Ornithology Research
https://doi.org/10.1007/s43388-022-00087-0

ORIGINAL ARTICLE

Unravelling the migratory patterns of the rufous-tailed attila within the Neotropics using citizen science and traditional data sources

Leonardo Esteves Lopes[1] · **Fabio Schunck**[2]

Received: 21 November 2021 / Revised: 15 February 2022 / Accepted: 17 February 2022

Abstract
Citizen science data is a useful tool for the study of bird migration, especially in the tropics, where more traditional sources of biological data are scarce. In this paper, we studied the seasonal migration of the rufous-tailed attila *Attila phoenicurus*, a migratory Neotropical passerine that is supposed to breed in the Brazilian Atlantic Forest. We (1) compared the relative contribution of different sources of data (citizen science and traditional sources) to unravel the migratory patterns of the rufous-tailed attila, and (2) tested the hypothesis that the species is an austral migrant that breeds in the Atlantic Forest and winters in Amazonia. We used data from citizen science, literature, museum specimens, and traditional sound archives to investigate the seasonal distribution of the species. Vouchered records were checked for identification mistakes. We found that citizen science allowed the collection of a huge amount of data in a short period of time, providing in two decades almost eight times the number of occurrences of the rufous-tailed attila that have been obtained during two centuries of ornithological studies by the scientific community. Our results confirmed that the rufous-tailed attila is an austral migrant that breeds in a comparatively narrow area in the southern portion of the Brazilian Atlantic Forest. Contrastingly, the winter grounds of the species are spread across a vast area in Amazonia. Citizen science data is a powerful tool for the development of tropical ornithology, but its use requires the understanding of the specific virtues and limitations of each major online database.

Keywords Atlantic Forest · *Attila phoenicurus* · Bird migration · eBird · Neotropics · WikiAves

Introduction

Understanding the exact breeding and non-breeding range of a bird species, including their migratory routes, is of paramount importance for assessing conservation status and defining conservation policies and management strategies (Faaborg et al. 2010). Despite that, basic information on the migratory patterns of most Neotropical birds is still lacking, including data on migratory phenology, migratory routes, and population-specific patterns of migration (Jahn et al. 2020). Despite of recent increase in knowledge of bird migration in the Neotropical region, traditional sources of data, including the scientific literature and ornithological collections, often provide an insufficient amount of data to accurately unravel the migratory patterns of most species (Remsen-Jr. and Parker-III 1990; Heckscher et al. 2011). Long-term field studies and the use of high-tech tracking devices, on the other hand, are often prohibitively costly for the chronically underfunded research institutions in the tropics.

A possible solution for filling this "Wallacean Shortfall" is the use of citizen science data (Areta and Juhant 2019; Lees et al. 2020), a tool that is growing in popularity among ornithologists (Bela et al. 2016; Turnhout et al. 2016; Schubert et al. 2019). In this paper, we investigated the migratory pattern of a Neotropical passerine, the rufous-tailed attila *Attila phoenicurus*, using data from our long-term fieldwork, traditional sources, and citizen science. Understanding the migration of the rufous-tailed attila also has conservation implications, because even though it is a globally Least Concern species, its population appears to be decreasing

Communicated by: Marcos Santos

✉ Leonardo Esteves Lopes
leo.cerrado@gmail.com

[1] Laboratório de Biologia Animal, IB, Universidade Federal de Viçosa–Campus Florestal, Florestal, Minas Gerais, Brazil

[2] Comitê Brasileiro de Registros Ornitológicos–CBRO, São Paulo, Brazil

Published online: 23 March 2022

(BirdLife International 2020). Furthermore, the species is highly sensitive to human disturbance (Parker-III et al. 1996) and is considered as Data Deficient in Argentina (MAyDS and AA 2017) and Paraguay (Guyra Paraguay 2005). Finally, its assumed breeding range (the nest of the species is undescribed, Crozariol 2016) is restricted to the highly threatened Atlantic Forest (Ribeiro et al. 2009), a biodiversity hotspot (Myers et al. 2000), thus the species is a high research priority (Parker-III et al. 1996) whose seasonal geographical distribution still requires further research (Chesser 2005).

The genus *Attila* includes seven species of Neotropical passerines restricted to humid forests (Ridgely and Tudor 2009; Walther 2020). Members of this genus are year-round residents, with the remarkable exception of the rufous-tailed attila (Walther 2020), which is a rare to locally fairly common species in the upper strata of tropical evergreen forests (Ridgely and Tudor 1994; Walther 2020). The rufous-tailed attila has long been thought to be restricted to the Atlantic Forest and forested patches within the Cerrado savannahs (Hellmayr 1929; Pinto 1944), until unexpected records from the Amazonia (Friedmann 1948; Todd 1950) dramatically changed our understanding of its movement ecology. Meyer de Schauensee (1966) and Short (1975) were the first authors to suggest that the rufous-tailed attila performs some kind of migration. Nonetheless, the first hypothesis about its migratory patterns was presented much later, predicting that it breeds in the southern part of the Brazilian Atlantic Forest and winters in a vast area in Amazonia (Chesser 1994; Ridgely and Tudor 1994). Although many subsequent authors have accepted this proposition (Parker-III et al. 1996; Aleixo et al. 2011; Pinho et al. 2017; Amaya-Espinel and Hostetler 2019), this hypothesis has never been tested (Somenzari et al. 2018). In this paper, we investigated the migratory patterns of the rufous-tailed attila using citizen science and traditional data sources. For that we (1) compared the relative contribution of different sources of data and (2) tested the hypothesis that the species is an austral migrant that breeds in the southern Atlantic Forest and winters in Amazonia. Finally, we discuss on the virtues and limitations of the two most popular citizen science projects consulted.

Methods

Data acquisition and database assembly

We searched for records of the rufous-tailed attila in traditional sources, such as literature and ornithological collections, as well as in citizen science sources. All records gathered were arranged in a database containing data on locality, latitude, longitude, date, habitat used, evidence of breeding activity, and biogeographic province where each record was obtained (Table S1, supplementary material). We obtained geographical coordinates and elevation from the original sources, ornithological gazetteers (Paynter-Jr. 1989; Paynter-Jr. and Traylor-Jr. 1991; Paynter-Jr. 1995), and the computer program Google Earth (https://earth.google.com). Records for which no precise locality was presented, which include all records from WikiAves (see below), were georeferenced to the municipal seat. It is important to note that the size of Brazilian municipalities varies greatly, with larger municipalities, as a rule, located in Amazonia (the area of the 152 municipalities that we georeferenced to the municipal seat ranged from 70 to 25,778 km^2, with a median of 499 km^2). All online resources were accessed in February 2020.

Citizen science

We checked for records in the following online databases that provide citizen science data: WikiAves (http://www.wikiaves.com.br), Xeno-Canto (http://www.xeno-canto.org), Fauna Paraguay (http://www.faunaparaguay.com), eBird (https://ebird.org), and the Internet Bird Collection (https://www.hbw.com/ibc — soon after our consultation, the IBC became part of the Macaulay Library, which also harbors traditional audio records collected by professional scientists, see below). WikiAves, despite covering only the Brazilian territory, is gaining popularity among researchers (e.g., Lees and Martin 2015; Schubert et al. 2019), regardless offering no tools for bulk data download. Therefore, we built an automated Web Scrapper implemented in Python for extracting the data available (see "Acknowledgements"). WikiAves became operational in 2008 and eBird in 2002, but only became global in 2010, gaining popularity in Brazil during the last 5 years or so.

Literature review

We performed a wide literature review using the search engine Google Scholar (https://scholar.google.com) and the advanced search tool of the Biodiversity Heritage Library (https://www.biodiversitylibrary.org). The current scientific names of the species, as well as its junior synonym *Pseudatilla phoenicurus*, were used as keywords.

