ORIGINAL ARTICLE

Distribution and migration phenology of Purple Martins (*Progne subis*) in Brazil

Clarissa O. Santos[1] · Jonathan M. Branco[1,2] · Maria C. T. D. Belotti[3] · Pedro Abilleira[4] · Joe Siegrist[5] ·
Jason Fischer[6] · Luciano M. Lima[1] · Mario Cohn-Haft[7] · Erika Hingst-Zaher[1]

Abstract

Purple Martins (*Progne subis*) are Neotropical migratory birds that breed across North America and spend their nonbreeding season in South America, primarily Brazil. They have been in a long-term population decline over the last five decades. There are several suggested causes for the decline, but to begin understanding the conservation needs of this species, it is necessary first to fill existing knowledge gaps about migration timing, distribution, and habitat use in Brazil. The presence of this species across most of Brazil makes it difficult to keep track of seasonal or long-term changes in its distribution without careful, widespread data collection. Citizen science offers an emerging opportunity to address knowledge gaps of roost distribution and phenology. Here, we compiled Purple Martin records from citizen science platforms, scientific collections, and bibliography to produce an overview of the distribution and phenology of the species in Brazil. It is present in most Brazilian states, but records are concentrated in the Amazon region. Previously known large roosts in southeast Brazil, especially in the state of São Paulo, have decreased in number of individuals over the last decade. Most records are from September to April, although phenology varies with latitude. In the equatorial region (5°N–5°S), which is crossed by all populations that come to Brazil, the number of reports shows strong temporal variation, probably related to the timing of migration in different populations.

✉ Clarissa O. Santos
clarissaoliveira2204@gmail.com

1 Instituto Butantan, Museu Biológico, São Paulo, SP, Brazil

2 Departamento de Ecologia, Universidade de São Paulo, São Paulo, SP, Brazil

3 Fish, Wildlife and Conservation Biology Department, Colorado State University, Fort Collins, CO, USA

4 Programa de Pós-Graduação Interunidades em Biotecnologia, Universidade de São Paulo, São Paulo, SP, Brazil

5 Purple Martin Conservation Association, Erie, PA, USA

6 Disney's Animals Science, and Environment, Lake Buena Vista, FL, USA

7 Instituto Nacional de Pesquisas da Amazônia, Manaus, AM, Brazil

Introduction

Purple Martins (*Progne subis*) are Neotropical migratory birds that breed across North America from January to August (Brown 1997; AOU 1998) and spend their nonbreeding season in South America, primarily Brazil (Sick 1997; Hill 2004; Fraser et al. 2017). As with other insectivorous migratory birds, Purple Martins have been in a long-term population decline, 37% over the last five decades, although trends differ regionally (Nebel et al. 2010; Michel et al. 2015; Sauer et al. 2017). Suggested causes for these declines include destruction of important stopover and wintering habitats (Rogers et al. 2010; Imlay et al. 2018; Kardynal et al. 2020), detrimental health effects of pesticide and heavy metal contamination (Bernhoft 2012; Nocera et al. 2012), and persecution by local human populations (Hill 2004). However, to begin understanding the conservation challenges faced by Purple Martins during the nonbreeding season, it is necessary first to fill existing knowledge gaps about migration timing, distribution, and habitat use in Brazil.

One challenge to identifying phenological patterns of distribution for Purple Martins is the presence of at least four other morphologically similar species in the genus *Progne* that co-occur in Brazil (Pacheco et al. 2021): Southern Martin (*P. elegans*), Gray-breasted Martin (*P. chalybea*), Caribbean Martin (*P. dominicensis*), and Cuban Martin (*P. cryptoleuca*). These species are not easily distinguishable in some plumages (Zimmer 70; Eisenmann 1959). Southern Martins breed in Argentina during austral spring and summer and winter in Brazil between April and September. Although their migration directions and seasonality are the opposite of those of Purple Martins, there are considerable periods of overlap between the two species in Brazil in April and May and between July and September (Eisenmann 1959). Gray-breasted Martins are present in Brazil year-round (Sick 1997; Billerman et al. 2020), although they vary in numbers regionally, probably due to poorly documented migratory movements (M. Cohn-Haft, pers. obs.). Caribbean and Cuban Martins have recently been found wintering in Brazil thanks to tracking studies (Perlut et al. 2017; García-Lau et al. 2021) and may coincide almost completely with Purple Martins.

On Purple Martin breeding grounds, the pre-migratory period is marked by the formation of flocks of up to hundreds of thousands of individuals that gather in specific locations used as overnight roosts. While this phenomenon has been studied primarily in North America (Brown 1997; Bridge et al. 2016), the same behavior has been observed during migration and the nonbreeding season in Brazil (Hill 1988, 1993). Purple Martins occur in most Brazilian states with large flocks reported from October to April. However, individuals may be observed as early as July (M. Cohn-Haft, pers. obs.; Somenzari et al. 2018). Roosts have been described from different habitat types, but most roost records are associated with forests (Fraser et al. 2012), particularly seasonally flooded islands or peninsulas. Large flocks of swallows (Hirundinidae), including Purple Martins, have also been reported in cities (Hill 1988; Willis and Oniki 2002; Hill 2004).

The presence of these birds in urban areas can elicit conflict with human residents. Newspaper articles report that people frequently associate these flocks with property damage, noise pollution, and fear of disease. Reportedly, efforts have been made to deter and relocate roosting birds away from urban environments. Large known roosts, especially in the state of São Paulo, seem to have shrunk, but it is hard to identify the method or quantify the impact of deterrent strategies on individual survival or population persistence (Sick 1997; Hill 2004).

Community (or "citizen") science offers an emerging opportunity to address the knowledge gaps of roost distribution and phenology. Birding has increased in Brazil in the last decade, due to widespread use of data collection devices (e.g., smartphones), and citizen science is also becoming increasingly popular (DeGroote et al. 2020). Online collaborative platforms provide a place where users can share and discuss their sightings. There are two main citizen science platforms used by Brazilian bird watchers: eBird, an online repository for birdwatching records developed by the Cornell Lab of Ornithology (Sullivan et al. 2009), and WikiAves, a Brazilian dataset of georeferenced avian photographs and sound recordings containing more than three million records of 1971 species. Recently, researchers have begun using WikiAves to study distribution and migration patterns of several Brazilian species (Lees and Martin 2015; Lees 2016; Klemann-Junior et al. 2017; Somenzari et al. 2018; DeGroote et al. 2020; Barbosa et al. 2021), demonstrating the utility and reliability of the dataset (Dália 2017; Schubert et al. 2019). Leveraging the observations of citizens to better understand bird distribution and migration patterns (Greenwood 2007; Hurlbert and Liang 2012; Zelt et al. 2012; Tulloch et al. 2013; Loss et al. 2015; Newson et al. 2016) enables a geographic breadth of data collection that would otherwise be prohibitive due to the time and resources required.

