were an example of biased inventoried or surveyed locations. These species were commonly indicated in the east, a region which tended to be more thoroughly visited (Hasui et al. 2018). However, they could have been more frequently reported from other regions of Paraná, should they had been visited (Hasui et al. 2018; Rodrigues et al. 2019). Such unevenness of records illustrate how unequal the number of species were reported by decade and that the bulk of historical ornithological knowledge in Paraná is uneven and mostly based on few, well-known eastern localities. Regions such as the southern borders with the state of Santa Catarina and with Argentina and Paraguay, large portions of interfluves of the lower Ivaí and Piquiri Rivers, and smaller gaps along the northern border with São Paulo remain virtually unknown (Hasui et al. 2018; Rodrigues et al. 2019). This Wallacean shortfall hampers the knowledge of large-scale patterns of biodiversity and was recently reported for small non-volant mammals in Paraná (Pereira et al. 2021).

Most reports came from the last 40 years, when forest coverage within the state was already reduced to 5% (Gubert Filho 2010; Project MapBiomias 2020). More reports exist when forests were more fragmented due to the use of standardized census methodologies, which began in the 1980s (Scherer-Neto 1984; Hasui et al. 2018), and were widely disseminated in the 1990s onwards (Vielliard & Silva 1990; Ribon

2010). This suggests that, in Paraná, forest bird communities were inventoried or censused on degraded and fragmented landscapes which also suffered from habitat loss, among the most pervasive negative consequences for Atlantic Forest terrestrial communities (Galetti et al. 2021). Some species may already be extinct in the State, such as *Ibycter americanus* and *Thalurania furcata*, the last records of which date from 1903 and 1937, respectively. Additionally, the loss of 95% of the former area may indicate that the thriving, isolated populations of some forest birds may go through time-lag thresholds, incapable of surviving for long, even if they are still found in some forest remnants (Banks-Leite et al. 2014; Uezu & Metzger 2016).

Some researchers deliberately did not incorporate their species lists into their ecological publications, not even as supplementary material. This led us to conclude that the surveys of bird communities – even in the best-known localities in Paraná – are far from being examples of long-term monitoring, such as have been carried out elsewhere (Willis & Oniki 2002; Willis 2004). Regular inventories and censuses should be carried out, especially where the avifauna is considered well-known and at the local level, to understand how bird communities will respond to fragmentation and, eventually, to the current climate crisis (Schunck et al. 2019; Jirinec et al. 2021; Pereira et al. 2021; Stouffer et al. 2021; Pereira et al. 2021). This will eventually further highlight the relevance of monitoring the bird community over time to detect species before their extinctions (Lees et al. 2015).

The distribution of Cerrado endemic species showed the importance of extending surveys to distinct regions. Such species were obviously found within Jaguariaíva surroundings, the southernmost reach of these savanna habitats in Brazil (Silva 1995; Straube et al. 2005). Few studies, however, explicitly acknowledged the Paraná River channel as a relevant southernmost range for several Cerrado species (Camargo 1946; Scherer-Neto et al. 2008), especially on the borders with Paraguay (Quagliato & Cavarzere 2021). Thus, we recommend future studies to be conducted in Cerrado areas within Paraná, as well as in locations we found to lack ornithological information in the state.

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Disclosure statement

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