Ornithological collections

LEL personally examined museum specimens in the following Brazilian and overseas collections, checking specimens identification, and recording the data from specimens labels: American Museum of Natural History, New York (AMNH); Carnegie Museum of Natural History, Pittsburgh (CM); Universidade Federal de Minas Gerais, Belo Horizonte (DZUFMG); Field Museum of Natural History,

Chicago (FMNH); Louisiana State University Museum of Natural Science, Baton Rouge (LSUMZ); Museu Nacional, Rio de Janeiro (MNRJ); Museu Paraense Emílio Goeldi, Belém (MPEG); Museu de Zoologia da Universidade de São Paulo, São Paulo (MZUSP); Natural History Museum, Tring (NHM; formerly BMNH); Naturhistoriska Riksmuseet, Stockholm (NRM); Senckenberg Naturmuseum, Frankfurt (SMF); National Museum of Natural History, Washington, DC (USNM); and Museum für Naturkunde, Berlin (ZMB). Curators of the following institutions kindly provided us with a list of specimens housed in the collections under their care: Museo Argentino de Ciencias Naturales Bernardino Rivadavia, Buenos Aires (MACN); Museu de Ciências Naturais da Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte (MCNA); Museu de Ciências Naturais da Fundação Zoobotânica do Rio Grande do Sul, Porto Alegre (MCN/FZBRS); Museu de Ciências e Tecnologia da Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre (MCP); Museu de História Natural Capão do Imbuia, Curitiba (MHNCI); Museo de La Plata, Buenos Aires (MLP); Naturhistorisches Museum, Vienna (NMW); and Zoologisches Forschungsinstitut und Museum Alexander Koenig, Bonn (ZFMK). We also checked for additional specimens in the online databases of all ornithological collections that contributed data to VertNet (http://vertnet.org) and Species Link (http://splink.cria.org.br).

Traditional sound archives

We checked for song recordings in the online databases of the Macaulay Library, Ithaca (http://macaulaylibrary.org) and the Fonoteca Neotropical Jacques Vielliard, Campinas (http://proj.lis.ic.unicamp.br/fnjv). The curator of the Arquivo Sonoro Prof. Elias Coelho, Rio de Janeiro (ASEC) sends to us a list of the recordings housed in that institution, after checking them. Macaulay Library is accepting contributions from citizen scientists since 2016 and, therefore, we only considered as obtained from a "traditional" source those records deposited in the Macaulay Library before its integration with eBird. All subsequent records were considered as citizen science data.

Database cleaning

The rufous-tailed attila is superficially similar in voice and morphology to the gray-hooded attila *Attila rufus* and is hardly separable from the female crested becard *Pachyramphus validus* (Hayes et al. 1994; Ridgely and Tudor 2009; García et al. 2016). These two resident species are occasionally misidentified as the rufous-tailed attila by inexperienced observers (pers. obs.). To remove erroneous records from the database, what can bias phenological estimates of hard-to-identify species (Gorleri and Areta 2022), LEL personally checked the identification of all digital vouchered records (i.e., photographs or song recordings) in the citizen science data sources consulted. Wagner Nogueira, who has worked as a moderator of WikiAves during the last 10 years, was kind enough to independently check at our request all digitally vouchered records of the rufous-tailed attila. WikiAves, Xeno-Canto, IBC, and Fauna Paraguay rely exclusively on digital vouchers that can be independently checked. Even though eBird also accepts the deposition of digital vouchers, this possibility is infrequently used, and most of eBird records cannot be objectively validated.

Fieldwork

FS conducted fieldwork in the Núcleo Curucutu of the Serra do Mar State Park (~23°56′ S; 46°39′ W), state of São Paulo, southeastern Brazil, which encompasses 36,134 ha. This park is in the Atlantic Forest domain and harbors a mosaic of vegetation types including high altitude grasslands, and high montane to lowland forests (Garcia and Pirani 2003; Pessenda et al. 2009). The local climate is humid subtropical with high rainfall throughout the year (Alvares et al. 2013). Annual precipitation ranged between 3497 and 4435 mm from 2008 to 2011 (Malagoli 2013).

FS conducted a four consecutive years field study in the Núcleo Curucutu from May 2007 to June 2011. He sampled 10 areas of the park, encompassing an elevational gradient ranging from 15 to 880 m a.s.l. Each area was sampled four times per year (one campaign of 3 days in each season), with the simultaneous use of three different survey methods: point counts (226 h of census), mist net captures (~3 million h.m^2), and visual observations. Given that the number of areas sampled varied across years, and that, for logistic constraints (e.g., heavy rains), it was not possible to sample all areas during all years, the final sampling effort was of 306 field days. From 2012 to 2018, the uppermost area of the park continued to be sampled for seven summer campaigns, one 5–6 days campaign per year, using the same methods used in the standardized sampling, totaling 39 field days. Additionally, during this period, opportunistic, non-standardized observations were conducted at different areas and habitats of the park during several short visits, totaling 25 field days (details in Schunck et al. 2019).

Data analysis

A preliminary analysis of the database obtained revealed that some records from different sources were duplicates (e.g., the same song record was deposited in Xeno-Canto as well as in WikiAves, or a museum specimen was cited multiple times in the literature). In a similar way, a same bird was frequently photographed and/or recorded by multiple birders travelling together, as revealed by their comments in

WikiAves and eBird. We, therefore, considered all records from the same locality and day as a single "occurrence" to reduce bias in the analysis.

For data analysis, we first examined the decadal variation in the number of occurrences of the species obtained during the last two centuries, evaluating how different sources of data (e.g., literature and museum specimens) provided different amounts of data through time. For that, we constructed a bar chart plotting the number of occurrences of the species for each decade and another one plotting the total number of records of the species for each type of data source. Second, we evaluated how the species is distributed through time in the distinct biogeographic provinces where it occurs. For that, we constructed a stacked bar chart plotting the number of occurrences of the species, classified accordingly to the biogeographic province where it was recorded, for each half month. Third, we evaluated how the latitudinal distribution of the species varies through time. For that, we constructed a scatterplot plotting latitude of each occurrence against ordinal dates, i.e., day of the year ranging from 1 (01 January) to 365 (31 December; 366 on leap years). Fourth, to confirm the migratory behavior of the species, we evaluated its seasonal and altitudinal occurrence in the Núcleo Curucutu by constructing a scatterplot plotting elevation against ordinal date of each occurrence.

For better visualization of the seasonal migratory pattern of the rufous-tailed attila, we mapped its occurrences during each month and then made two short movies using the 12 maps obtained as frames. In the first movie, we plotted all occurrences from all sources consulted in a vegetation map of South America (i.e., presence only maps with no control for temporal or spatial sampling bias). In the second movie, we only used data from the two major citizen science data sources consulted, what allowed us to better control for sampling bias (the entire databases of eBird and WikiAves together provided ~20 million records for South America at the time of consultancy). We used a grid of square cells (1° latitude × 1° longitude) to calculate, for each month of the year, the proportion of records available for that grid cell that corresponded to the rufous-tailed attila (i.e., number of records of the studied species in a given grid cell / total number of records of all bird species in that same cell). A color scale was then used to indicate how frequent were records of the rufous-tailed attila found in each cell in relation to the records of all other species. For this analysis, we used the packages "raster" and "rgdal" in R version 3.6.2 (R Core Team 2019).

After observing that the number of records of the rufous-tailed attila for the Atlantic Forest during the wintering period (April-September) of the species seemed to vary considerably between vouchered and unvouchered databases, we constructed a stacked bar chart plotting the number of unlikely occurrences of the species (i.e., occurrences in the assumed breeding range during the wintering season), classified accordingly to the source of data, for each month.

Results

We gathered 3367 dated records of the rufous-tailed attila, but with a high number of redundant records (e.g., same bird photographed by multiple birders) that, if excluded, resulted in 2344 occurrences. Even though the first specimen of the rufous-tailed attila was collected in 1818 (specimen NMW 17176), the species was only described in 1868, therefore half a century later. Except for a single specimen collected in 1882 (AMNH 33002), the species remained unrecorded for about a century after it has been first collected. Since the 1920s, records of the species have been obtained in every decade until the number of records exponentially increased during the twenty-first century (Fig. 1). This sudden increase was mainly due to the explosion in popularity of birdwatching in the Neotropics in the second decade of the twenty-first century, largely fueled by eBird and, in Brazil, WikiAves. These two citizen science data sources alone contributed, during the last decade (2011–2020), with 1823 occurrences, with almost eight times the number of occurrences of the rufous-tailed attila that have been obtained during two centuries of ornithological studies by the scientific community (Fig. 2).