Uncertainties concerning Purple Martin natural history pose an obstacle to any conservation initiative on the species' nonbreeding grounds. However, considering their hemisphere-wide distribution, understanding where and when Purple Martins are present is only feasible with the help of citizen science. The objective of this study was to use data gathered from several different online repositories of citizen science data, including a dedicated project launched in 2018 entitled "Projeto Andorinha Azul," scientific collections, and available literature to produce the first comprehensive summary of the distribution and seasonality of the Purple Martin in Brazil.

Methods

Data acquisition

Scientific collections and bibliography

Our data were obtained from online searches and museum specimens. We compiled records from the Global Biodiversity Information Facility (GBIF 2020), contacted Brazilian museums, and examined specimens at the Museu de Zoologia da Universidade de São Paulo, all from 1924 to 2015. We also conducted a bibliographic search for Purple Martin records, using Google Scholar and Web of Science, selecting papers that indicated the municipality, month, and year of record, from 1816 to 2014 (von Pelzeln and Natterer 1871; Antas et al. 1986; Vasconcelos et al. 2006; Fernandes et al. 2007; Kirwan and Shirihai 2008; Pereira et al. 2008;

Pinheiro and Dornas 2009; Whittaker 2009; Aguiar et al. 2010; Camacho and Accorsi 2016).

Citizen science

We compiled species records that included digitally archived photographs from eBird (2004–2019) and from WikiAves (from 2006 to 2019). The main difference between these websites is that all records in WikiAves are supported by a digital voucher, either a sound recording or photograph, whereas many eBird records are not vouchered. For this study, we only used photographic records. Another difference is the general public: eBird is more commonly used by international birders whereas WikiAves is mostly used by Brazilian birders. To stimulate citizen data contribution and increase temporal and geographic coverage, we created a project website (andorinhaazul.org), in which information regarding the project, species, and contacts can be found; a Facebook page to post and exchange information about the species; and a WhatsApp group in which birders from throughout Brazil reported sightings of Purple Martins. We gathered reports on these two social media from the end of 2018 to 2019. In this group, we also exchanged information about the species and discussed potential human-wildlife conflicts at the roosts.

Data processing

We removed records of uncertain identification and kept only one record per date from the same municipality.

Data analysis and visualization

To produce an overview of Purple Martin distribution in Brazil, we plotted a hexagonal binning map indicating the number of records per 10,000 km^2 hexagon. To explore possible sources of numerical bias, we analyzed the correlation between human population size (IBGE 2020) and number of bird watchers (WikiAves 2021), as well as the correlation between these numbers and the total number of records from each state over the period of records. In both cases, we employed simple linear regressions and considered a $P \leq 0.05$ as significant. To characterize seasonality of Purple Martin observations, we produced graphs of the monthly distribution of all records combined and for each of four latitudinal intervals: North of 5°S, 5–15°S, 15–25°S, and South of 25°S (Russell and Gauthreaux-Jr. 1999; Kelly et al. 2017).

We used R software, version 3.6.3 (R Core Team 2020) to produce the charts with the "ggplot2" R package (Wickham 2016) as well as for the statistical analysis using the native linear model function, and used QGIS software, version 3.6 (QGIS Development Team 2019) to plot the map.

Results

We gathered 859 records of Purple Martin and, after excluding 333 duplicates and 85 records in which identification was not possible, we used 441 records to visualize distribution and seasonality in Brazil (Supplementary material Table S1). Of those, 337 were from WikiAves, 52 from scientific collections, 21 from literature, 15 from the WhatsApp group, 15 from eBird, and one from Facebook (Fig. 1). The citizen science data were collected up to December 2019. The first record of the Purple Martin in Brazil was documented by the naturalist Johann Natterer in the municipality of Manaus in the state of Amazonas in 1816 (von Pelzeln and Natterer 1871). The next record from our dataset is from 21 March 1924 in the municipality of Belém, Pará state, a specimen from the collection of the Museu de Zoologia da Universidade de São Paulo. Prior to 2003, all records in our database were from scientific collections and literature, with citizen science records incorporated from 2004 onward. Between 1932 and 2000, few records were made in consecutive years, but since 2001, Purple Martins were recorded every year. After 2009, the year WikiAves was launched, the number of records increased dramatically (Fig. 2).

Purple Martins were registered in 155 different municipalities from 23 Brazilian states. We highlight three localities in the north of Brazil and three in the southeast, which among them had the highest density of records (Fig. 3). Most records (49%) were from northern Brazil, followed by southeast (24%), northeast (14%), west-central (10%), and
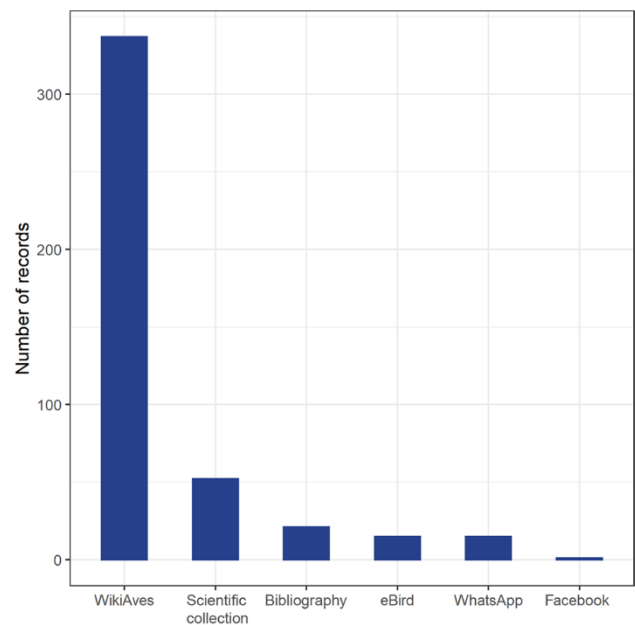

Fig. 1 Total number of Purple Martin (*Progne subis*) records in Brazil recorded between 1816 and 2019, grouped by data source

Fig. 2 Number of Purple Martin (*Progne subis*) records per year in Brazil, between 1816 and 2019, colored by data source. The asterisk (*) represents the year when WikiAves was released. Records can be added to WikiAves with retroactive dates
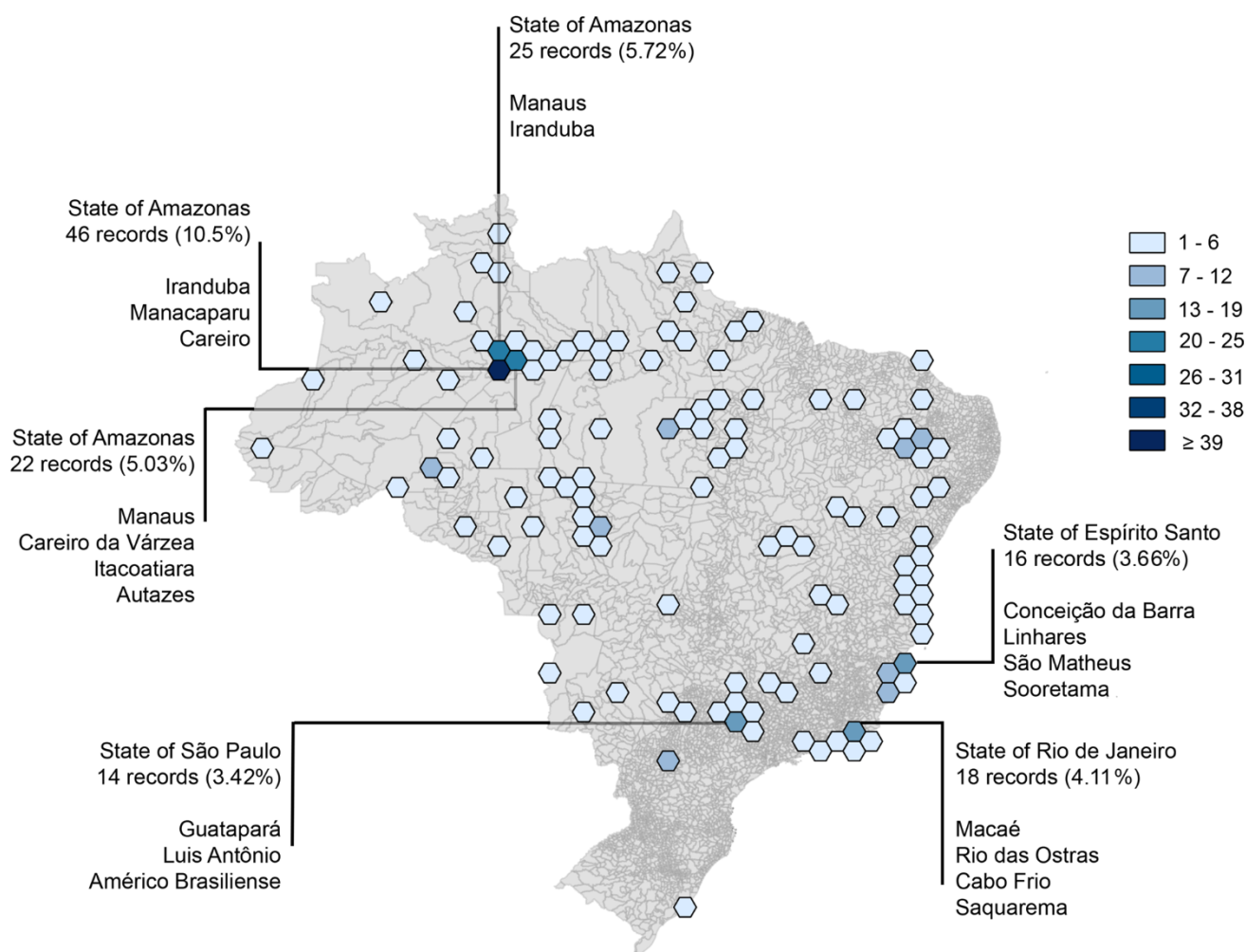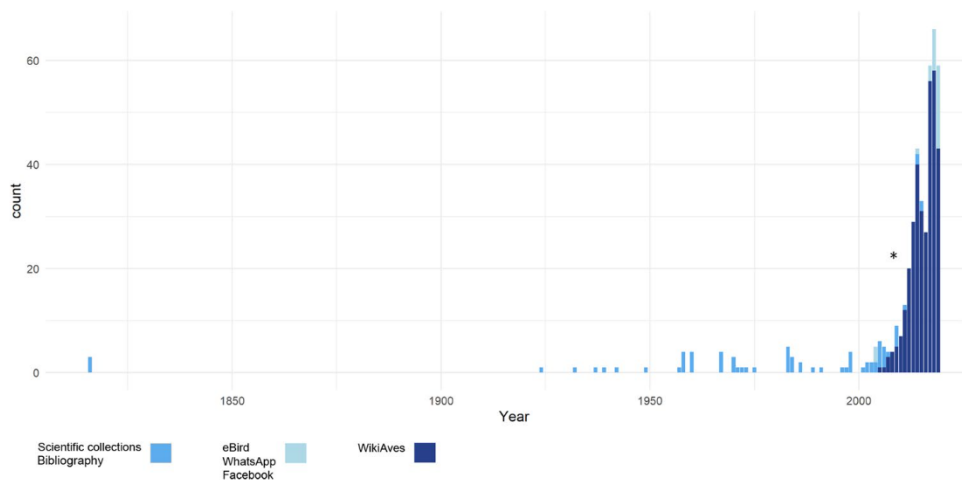

Fig. 3 Map of the distribution of Purple Martin (*Progne subis*) records in Brazil from 1816 to 2019. Only hexagons with more than one record were displayed. The highlights emphasize the ones that have more than thirteen records in that period, with the number of records, the percentage in the dataset, and the municipalities where the records were made. Each hexagon has an area of 10,000 km²

south (3%). Records were particularly abundant from the city of Manaus and nearby communities (23%). The number of registered bird watchers on WikiAves from each state correlated positively with the respective state population (adjusted $R^2 = 0.903$; $df = 25$; $P < 0.001$; coefficient: 2.231 $* 10^{-4}$) (Fig. 4A). However, reports of Purple Martins from each state did not correlate with either the state's population (adjusted $R^2 = -0.021$; $df = 25$; $P = 0.511$) (Fig. 4B) or the number of birdwatchers per state (adjusted $R^2 = -0.036$; $df = 25$; $P = 0.780$) (Fig. 4C), suggesting that observed patterns of distribution were not simply an artifact of greater survey effort in areas with more birdwatchers. Instead, records of Purple Martins were unequally distributed across the country, being much higher in the state of Amazonas (0.311 records per birdwatcher) than in regions with greater numbers of birdwatchers, such as the state of São Paulo (0.002 records per birdwatcher), and much higher than the country-wide average (0.035 reports per birdwatcher). It is possible, however, that the number of birdwatchers submitting sightings from a certain location can be higher than the number of registered birdwatchers for that state if there is a hotspot for birdwatching tourism. It was not possible to determine the influence of birdwatching tourism on the number of records found.