The rufous-tailed attila exhibits marked seasonal variation in its geographical distribution (Fig. 3). Occurrences of the species in the Atlantic Forest, where it is now confirmed to breed (e.g., EBIRD:OBS579889077, WA 2946229), are comparatively abundant and concentrated from the second half of October to the first half of March (Figs. 3 and 4), but some few isolated occurrences are available for all other months of the year (see Videos S1 and S2, supplementary material). The breeding range of the species is restricted to the southern portion of the Brazilian Atlantic Forest, especially along the Serra do Mar Coastal Forests and, to a lesser extent, the Araucaria Moist Forests (*sensu* Olson et al. 2001) (Fig. 5). Its elevational range spans from sea level to almost 2000 m a.s.l. The seasonal occurrence of the species in the Atlantic Forest is corroborated by our long-term fieldwork. We recorded the species throughout the entire elevational range of the Núcleo Curucutu from November to March, obtaining no record from April to October, even after 11 years of fieldwork (Fig. 6).

The 21 occurrences of the species for the South American Dry Diagonal, which is formed by the Caatinga, Atlantic Dry Forests, Cerrado, Pantanal, Chiquitano Dry Forests, and Dry Chaco biogeographic provinces, are from mid-March to early November.

Occurrences for Amazonia are few (only 61 dated occurrences) and scattered from the last week of March

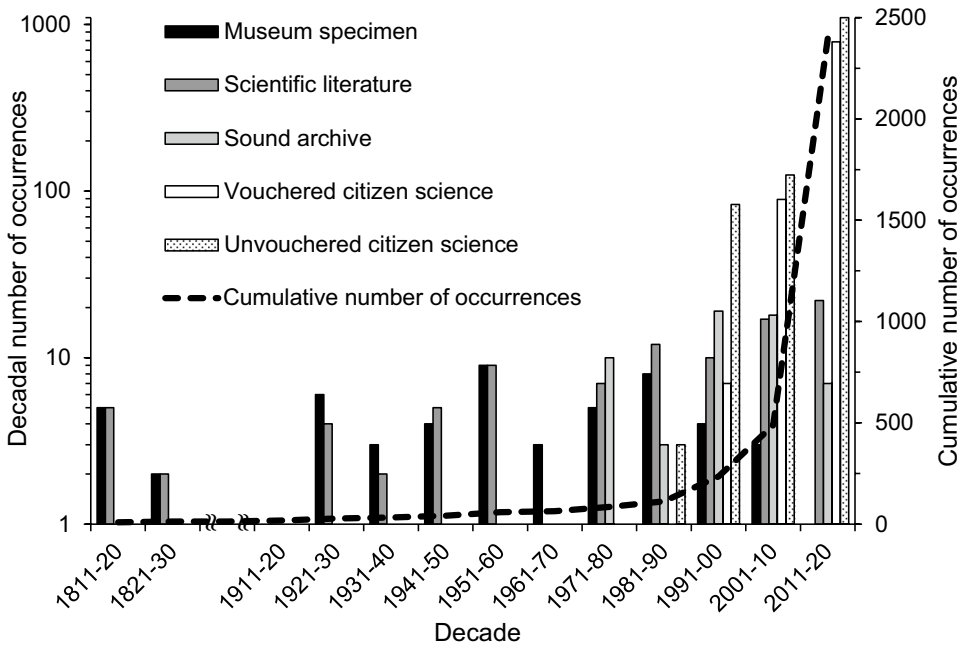

Fig. 1 Decadal distribution of the number of occurrences of the rufous-tailed attila *Attila phoenicurus* during the last two centuries, indicating the different sources of records. The cumulative number of occurrences is depicted in linear scale (right *y* axis) for a better visualization of the exponential increase in the number of records during the last two decades. Note that the total number of occurrences is slightly smaller than the sum of the number of occurrences from different sources. This is because a same record has frequently been made available in different sources (e.g., a museum specimen cited in the literature)

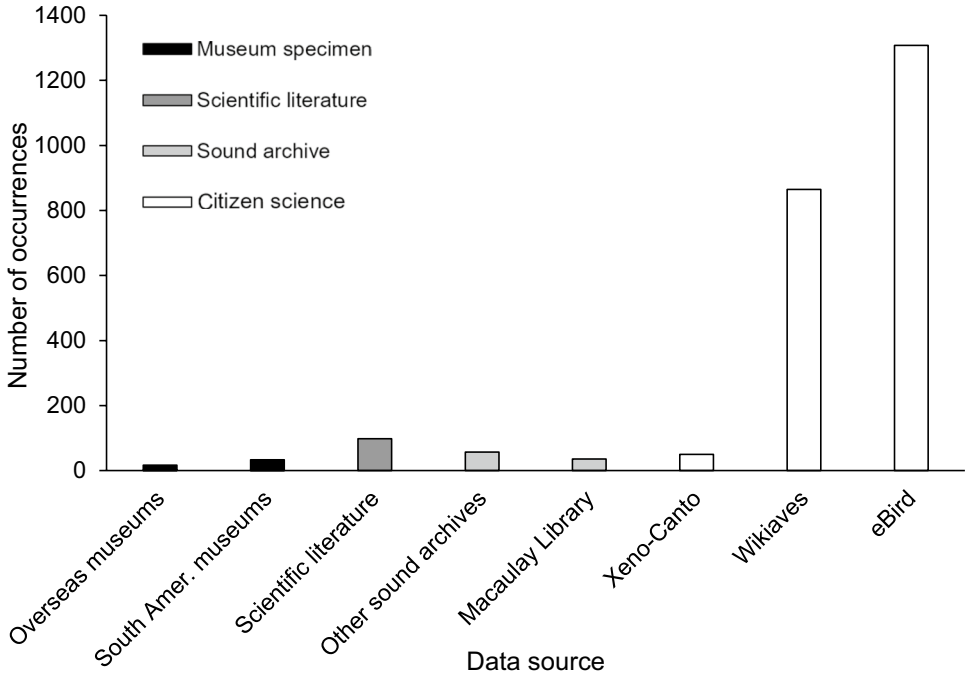

Fig. 2 Number of dated occurrences of the rufous-tailed attila *Attila phoenicurus* obtained from different sources. Macaulay Library refers exclusively to the records available before its partnering with eBird

to the first week of November (Figs. 3 and 4). Due to the small number of occurrences in Amazonia, it is not possible to determine if the species winters in the whole of central Amazonia, in a small portion of it, or if it performs any predictable regular movement within it (Fig. 5). All occurrences obtained in Amazonia are from evergreen forests, and those few occurrences for which the author explicitly specified the type of habitat used included non-flooded (*terra firme*, Novaes 1976; Bates et al. 1992; Aleixo et al. 2011) and seasonally flooded habitats (*várzea* and *igapó*, Whittaker 2009; Lees et al. 2013), but usually close to riverine habitats.

At a country level, the five dated occurrences of the species for Bolivia were obtained from mid-March to the end of August, while the nine dated occurrences for Paraguay are scattered from mid-March to the end of October, with the only exception of a purported sight record for 15th January (maybe an identification mistake). The 14 dated occurrences for Argentina are from February (5 records), March (2), May (1), July (1), October (4), and November (1), almost all of

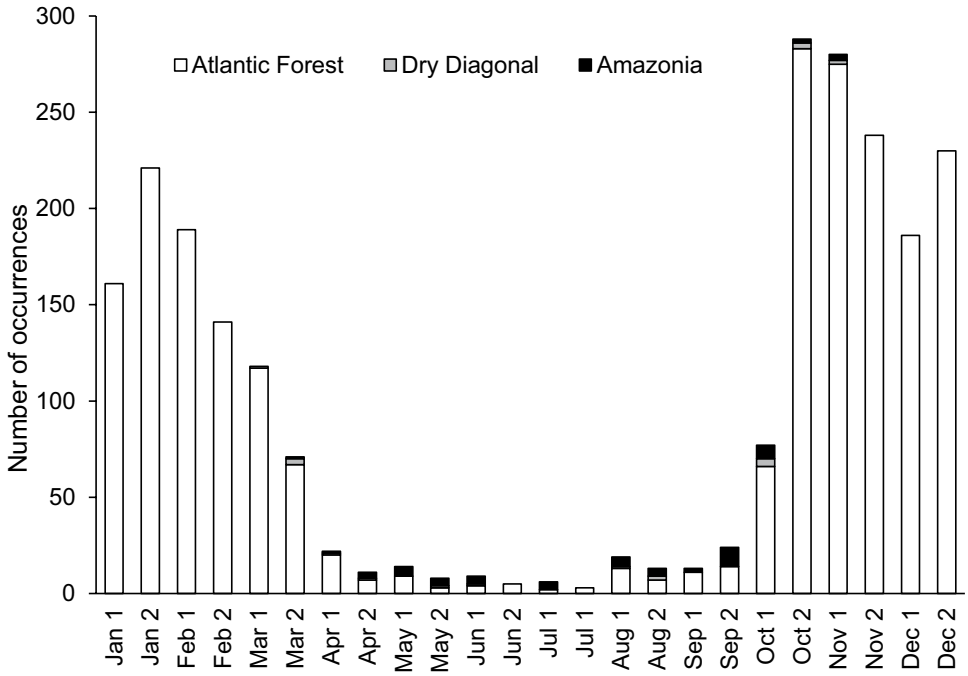

Fig. 3 Number of occurrences of the rufous-tailed attila *Attila phoenicurus* obtained throughout the year in each major South American biogeographic province. "Dry Diagonal" includes occurrences obtained in the Cerrado, Pantanal, Chiquitano Dry Forests, and Chaco. Data from museum specimens, literature, sound archives, and citizen science data sources. Each month was divided in two periods of ~15 days

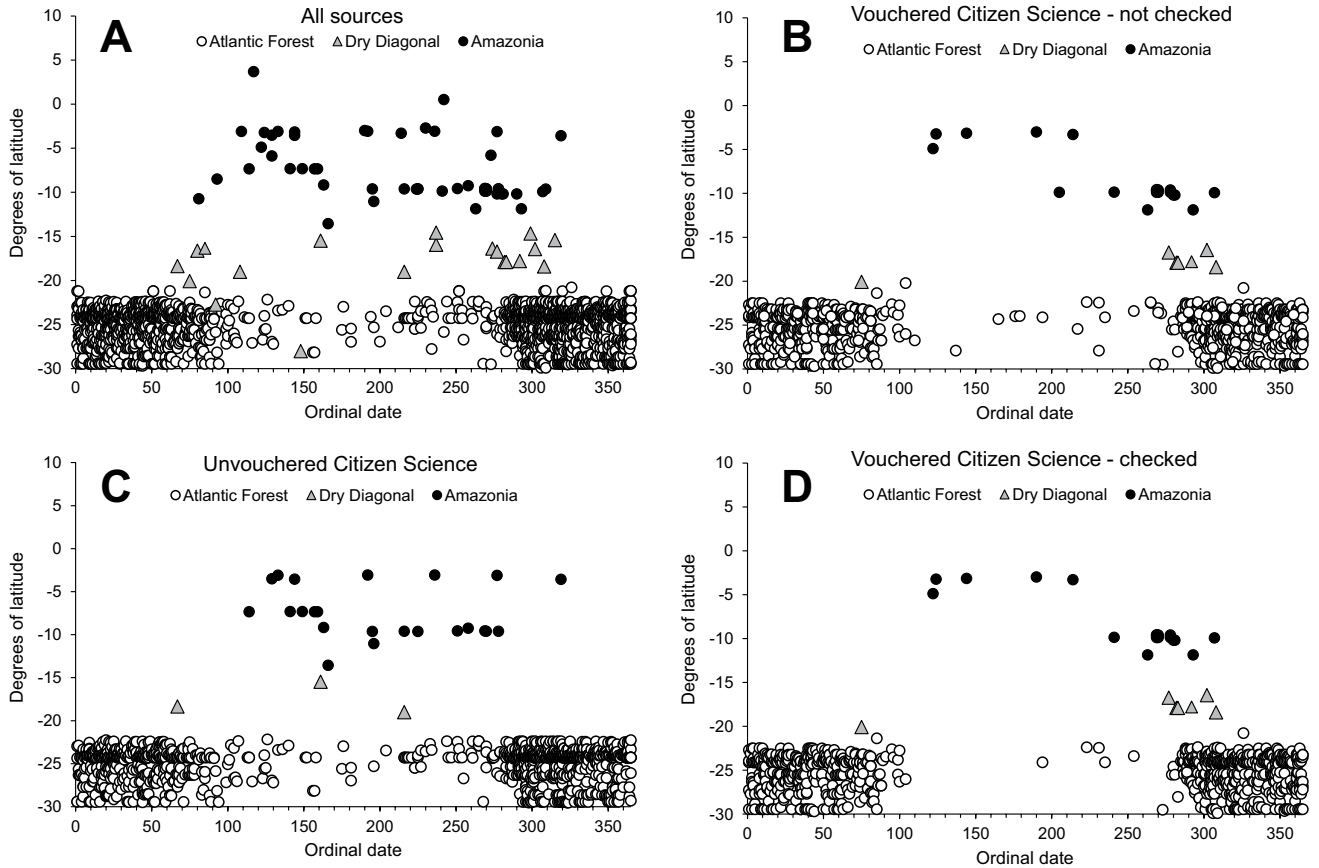

Fig. 4 Annual variation in the latitudinal distribution of the rufous-tailed attila *Attila phoenicurus* in South America. Day of year ranging from 1 (1st January) to 365 (31st December; 366 in leap years). "Dry Diagonal" includes records obtained in the Cerrado, Pantanal, Chiquitano Dry Forests, and Chaco. **A** All sources of data combined; **B** raw data (not checked) from vouchered citizen science data sources; **C** data from unvouchered citizen science data sources; and **D** data from vouchered citizen science data sources after checking (identification mistakes and misdated records removed)