Most records (total days on which Purple Martins were reported during the two-century sample period) in Brazil occurred from September through April (Fig. 5). May and June had the lowest number of records, with fewer than ten each, followed by July (13) and August (17). Between September and December, the number of records varied from 41 to 51. January and February were the months with most records (58 and 59, respectively). At latitudes North of 5°S, records start to increase in July and peak in
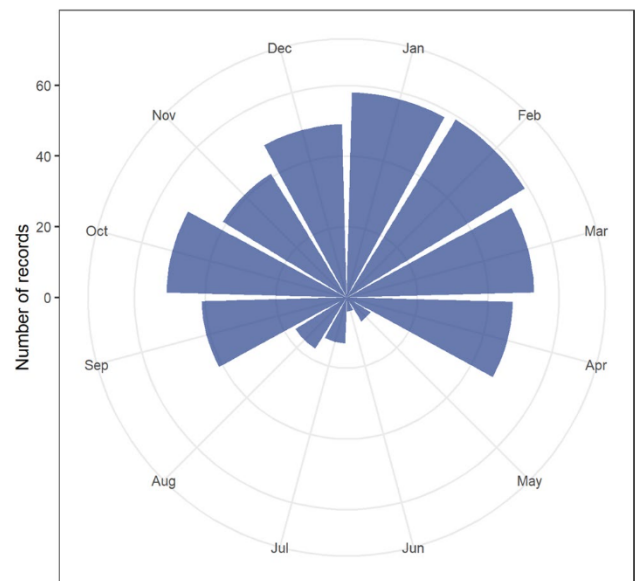

Fig. 5 Number of records of Purple Martins (*Progne subis*) in Brazil from 1816 to 2019, aggregated by month

September before declining from October to November. From December through February, the number of records was similar to previous months, before increasing in March and decreasing in April. Between 5°S and 15°S, there were few records from May to September, but large numbers during the remainder of the year, particularly in October and November. For latitudes between 15°S and 25°S, numbers slowly increased from October to December, then peaked dramatically in January and remained high through April (Fig. 6). Only two records were encountered South of 25°S, both in October.
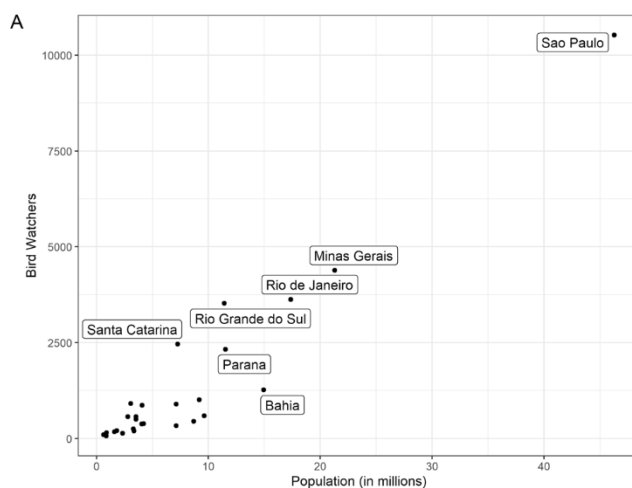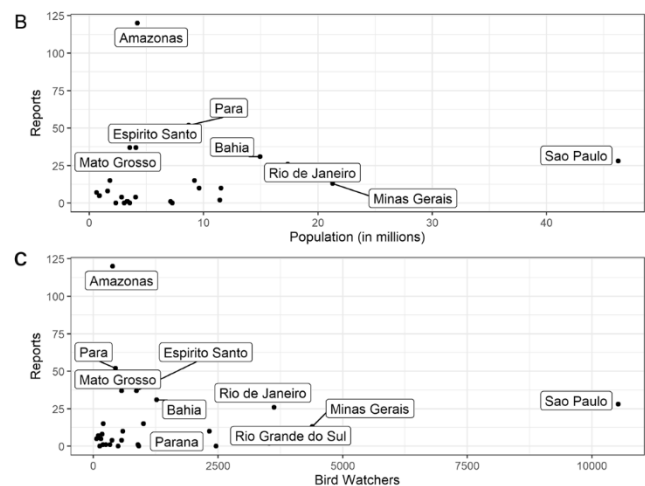

Fig. 4 **A** Correlation between the number of birdwatchers registered in WikiAves and the population size of each Brazilian state. **B** Number of reports in the dataset by population size (IBGE 2020) for each state of Brazil. **C** Number of reports in the dataset by number of registered birdwatchers from WikiAves for each state of Brazil
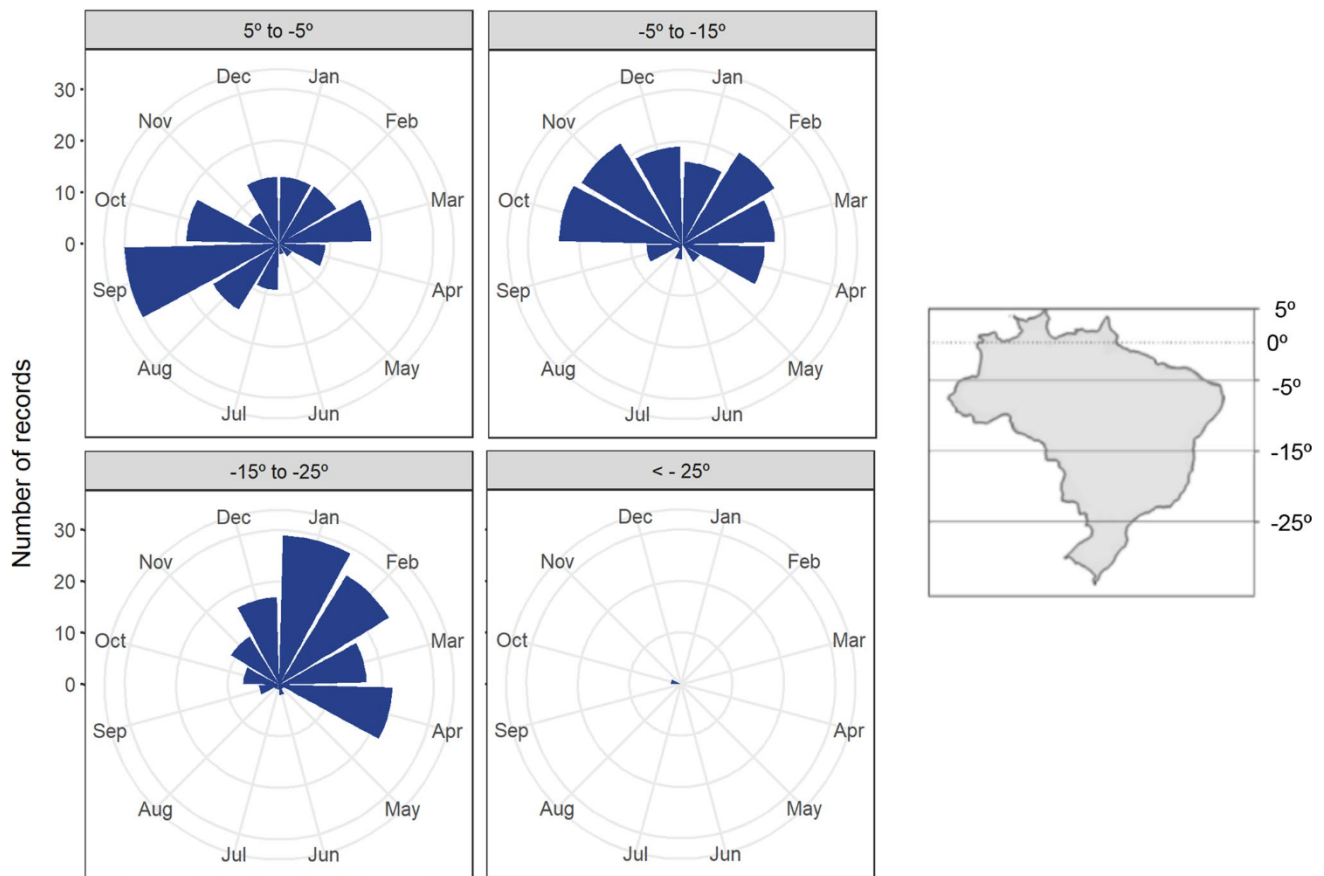
Fig. 6 Number of records of Purple Martins (*Progne subis*) from 1816 to 2019, aggregated by month, for each latitudinal interval: North of 5°S, 5–15°S, 15–25°S, and South of 25°S

Discussion

The results of the records shown here indicate that Purple Martins are present across most of Brazil (except Rio Grande do Norte, Sergipe, and Santa Catarina states). It is also evident how arrival and departure varies in different regions of Brazil. We found records in all months, but the species is most commonly observed between August and April, with different peaks depending on latitude. The use of citizen science was crucial to gather this amount of data and to visualize Purple Martin presence across the entire country.

By using citizen science, Purple Martins were found even in a region where they were not expected to occur. Until recently, reviews of migratory birds in Brazil had not included Purple Martins in Rio Grande do Sul, the southernmost Brazilian state (Somenzari et al. 2018). The first and only record for this state is from WikiAves of an adult male in October 2018, in the municipality of Tavares (WA3148713). Discussion regarding the correct identification of this record, including suggestions that it be a late Southern Martin, can be found on the online platform.

Where, Glayson Bencke (pers. comm.) pointed out that this individual was molting its flight feathers and at a time when Southern Martin should not be molting (Eisenmann 1959). This record then is an example of how interactions between birdwatchers and ornithologists mediated through a collaborative online platform can improve the reliability of citizen science data.

The wide distribution of Purple Martins in a country as extensive as Brazil shows how the species is capable of associating with different biomes and landscapes, though further investigation is necessary to establish their optimal habitats. In addition to providing useful distributional data, these records provide information on regional and temporal differences in habitat use and how they changed through time. In northern Brazil, roosts and diurnal flocks were mainly associated with forest habitats (Fraser et al. 2012) and wetlands (Coelho 2020). In southeastern Brazil, Purple Martins used to be seen commonly roosting in town squares, especially in the western and northeastern parts of the state of São Paulo. In 1986, roosts with 10,000 to 20,000 individuals were recorded in the municipalities of Ibira and Barretos (Hill 1988). In São José do Rio Preto, in the same general region,

Purple Martins were collected in 1984 and 1985 (Supplementary material Table S1) and were recorded during the 1990s. The last record from the municipality occurred in 2002 on WikiAves. Between 1990 and 2004, the number of martins and swallows that used the squares of Ribeirão Preto as an overnight roost decreased ten times (Davidar and Morton 1993; Hill 2004). Until 1993, large groups were registered in Rio Claro, also in São Paulo state (Willis and Oniki 2002). More recently, however, the municipalities in the state of São Paulo with the highest number of records were Guatapará and Luis Antonio, but according to Wiki-Aves, reports between 2017 and 2018 involved only a few hundred individuals (Supplementary Material Table S1; WikiAves 2019). These cities are in Ribeirão Preto's surrounding region and are significantly smaller, suggesting that along with the decrease in the size and number of roosts associated with people, Purple Martins are roosting in less urbanized areas, where agriculture is the main land cover (IBGE 2018).

Elsewhere in southeastern Brazil, Purple Martins have been recorded in more heterogeneous landscapes. In the states of Rio de Janeiro and Espírito Santo, where records are concentrated mainly in coastal municipalities, in a mosaic of urban areas, forest fragments, and rural vegetation (IBGE 2018). Collectively, these records suggest that either Purple Martin roost habitat selection has undergone a natural shift or human disturbance (whether intentional persecution or unintentional disturbance) has displaced martins from many of the urban locations they once frequented. These findings point to the often-neglected fact that many species use urban areas as a viable habitat, either because they are generalist species or because they adapted to this environment over time. Conservation and habitat management should consider the resources available in urban areas, which can sometimes be crucial for the species that use them.