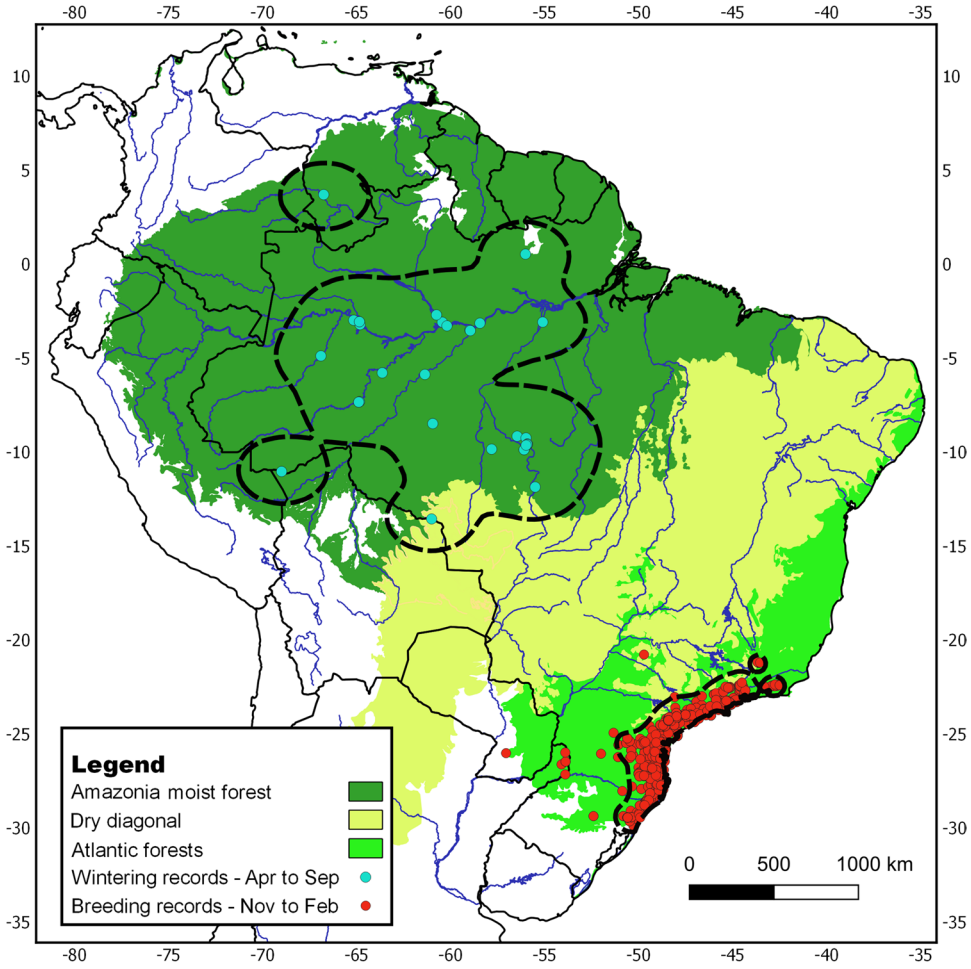

Fig. 5 Breeding (Atlantic Forest, November to February) and wintering (Amazonia, April to September) ranges of the rufous-tailed attila *Attila phoenicurus* in South America, as delimited by the dashed lines (derived from Kernel density estimation, using a 95% isopleth and bandwidth estimated with the Plug in the Equation method, Signer and Balkenhol 2015). The scarce records obtained in the breeding range during the winter period and vice versa are not shown (compare with Video S1 and Fig. 4). Records obtained in the Atlantic Forest region outside the dashed line (including all records for Argentina and Paraguay) probably refer to vagrant or transient birds (see text for details). Vegetation map after Olson et al. (2001)

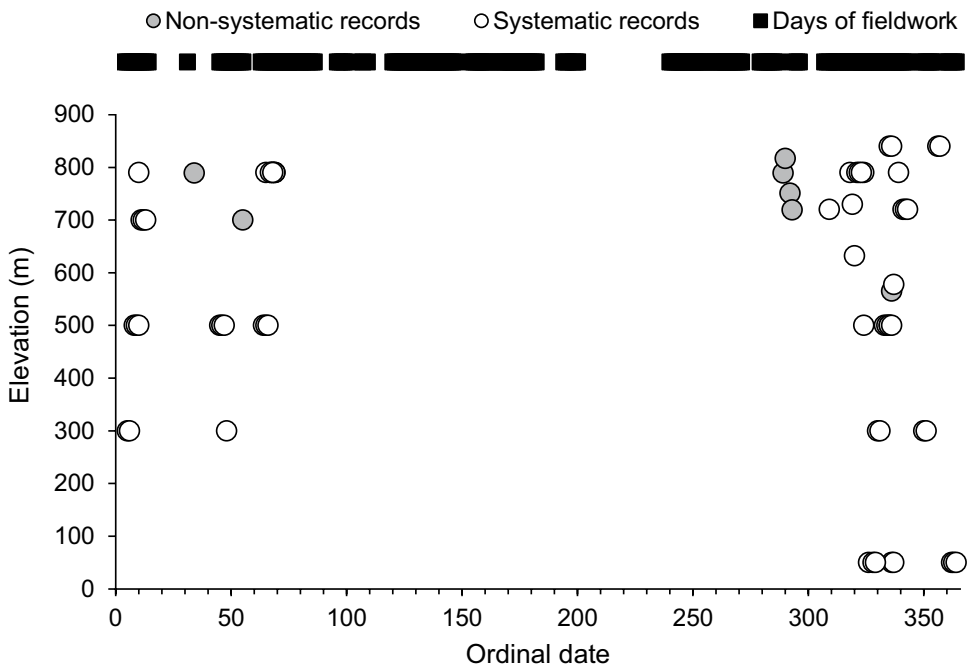

Fig. 6 Seasonal occurrence of the rufous-tailed attila *Attila phoenicurus* in the Núcleo Curucutu, Serra do Mar State Park, eastern São Paulo, southeastern Brazil. Day of year ranging from 1 (1st January) to 365 (31st December; 366 on leap years). "Systematic records" are those obtained during the standardized censuses (2007–2011), while "non-systematic records" are those obtained opportunistically during fieldwork with other purposes (2012–2018). Days when we conducted fieldwork, which occurred along 11 years and from 15 to 880 m a.s.l., are summarized by the black bar in the upper part of the figure. We obtained no record of the species from 11th March to 17th October

them for the Department of Misiones, where the species occurs in the Upper Paraná Atlantic Forest possibly as a transient bird. Therefore, we found no evidence of a breeding population in any country other than Brazil, but readers must remember that WikiAves only covers the Brazilian territory and, consequently, data from other South American countries are scarcer.

In brief, the rufous-tailed attila breeds in the subtropical portion of the Atlantic Forest from the second half of October to the first half of March. Post-breeding migration through the Dry Diagonal takes part mostly from the second half of March to early April. The species then winters in Amazonia from April to late September, with the pre-breeding migration taking part mostly in October. This is only a general pattern because considerable variation (individual and/or geographic) in migration schedule seems to occur.

When checking records housed in the vouchered citizen science data sources, we found 58 erroneous records in WikiAves (which corresponds to 5.0% of the records available in this website), 4 in the Macaulay Library (1.2%), and 1 in the Internet Bird Collection (11.1%). As we predicted, the most misidentified species were the crested becard (37 records, predominantly of females, but also of males) and the gray-hooded attila (eight records). Other misidentified species were the chestnut-crowned becard *Pachyramphus castaneus* (7 records), ruby-crowned tanager *Tachyphonus coronatus* (3 records of females), and one record each of the buff-fronted foliage-gleaner *Philydor rufum*, the buff-browed foliage-gleaner *Syndactyla rufosuperciliata*, the cliff flycatcher *Hirundinea ferruginea*, Swainson's flycatcher *Myiarchus swainsoni* (calls), and the golden-chevroned tanager *Tangara ornata*. Three additional records were from other species that we could not identify with certainty.

After eliminating all these erroneous records, 93 unlikely occurrences remained, 75 of them from eBird, 4 from WikiAves, and 14 from other sources (Fig. 7). A comparison of the proportion of unlikely occurrences between the two major citizen science data sources suggests that identification mistakes are more frequent in eBird than WikiAves. Despite that, the migratory patterns of the rufous-tailed attila revealed by the two online databases are much the same, only slightly blurred in the unvouchered database when compared to the vouchered database.

Discussion

Our study confirmed the well-stablished idea that citizen science projects are powerful tools to collect huge amounts of data in a short period of time (Walker and Taylor 2017; Schubert et al. 2019), helping to elucidate the migration patterns of tropical birds (Lees and Martin 2015; Lees 2016; Somenzari et al. 2018). The huge database from multiple sources gathered here strongly supported the hypothesis that the rufous-tailed attila is an austral migrant that stays for about 5 or 6 months in the Atlantic Forest, where they breed, and then migrate to Amazonia through the South American Dry Diagonal. Birds stay in Amazonia for about 5 or 6 months and then return to the Atlantic Forest through the Dry Diagonal.