Despite the wide distribution in Brazil, records of Purple Martins were most concentrated in the Amazon, mainly in the vicinity of Manaus (state of Amazonas) and adjacent municipalities. We found one area, covering the municipalities of Iranduba, Manacapuru, and Careiro with more than 40 records and two with more than 20 records (Fig. 3). Locally, this may reflect a bias in citizen science data related to human population density (Geldmann et al. 2016), particularly in regions with low levels of development like the Amazon Basin. No such bias was found at the national level, however, since states in the north have the lowest human density in the country and the lowest number of birdwatchers registered on WikiAves (IBGE 2020; WikiAves 2021) (Fig. 4A) yet contained the highest concentration of records (Fig. 4B).

This concentration of records in the Amazon might be explained by differences in the distribution of subspecies on the nonbreeding grounds. Data from geolocators suggest that the subspecies *P. s. arboricola*, which breeds in the western USA and Canada, spends the boreal winter in southeastern Brazil. Eastern North American *P. s. subis* mostly overwinter in the Amazon region (Fraser et al. 2012). Nonbreeding grounds of a third subspecies (*P. s. hesperia*), which nests in the southwestern USA and Mexico, have yet to be determined. The overall population of *P. s. arboricola* is substantially smaller than that of *P. s. subis* (Tautin et al. 2008), so fewer individuals of this taxon are expected to be found. Furthermore, it is possible that individuals migrating to or from points further south in Brazil use the Amazon as a stopover ground, further increasing the likelihood of sightings from there.

Regarding seasonality, records were much lower during the southern winter months, from May to August, with only four records in June, over 95 years. The fact that the species may be found in Brazil at practically any time of year, without strict seasonality is probably related to differences among breeding populations in migration timing. The dates of arrival of the species on their breeding ground show a variation in the latitude and the age of the birds (Morton and Derrickson 1990; Fraser et al. 2013). At lower breeding latitudes, such as in Florida, martins begin to arrive in the second half of January, while at higher latitudes in Canada, the breeding season does not begin until May (Stutchbury et al. 2016). As for age, the arrival day on the breeding grounds varies significantly between older and younger birds. Sub-adults under 2 years old arrive on average 7 weeks after the arrival of the first adult martins observed in a colony each year (Morton and Derrickson 1990). In northern latitudes at the limit of the breeding ground, sub-adults return at the end of June (Darling et al. 2004) which may justify unusual records made in June in Brazil. Between April and June, numbers in Brazil decrease and begin to rise again in the second half of July. Geolocator data revealed a male Purple Martin from Florida that arrived in Amazonia on 19 July (Stutchbury et al. 2016), so these individuals that appear in July (as early as the first week, M. Cohn-Haft, pers. obs.) are probably the first newcomers from the concluding breeding season. The fact that different subspecies of Purple Martins migrate from and to different regions (Fraser et al. 2012) may contribute to the differences found in migration timing. In southeastern Brazil, birds were reported arriving later, peaking in January to April, and are *P. s. arboricola*, whereas birds coming to the Amazon region can be attributed to the subspecies *P. s. subis* (Fraser et al. 2012). Furthermore, the second peak encountered in the Amazon in March and April may be a result of birds from the southeast passing through the region as they migrate back to North America. This would indicate that populations of Purple Martins from the western USA and Canada depart North America later and also migrate back later than eastern breeding populations.

The recent declines in Purple Martin populations on the breeding grounds (Sauer et al. 2017) suggest the importance of conservation measures throughout the species' range. Conservation actions include raising the awareness of local communities to the importance of this species and sustainably leveraging the touristic potential of the roosting phenomena as a reason for conserving habitats. There are many current challenges to these efforts, such as the lack of understanding of spatial and temporal dynamics of roost formation behavior in Brazil and the identification of potential threats including hydroelectric dams, chemical contaminants, deforestation, and human-wildlife conflict. These challenges are further aggravated by the wide distribution and timing variation in different regions of Brazil. In this scenario, community science can be an important source of data.

The historical engagement of the public in the conservation of Purple Martins in the Northern Hemisphere (Zelt et al. 2012; Hvenegaard and Fraser 2014; Arab et al. 2016) is an example of what can be done in South America. The use of citizen science platforms enhances data collection by increasing sample size (Robinson et al. 2020), providing a useful complement to on-line repositories of systematized information (Alves 2007). This study reinforces how the popularization of these tools can contribute to the monitoring of Purple Martins, and highlights areas local communities could monitor roosts and develop tourism to observe roost phenomena. Beyond data collection, the interest of engaged birders can be leveraged to equip and empower community members to be advocates for the conservation of species like Purple Martins.

Declarations

References

Aguiar KMO, Naiff RH, Xavier B (2010) Aves da Reserva Biológica do Lago Piratuba, Amapá, Brasil. Ornithologia 4:1–14

Alves MAS (2007) Sistemas de migrações de aves em ambientes terrestres no Brasil: exemplos, lacunas e propostas para o avanço do conhecimento. Rev Bras Ornitol 15:243–250

AOU (1998) Checklist of North American birds, 7th edn. American Ornithologists' Union, Washington, DC

Antas PTZ, Yamashita C, Valle MP (1986) First record of Purple Martin (*Progne subis*) in Mato Grosso state, Brazil. J Field Ornithol 57:171–172

Arab A, Courter JR, Zelt J (2016) A spatio-temporal comparison of avian migration phenology using citizen science data. Spat Stat 18:234–245. https://doi.org/10.1016/j.spasta.2016.06.006

Barbosa KVC, Develey PF, Ribeiro MC, Jahn AE (2021) The contribution of citizen science to research on migratory and urban birds in Brazil. Ornithol Res 29:1–11. https://doi.org/10.1007/s43388-020-00031-0

Bernhoft RA (2012) Mercury toxicity and treatment: a review of the literature. J Environ Public Health 2012:460508. https://doi.org/10.1155/2012/460508

Billerman SM, Keeney BK, Rodewald PG, Schulenberg TS (eds) (2020) Birds of the world. Cornell Laboratory of Ornithology, Ithaca, NY

Bridge ES, Pletschet SM, Fagin T, Chilson PB, Horton KG, Broadfoot KR, Kelly JF (2016) Persistence and habitat associations of Purple Martin roosts quantified via weather surveillance radar. Landsc Ecol 31:43–53. https://doi.org/10.1007/s10980-015-0279-0

Brown CR (1997) Purple Martin: *Progne subis*. American Ornithologists' Union, Ocala, USA

Camacho I, Accorsi M (2016) Confirmação da Sora, *Porzana carolina*, em território brasileiro e contribuições para a conservação das áreas úmidas da Área de Proteção Ambiental de Maricá (RJ) para espécies migratórias Neárticas. Atual Ornitol 191:60–66

Coelho MPB (2020) Férias na Amazônia? Uso e seleção de hábitat de uma ave migratória, a Andorinha-azul (*Progne subis*, Hirundinidae), durante o período de invernagem na Amazônia brasileira. MSc. Dissertation, Universidade Federal do Amazonas

Dália MN (2017) Testando dados de localização municipal para a construção de modelos de nicho grineliano (MNG): um primeiro

passo para o uso de registros do WikiAves como fonte para modelagem. Atual Ornitol 198:18–21

Darling LM, Finlay JC, Gillespie TW, Cousens B, Kostka S, Baker A (2004) Recovery of the Purple Martin in British Columbia: more than a nest box program. Proceedings of the Species at Risk 2004 Pathways to Recovery Conference 2004, p. 1–10

Davidar P, Morton ES (1993) Living with parasites: prevalence of a blood parasite and its effect on survivorship in the Purple Martin. Auk 110:109–116. https://doi.org/10.1093/auk/110.1.109

DeGroote LW, Hingst-Zaher E, Moreira-Lima L, Whitcare JV, Slyder JB, Wenzel JW (2020) 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

Eisenmann E (1959) South American migrant swallows of the genus *Progne* in Panama and northern South America; with comments on their identification and molt. Auk 76:528–532. https://doi.org/10.2307/4082326

Fernandes FR, Cruz LD, Rodrigues AAF (2007) Diet of the Gray-Breasted Martin (Hirundinidae: *Progne chalybea*) in a wintering area in Maranhão, Brazil. Rev Bras Ornitol 15:445–447

Fraser KC, Silverio C, Kramer P, Mickle N, Aeppli R, Stutchbury BJ (2013) A trans-hemispheric migratory songbird does not advance spring schedules or increase migration rate in response to record-setting temperatures at breeding sites. PLoS ONE 8:e64587. https://doi.org/10.1371/journal.pone.0064587

Fraser KC, Stutchbury BJ, Silverio C, Kramer PM, Barrow J, Newstead D et al (2012) Continent-wide tracking to determine migratory connectivity and tropical habitat associations of a declining aerial insectivore. Proc R Soc Lond B, Biol Sci 279:4901–4906. https://doi.org/10.1098/rspb.2012.2207

Fraser KC, Shave A, Savage A, Ritchie A, Bell K, Siegrist J, Ray JD, Applegate K, Pearman (2017) Determining fine-scale migratory connectivity and habitat selection for a migratory songbird by using new GPS technology. J Avian Biol 48:339–345. https://doi.org/10.1111/jav.01091

García-Lau I, Bani S, Kent G, González A, Rodríguez-Ochoa A, Jiménez A, Acosta M, Mugica L, Meyer K (2021) Tracking Cuban Martin (*Progne cryptoleuca*) migration to wintering location and back using geolocators: solving a mystery. Ornithol Res 29:106–112. https://doi.org/10.1007/s43388-021-00057-y

GBIF.org (25 September 2020) GBIF occurrence download. https://doi.org/10.15468/dl.tvew6e

Geldmann J, Heilmann-Clausen J, Holm TE, Levinsky I, Markussen B, Olsen K, Rahbek C, Tøttrup AP (2016) What determines spatial bias in citizen science? Exploring four recording schemes with different proficiency requirements. Divers Distrib 22:1139–1149. https://doi.org/10.1111/ddi.12477

Greenwood JJ (2007) Citizens, science and bird conservation. J Ornithol 148:77–124. https://doi.org/10.1007/s10336-007-0239-9

Hill JR III (1988) A tale of two cities: the Purple Martin on its Brazilian wintering grounds. Purple Martin Update 1:1–5

Hill JR III (1993) A giant martin roost on the Amazon River. Purple Martin Update 4:5–7

Hill JR III (2004) The PMCA's 2004 research trip to Purple Martin's Brazilian wintering grounds. Purple Martin Update 13:2–7

Hurlbert AH, Liang Z (2012) Spatiotemporal variation in avian migration phenology: citizen science reveals effects of climate change. PLoS ONE 7:e31662. https://doi.org/10.1371/journal.pone.0031662

Hvenegaard G, Fraser L (2014) Motivations and benefits of citizen scientists engaged in Purple Martin migration research. Hum Dimens Wildl 19:561–563. https://doi.org/10.1080/10871209.2014.940562

IBGE (2018) Monitoramento da cobertura e uso da terra do Brasil. https://www.ibge.gov.br/apps/monitoramento_cobertura_uso_terra/v1/. Accessed 15 November 2020

IBGE (2020) Estimativas de população. https://www.ibge.gov.br/estatisticas/sociais/populacao/9103-estimativas-de-populacao.html?=&t=o-que-e. Accessed 16 January 2021

Imlay TL, Hobson KA, Roberto-Charron A, Leonard ML (2018) Wintering areas, migratory connectivity and habitat fidelity of three declining Nearctic-Neotropical migrant swallows. Anim Migr 5:1–16. https://doi.org/10.1515/ami-2018-0001

Kardynal KJ, Jardine TD, Génier CS, Bumelis KH, Mitchell GW, Evans M, Hobson KA (2020) Mercury exposure to swallows breeding in Canada inferred from feathers grown on breeding and non-breeding grounds. Ecotoxicology 29:876–891. https://doi.org/10.1007/s10646-020-02249-6

Kelly JF, Horton KG, Stepanian PM, de Beurs K, Pletschet S, Fagin T, Bridge ES, Chilson PB (2017) The pulse of the planet: measuring and interpreting phenology of avian migration. In: Chilson P, Frick W, Kelly J, Liechti F (eds) Aeroecology. Springer, Cham, pp 401–425 https://doi.org/10.1007/978-3-319-68576-2_16

Kirwan GM, Shirihai H (2008) Notes on open-country birds in the Brazilian state of Rondônia. Cotinga 29:178–180

Klemann-Junior L, Vallejos MAV, Scherer-Neto P, Vitule JRS (2017) Traditional scientific data vs. uncoordinated citizen science effort: a review of the current status and comparison of data on avifauna in southern Brazil. PLoS One 12:e0188819. https://doi.org/10.1371/journal.pone.0188819