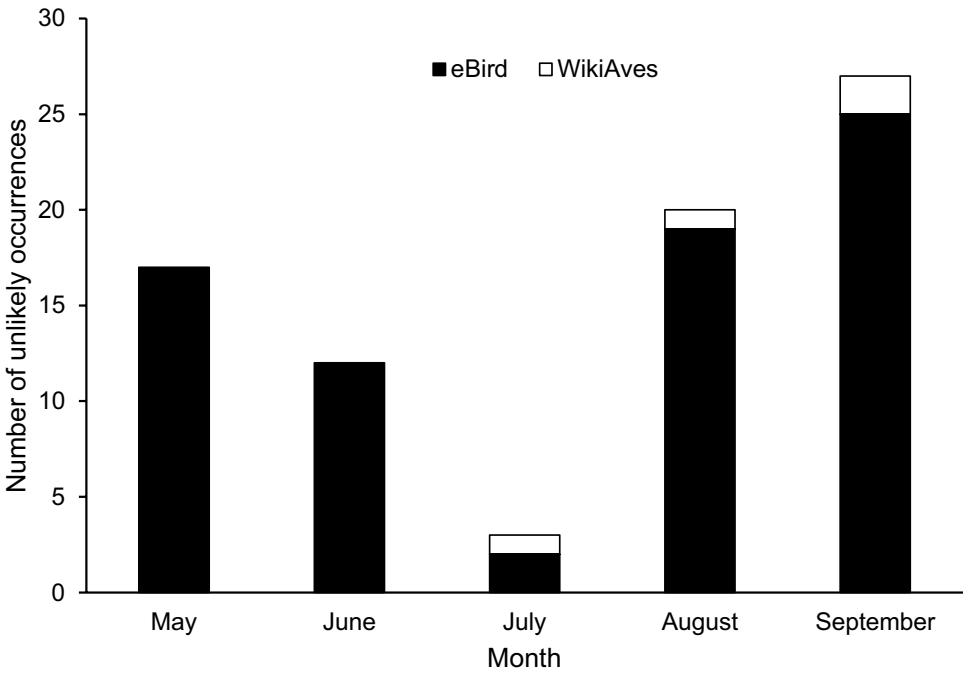

Fig. 7 Number of occurrences available for the Atlantic Forest in the period between May and September, when rufous-tailed attilas *Attila phoenicurus* are expected to be in their wintering grounds. These occurrences are unlikely and even though some of them may represent good records, we interpreted them as evidence of error, such as misdating or misidentification. All WikiAves records included here have been checked, with identification mistakes excluded

Despite the obvious migration pattern summarized above, we found scarce records of the rufous-tailed attila for the Atlantic Forest during the wintering period (< 1% of the records available for the Atlantic Forest). We suspect that these records, which are scattered across the entire breeding range of the species, probably refer to birds that failed to migrate (e.g., birds in poor body condition), identification mistakes, or incorrect dating (see below). However, the possibility that the species or some of its populations exhibit partial migration (Şekercioğlu 2010; Hegemann et al. 2015) cannot be completely ruled out with the data at hand.

Several bird species that breed in the southern part of South America winter in the northern part of the continent (Joseph 1997), such as some populations of the rufous-thighed kite *Harpagus diodon* (Lees and Martin 2015; Areta and Juhant 2019), the semi-collared nighthawk *Lurocalis semitorquatus nattereri* (Somenzari et al. 2018), the fork-tailed flycatcher *Tyrannus s. savana* (Jahn et al. 2013), and the chivi vireo *Vireo chivi diversus* (Capllonch and Wagner 2009; Somenzari et al. 2018). Nevertheless, to the best of our knowledge, no austral or intra-tropical long-distance migratory bird species has its breeding range completely restricted to such a small area of the Atlantic Forest, as described here for the rufous-tailed attila.

Species "restricted to a region during part of their lives" are considered semi-endemic and should receive special attention in conservation strategy and prioritization (Gómez and Garza 1996). The rufous-tailed attila is noteworthy in this aspect because its narrow breeding range within the subtropical Atlantic Forest strongly contrasts with its wide wintering range in Amazonia, where it is known to winter in Brazil, Venezuela, and possibly Bolivia. Fortunately, the breeding range of the rufous-tailed attila is mostly restricted to the best-preserved sub-region of the Atlantic Forest (Ribeiro et al. 2009), while its wintering range is centered in the mostly undisturbed central part of Amazonia (Trancoso et al. 2010).

The identification of the exact limits of the wintering range of the species is hampered by the low number of occurrences in Amazonia (only 3% of the occurrences were obtained outside the Atlantic Forest). This probably occurs because the number of ornithologists and citizen scientists collecting data in this region is much lower than in the Atlantic Forest in addition that the species is mostly silent when out of its breeding range, being easily overlooked (Restall et al. 2006; Ridgely and Tudor 2009). Therefore, it is difficult to refer the few scattered occurrences outside of the Atlantic Forest to transient birds or to wintering birds, and only studies using other techniques may help solve this issue. For example, studies using geolocator technology found evidence that the veery *Catharus fuscescens* (Heckscher et al. 2011), a Neartic-Neotropical migrant, and the fork-tailed flycatcher (Jahn et al. 2013), a South American Temperate-Tropical migrant, winter in a wide region in Amazonia. Veery's movement may be prompted by ecological factors associated with the seasonal flood pulse of the Amazonian rivers (Heckscher et al. 2011).

Despite the obvious advantages of the use citizen science data in studies like this, some words regarding the virtues and limitations of the two most popular citizen science projects consulted are worth mentioning. We recognize the great job done by eBird and WikiAves and do not want to dismiss their value, but rather, our intention is to present some thoughts and suggestions for improvements. Among the citizen science data sources consulted, eBird is by far the best-known project, providing many facilities for its users, including options for bulk data download, specifically designed R packages, and other analytical tools (Sullivan et al. 2014; Walker and Taylor 2017). On the other hand, a problem we faced when using eBird data was to decide on the acceptance of a given unlikely occurrence of the rufous-tailed attila in the absence of documentation (WikiAves, in contrast, is entirely based on vouchered records). Even though eBird allows observers to share their photos and sound records through the Macaulay Library, providing permanent and easily accessible vouchers, this facility has been poorly explored by most eBird users. For example, at the time of consultancy, eBird hosted only 48 photographs of the rufous-tailed attila. Therefore, we highly recommend eBird users to document their records, especially those of rare, poorly known, and/or hard to identify species, uploading them to the Macaulay Library.

WikiAves, in contrast to eBird, has seldom been used in more analytical studies (but see Schubert et al. 2019; DeGroote et al. 2021; Gorleri and Areta 2022). An obvious disadvantage of WikiAves in comparison to eBird is that it is presence-only data (even though the number of records of all species for a region can be used as a proxy for sampling effort). Nevertheless, the main reason for WikiAves being so infrequently used is that it lacks tools for bulk data download, and, therefore, data mining requires individual access to each record or requires access to the dataset through the site administrator. Although Schubert et al. (2019) have developed a semi-automated data-mining routine for downloading WikiAves data, we urge its curators to implement tools that expand WikiAves search capabilities and enable open methods for accessing its database (downloading the required data as a .csv file, for example). Another possibility for WikiAves is to share the metadata of its records with another institution that already provides tools that facilitate data access, such as Xeno-Canto did in 2018 after partnering with the Global Biodiversity Information Facility (https://www.gbif.org), what enabled the download of the data requested in an analyzable format. Another important improvement would be the incorporation of exact geographical coordinates to

each record as a routine, even if not mandatory. Despite these limitations, the WikiAves' huge database (~3.8 million vouchered records by October 2021) is an almost endless source of information and insights for further studies. WikiAves has revolutionized the Brazilian ornithology during the last decade by providing a huge amount of data about bird distribution and natural history, also helping to popularize birdwatching among thousands of people.

Finally, we found evidence that unvouchered citizen science data are more prone to identification mistakes than vouchered data. The role of identification mistakes as a source of noise in citizen science data has received considerable attention (Gorleri and Areta 2022), but to what extent the use of vouchered records can reduce such noise still needs to be investigated. Digital vouchers can help regional as well as anyone interested, who can instantly peer-review the record, thus improving the collective validation of the database (Turnhout et al. 2016). For example, during this study, we have written to authors of all records that we thought to represent identification mistakes, and, after just some few days, most of them have been corrected. Therefore, a thorough investigation of the role of digital vouchers in improving the reliability of citizen science data is much desirable.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s43388-022-00087-0.

Acknowledgements Núcleo Curucutu Team, Valder and Ivanildo Nascimento, Wesley Soares, Marco Antonio Rego, Aline Corrêa, Cláudio Nucitelli, Giulyana Benedicto, Kleber Rodrigues, Marcos Melo, Karlla Barbosa, Leo Malagoli, Vagner Cavarzere, and João Bosco helped during fieldwork. André Costa and José Augusto Nacif helped on gathering data from WikiAves. Antonina Selezneva elaborated the figures used in the Video S2. The following museum personnel kindly allowed us to study material under their care: Joel Cracraft, Peg Hart, and Paul Sweet (AMNH), Hein van Grouw and Mark Adams (BMNH), Bradley Livezey and Steve Rogers (CM), Marcos Rodrigues (DZUFMG), Ben Marks and John Bates (FMNH), James van Remsen-Jr. (LSUMZ), Marcos Raposo and Jorge Nacinovic (MNRJ), Alexandre Aleixo and Fátima Lima (MPEG), Luis Fábio Silveira (MZUSP), Ulf Johansson and Daniela Kalthoff (NRM), Gerald Mayr (SMF), Storrs Olson and Brian Schmidt (USNM), and Sylke Frahnert and Pascal Eckhoff (ZMB). The following museum personnel kindly sent to us data on specimens housed under their care: Alejandro Bodrati (MACN and MLP), Glayson Bencke (MCN/FZBRS), Marcelo Vasconcelos (MCNA), Carla Fontana (MCP), Pedro Scherer Neto (MHNCI), Hans-Martin Berg (NMW), and Karl-Ludwig Schuchmann (ZFMK). Luiz Antônio Gonzaga provided data on recordings housed in ASEC. We also thank to all those institutions and people that made available online their records through WikiAves, eBird, Internet Bird Collection, Fauna Paraguay, Xeno-Canto, Macaulay Library, Fonoteca Neotropical Jacques Vielliard, Species Link, and VertNet portals. Wagner Nogueira kindly reviewed recordings from all vouchered citizen science data sources and provided constructive criticism on an earlier version of this manuscript. Alex Jahn presented valuable comments on the manuscript.

Funding LEL received a grant from FAPEMIG (APQ-04082-10) and a research fellowship from CNPq (309660/2017-3), also benefiting from a collection study grant from the American Museum of Natural History. FS received financial support from the Fundação Grupo Boticário, having also received the donation of field equipment from the Birder's Exchange Program of the American Birding Association.

Declarations

Ethics approval The procedures employed in this study complied with the laws of Brazil, where they were carried out. CEMAVE-ICMBio, Fundação Florestal de São Paulo, and Núcleo Curucutu provided the permits for conducting this study.

Consent to participate All the authors consent to participate in this study.

Consent for publication All the authors consent to publish this study.

Conflict of interest The authors declare no competing interests.

References

Aleixo A, Lima MFC, Castro M, Pontes E, Miranda LS (2011) Notes on the vertebrates of northern Pará, Brazil: a forgotten part of the Guianan Region, II. Avifauna. Bol Mus Para Emílio Goeldi Cienc Nat 6:11–65

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G (2013) Köppen's climate classification map for Brazil. Meteorol Z 22:711–728. https://doi.org/10.1127/0941-2948/2013/0507

Amaya-Espinel JD, Hostetler ME (2019) The value of small forest fragments and urban tree canopy for Neotropical migrant birds during winter and migration seasons in Latin American countries: a systematic review. Landsc Urban Plan 190:103592. https://doi.org/10.1016/j.landurbplan.2019.103592

Areta JI, Juhant MA (2019) The rufous-thighed kite *Harpagus diodon* is not an endemic breeder of the Atlantic Forest: lessons to assess Wallacean shortfalls. Ibis 161:337–345. https://doi.org/10.1111/ibi.12645

Bates JM, Parker-III TA, Caparella P, Davis TJ (1992) Observations on the campo, cerrado and forest avifaunas of eastern Dpto. Santa Cruz, Bolivia, including 21 species new to the country. Bull Br Ornithol Club 112:86–98

Bela G, Peltola T, Young JC, Balázs B, Arpin I, Pataki G, Hauck J, Kelemen E, Kopperoinen L, Herzele A, van Keune H, Hecker S, Suskevics M, Roy HE, Itkonen P, Külvik M, László M, Basnou C, Pino J, Bonn A (2016) Learning and the transformative potential of citizen science. Conserv Biol 30:990–999. https://doi.org/10.1111/cobi.12762

BirdLife International (2020) Species factsheet: *Geositta*. IUCN red list for birds. BirdLife International. http://datazone.birdlife.org/home. Accessed 28 March 2020

Capllonch P, Wagner EM (2009) *Vireo olivaceus chivi* y *V. o. diversus* (Vireonidae): distribución y migración. Rev Bras Ornitol 17:204–209

Chesser RT (1994) Migration in South America: an overview of the austral system. Bird Conserv Int 4:91–107. https://doi.org/10.1017/S0959270900002690

Chesser RT (2005) Seasonal distribution and ecology of South American austral migrant flycatchers. In: Greenberg R, Marra PP (eds) Birds of two worlds: the ecology and evolution of migration. Johns Hopkins University Press, Baltimore, USA, pp 168–181

Crozariol MA (2016) Espécies de aves com ninhos não descritos ou pouco conhecidos das famílias Tityridae, Platyrinchidae,

Pipritidae, Pipromorphidae e Tyrannidae: um pedido de auxílio aos observadores de aves! Atual Ornitol 189:18–23
DeGroote LW, Hingst-Zaher É, Moreira-Lima L, Whitacre JV, Slyder JB, Wenzel JW (2021) Citizen science data reveals the cryptic migration of the common potoo *Nyctibius griseus* in Brazil. Ibis 163:380–389. https://doi.org/10.1111/ibi.12904
Faaborg J, Holmes RT, Anders AD, Bildstein KL, Dugger KM, Gauthreaux-Jr SA, Heglund P, Hobson KA, Jahn AE, Johson DH, Latta SC, Levey DJ, Marra PP, Merkord CL, Nol E, Rothstein SI, Sherry TW, Sillett S, Thompson-III FR, Warnock N (2010) Conserving migratory land birds in the New World: do we know enough? Ecol Appl 20:398–418. https://doi.org/10.1890/09-0397.1
Friedmann H (1948) Birds collected by the National Geographic Society's expeditions to northern Brazil and southern Venezuela. Proc U S Nat Mus 97:373–569
García NC, Trujillo-Arias N, Kopuchian C, Cabanne GS (2016) First documented record of the rufous-tailed attila (Tyrannidae) for Corrientes, Argentina. Rev Bras Ornitol 24:68–71
Garcia RJF, Pirani JR (2003) Revisão sobre o diagnóstico e caracterização da vegetação campestre junto à crista de serras, no Parque Estadual da Serra do Mar, SP, Brasil. Hoehnea 30:217–241
Gómez H, Garza S (1996) The conservation importance of semiendemic species. Conserv Biol 10:674–675. https://doi.org/10.1046/j.1523-1739.1996.10020674.x
Gorleri FC, Areta JI (2022) Misidentification in citizen science bias the phenological estimates of two hard-to-identify *Elaenia* flycatchers. Ibis 64:13–26. https://doi.org/10.1111/ibi.12985
Guyra Paraguay (2005) Atlas de las aves de Paraguay. Guyra Paraguay, Asunción, Paraguay
Hayes FE, Scharf PA, Ridgely RS (1994) Austral bird migrants in Paraguay. Condor 96:83–97. https://doi.org/10.2307/1369066
Heckscher CM, Taylor SM, Fox JW, Afanasyev V (2011) Veery (*Catharus fuscescens*) wintering locations, migratory connectivity, and a revision of its winter range using geolocator technology. Auk 128:531–542. https://doi.org/10.1525/auk.2011.10280
Hegemann A, Marra PP, Tieleman BR (2015) Causes and consequences of partial migration in a passerine bird. Am Nat 186:531–546. https://doi.org/10.1086/682667
Hellmayr CE (1929) Catalogue of birds of the Americas and the adjacent islands in Field Museum of Natural History, part VI, Oxyruncidae, Pipridae, Cotingidae, Rupicolidae, Phytotomidae. Field Mus Nat Hist Publ Zool Ser 13:1–258
Jahn AE, Cueto VR, Fontana CS, Guaraldo AC, Levey DJ, Marra PP, Ryder TB (2020) Bird migration within the Neotropics. Auk 137:1–23. https://doi.org/10.1093/auk/ukaa033
Jahn AE, Levey DJ, Cueto VR, Ledezma JP, Tuero DT, Fox JW, Masson D (2013) Long-distance bird migration within South America revealed by light-level geolocators. Auk 130:223–229. https://doi.org/10.1525/auk.2013.12077
Joseph L (1997) Towards a broader view of Neotropical migrants: consequences of a re-examination of austral migration. Ornitol Neotrop 8:31–36
Lees AC (2016) Evidence for longitudinal migration by a "sedentary" Brazilian flycatcher, the ash-throated casiornis. J Field Ornithol 87:251–259. https://doi.org/10.1111/jofo.12159
Lees AC, Martin RW (2015) Exposing hidden endemism in a Neotropical forest raptor using citizen science. Ibis 157:103–114. https://doi.org/10.1111/ibi.12207
Lees AC, Rosenberg KV, Ruiz-Gutierrez V, Marsden S, Schulenberg TS, Rodewald AD (2020) A roadmap to identifying and filling shortfalls in Neotropical ornithology. Auk 137:1–17. https://doi.org/10.1093/auk/ukaa048
Lees AC, Zimmer KJ, Marantz CA, Whittaker A, Davis BJW, Whitney BM (2013) Alta Floresta revisited: an updated review of the avifauna of the most intensively surveyed locality in south-central Amazonia. Bull Br Ornithol Club 133:178–239
Malagoli LR (2013) Diversidade e distribuição dos anfíbios anuros do Núcleo Curucutu do Parque Estadual da Serra do Mar, SP. Universidade Estadual Paulista Júlio de Mesquita Filho, Rio Claro
MAyDS, AA (2017) Categorización de las Aves de la Argentina. Ministerio de Ambiente y Desarrollo Sustentable de la Nación, Aves Argentinas, Buenos Aires
Meyer de Schauensee R (1966) The species of birds of South America with their distribution. Academy of Natural Sciences of Philadelphia, Narberth
Myers N, Mittermeier RA, Mittermeier CG, Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858. https://doi.org/10.1038/35002501
Novaes FC (1976) As aves do rio Aripuanã, estados de Mato Grosso e Amazonas. Acta Amazon 6:61–85
Olson DM, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GVN, Underwood EC, D'Amico JA, Itoua I, Strand HE, Morrison JC, Loucks CJ, Allnutt TF, Ricketts TH, Kura Y, Lamoreux JF, Wettengel WW, Hedao P, Kassem KR (2001) Terrestrial ecoregions of the World: a new map of life on Earth. BioScience 51:933–938. https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2
Parker-III TA, Stotz DF, Fitzpatrick JW (1996) Ecological and distributional databases. In: Stotz DF, Fitzpatrick JW, Parker-III TA, Moskovits DK (eds) Neotropical birds: ecology and conservation. University of Chicago Press, Chicago, pp 113–436
Paynter-Jr RA (1989) Ornithological gazetteer of Paraguay, 2nd edn. Museum of Comparative Zoology, Cambridge
Paynter-Jr RA (1995) Ornithological gazetteer of Argentina, 2nd edn. Museum of Comparative Zoology, Cambridge
Paynter-Jr RA, Traylor-Jr MA (1991) Ornithological gazetteer of Brazil, 2 vols. Museum of Comparative Zoology, Cambridge
Pessenda L, Oliveira PE, Mofatto M, Medeiros VB, Garcia RJF, Aravena R, Bendassoli JA, Leite AZ, Saad AR, Etchebeher ML (2009) The evolution of a tropical rainforest/grassland mosaic in southeastern Brazil since 28,000 14C yr BP based on carbon isotopes and pollen records. Quat Res 71:437–452. https://doi.org/10.1016/j.yqres.2009.01.008
Pinho JB, Aragona M, Hakamada KYP, Marini MÂ (2017) Migration patterns and seasonal forest use by birds in the Brazilian Pantanal. Bird Conserv Int 27:371–387. https://doi.org/10.1017/S0959270916000290
Pinto OMO (1944) Catálogo das aves do Brasil e lista dos exemplares existentes na coleção do Departamento de Zoologia, 2a parte. Ordem Passeriformes (continuação): superfamília Tyrannoidea e subordem Passeres. Departamento de Zoologia, Secretaria da Agricultura, Indústria e Comércio, São Paulo
R Core Team (2019) R: a language and environment for statistical computing, version 3.6.2. R Foundation for Statistical Computing. https://www.R-project.org. Accessed 10 Nov 2019
Remsen-Jr JV, Parker-III TA (1990) Seasonal distribution of the azure gallinule (*Porphyrula flavirostris*) with comments on vagrancy in rails and gallinules. Wilson Bull 102:380–399
Restall R, Rodner C, Lentino M (2006) Birds of northern South America, vol. 1, species accounts. Christopher Helm, London
Ribeiro MC, Metzger JP, Martensen AC, Ponzoni FJ, Hirota MM (2009) The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biol Conserv 142:1141–1153. https://doi.org/10.1016/j.biocon.2009.02.021
Ridgely RS, Tudor G (1994) The birds of South America, vol. 2, the suboscine passerines. University of Texas Press, Austin
Ridgely RS, Tudor G (2009) Field guide to the songbirds of South America: the passerines. University of Texas Press, Austin

Schubert SC, Manica LT, Guaraldo AC (2019) Revealing the potential of a huge citizen-science platform to study bird migration. Emu 119:364–373. https://doi.org/10.1080/01584197.2019.1609340

Schunck F, Silveira LF, Nascimento VS (2019) 118 years of ornithological knowledge of a forgotten region of the Atlantic Forest near the largest city in South America. Wilson J Ornithol 131:758–773. https://doi.org/10.1676/1559-4491-131.4.758

Şekercioğlu ÇH (2010) Partial migration in tropical birds: the frontier of movement ecology. J Anim Ecol 79:933–936. https://doi.org/10.1111/j.1365-2656.2010.01739.x

Short LL (1975) A zoogeographical analysis of the South American Chaco avifauna. Bull Am Mus Nat Hist 154:163–352

Signer J, Balkenhol N (2015) Reproducible home ranges (rhr): a new, user-friendly R package for analyses of wildlife telemetry data. Wildl Soc Bull 39:358–363. https://doi.org/10.1002/wsb.539

Somenzari M, Amaral PP, Cueto VR, Guaraldo AC, Jahn AE, Lima DM, Lima PC, Lugarini C, Machado CG, Martinez J, Nascimento JLX, Pacheco JF, Paludo D, Prestes NP, Serafini PP, Silveira LF, Sousa AEBA, Sousa NA, Souza MA et al (2018) An overview of migratory birds in Brazil. Pap Avulsos Zool 58:e20185803. https://doi.org/10.11606/1807-0205/2018.58.03

Sullivan BL, Aycrigg JL, Barry JH, Bonney RE, Bruns N, Cooper CB, Damoulas T, Dhondt AA, Dietterich T, Farnsworth A et al (2014) The eBird enterprise: an integrated approach to development and application of citizen science. Biol Conserv 169:31–40. https://doi.org/10.1016/j.biocon.2013.11.003

Todd WEC (1950) Critical notes on the cotingas. Proc Biol Soc Wash 63:5–7

Trancoso R, Carneiro Filho A, Tomasella J, Schietti J, Forsberg BR, Miller RP (2010) Deforestation and conservation in major watersheds of the Brazilian Amazon. Environ Conserv 36:277–288. https://doi.org/10.1017/S0376892909990373

Turnhout E, Lawrence A, Turnhout S (2016) Citizen science networks in natural history and the collective validation of biodiversity data. Conserv Biol 30:532–539. https://doi.org/10.1111/cobi.12696

Walker J, Taylor PD (2017) Using eBird data to model population change of migratory bird species. Avian Conserv Ecol 12:4. https://doi.org/10.5751/ACE-00960-120104

Walther B (2020) Rufous-tailed attila (*Attila phoenicurus*). In: del Hoyo J, Elliott A, Sargatal J, Christie DA, de Juana E (eds.). Handbook of the birds of the world alive. Retrieved from https://www.hbw.com/node/57521 on March 2020. Lynx Editions, Barcelona

Whittaker A (2009) Pousada Rio Roosevelt: a provisional avifaunal inventory in south-western Amazonian Brazil, with information on life history, new distributional data and comments on taxonomy. Cotinga 31:20–43