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

Loss SR, Loss SS, Will T, Marra PP (2015) Linking place-based citizen science with large-scale conservation research: a case study of bird-building collisions and the role of professional scientists. Biol Conserv 184:439–445. https://doi.org/10.1016/j.biocon.2015.02.023

Michel NC, Smith AC, Clark RG, Morrissey CA, Hobson KA (2015) Differences in spatial synchrony and interspecific concordance inform guild-level population trends for aerial insectivorous birds. Ecography 39:774–786. https://doi.org/10.5061/dryad.364mb

Morton ES, Derrickson KC (1990) The biological significance of age-specific return schedules in breeding Purple Martins. Condor 92:1040–1050. https://doi.org/10.2307/1368740

Nebel S, Mills A, McCracken JD, Taylor PD (2010) Declines of aerial insectivores in North America follow a geographical gradient. Avian Conserv Ecol 5:1. https://doi.org/10.5751/ACE-00391-050201

Newson SE, Moran NJ, Musgrove AJ, Pearce-Higgins JW, Gillings S, Atkinson PW, Miller R, Grantham MJ, Baillie SR (2016) Long-term changes in the migration phenology of UK breeding birds detected by large-scale citizen science recording schemes. Ibis 158:481–495. https://doi.org/10.1111/ibi.12367

Nocera JJ, Blais JM, Beresford DV, Finity LK, Grooms C, Kimpe LE, Kyser K, Michelutti N, Reudink MW, Smol JP (2012) Historical pesticide applications coincided with an altered diet of aerially foraging insectivorous chimney swifts. Proc R Soc Lond B, Biol Sci 279:3114–3120. https://doi.org/10.1098/rspb.2012.0445

Pacheco JF, Silveira LF, Aleixo A et al (2021) Annotated checklist of the birds of Brazil by the Brazilian Ornithological Records Committee—second edition. Ornithol Res 29:94–105. https://doi.org/10.1007/s43388-021-00058-x

Pereira GA, Whittaker A, Whitney BM, Zimmer KJ, Dantas SM, Roda SA, Bevier LR, Coelho G, Hoyer RC, Albano C (2008) Novos registros de aves para Pernambuco, Brasil, com notas sobre algumas espécies pouco conhecidas no Estado. Rev Bras Ornitol 16:47–53

Perlut NG, Klal TC, Rakhimberdiev E (2017) Geolocator data reveal the migration route and wintering location of a Caribbean Martin

(*Progne dominicensis*). Wilson J Ornithol 129:605–610. https://doi.org/10.1676/16-142.1

Pinheiro RT, Dornas T (2009) Distribuição e conservação das aves na região do Cantão, Tocantins: ecótono Amazônia/Cerrado. Biota Neotrop 9:187–205. https://doi.org/10.1590/S1676-06032009000100019

QGIS Development Team (2019) QGIS geographic information system. Open Source Geospatial Foundation Project. http://qgis.osgeo.org Accessed in April of 2020

R Core Team (2020) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria

Robinson OJ, Ruiz-Gutierrez V, Reynolds MD, Golet GH, Strimas-Mackey M, Fink D (2020) Integrating citizen science data with expert surveys increases accuracy and spatial extent of species distribution models. Divers Distrib 26:976–986. https://doi.org/10.1111/ddi.13068

Rogers DI, Yang H-Y, Hassell CJ, Boyle AN, Rogers KG, Chen B, Zhang Z-W, Piersma T (2010) Red Knots (*Calidris canutus piersmai* and *C. c. rogersi*) depend on a small threatened staging area in Bohai Bay, China. Emu 110:307–315. https://doi.org/10.1071/MU10024

Russell KR, Gauthreaux-Jr SA (1999) Spatial and temporal dynamics of a Purple Martin pre-migratory roost. Wilson Bull 111:354–362

Sauer JR, Pardieck KL, Ziolkowski-Jr DJ, Smith AC, Hudson MAR, Rodriguez V, Berlanga H, Niven DK, Link WA (2017) The first 50 years of the North American breeding bird survey. Condor 119:576–593. https://doi.org/10.1650/CONDOR-17-83.1

Schubert SC, Manica LT, Guaraldo ADC (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

Sick H (1997) Ornitologia brasileira. Nova Fronteira, Rio de Janeiro

Somenzari M, Amaral PPD, Cueto VR et al. (2018) An overview of migratory birds in Brazil. Pap Avulsos Zool 58:20185803. https://doi.org/10.11606/1807-0205/2018.58.03

Stutchbury BJ, Fraser KC, Silverio C, Kramer P, Aeppli B, Mickle N, Pearman M, Mejeur J (2016) Tracking mated pairs in a long-distance migratory songbird: migration schedules are not synchronized within pairs. Anim Behav 114:63–68. https://doi.org/10.1016/j.anbehav.2016.01.016

Sullivan BL, Wood CL, Iliff MJ, Bonney RE, Fink D, Kelling S (2009) eBird: a citizen-based bird observation network in the biological sciences. Biol Conserv 142:2282–2292. https://doi.org/10.1016/j.biocon.2009.05.006

Tautin J, Cousens B, Kostka K, Kotska S, Airola DA (2008) Addressing regional declines in Purple Martin populations. In: Rich TD, Arizmendi C, Demarest D, Thompson C (eds), Tundra to tropics: connecting birds, habitats and people. In: Proceedings of the fourth international partners in flight conference. Partners in Flight, McAllen, pp 82–87

Tulloch AI, Possingham HP, Joseph LN, Szabo J, Martin TG (2013) Realising the full potential of citizen science monitoring programs. Biol Conserv 165:128–138. https://doi.org/10.1016/j.biocon.2013.05.025

Vasconcelos MF, D'Angelo-Neto S, Kirwan GM, Bornschein MR, Diniz MG, Silva JF (2006) Important ornithological records from Minas Gerais state, Brazil. Bull Br Ornithol Club 126:212–238

von Pelzeln A, Natterer J (1871) Zur Ornithologie brasiliens: resultate von Johann Natterers reisen in den Jahren 1817 bis 1835. A. Pichler's Witwe & Sohn, Wien, pp 402

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

Wickham H (2016) ggplot2: elegant graphics for data analysis. Springer-Verlag New York. ISBN 978–3–319–24277–4. https://ggplot2.tidyverse.org

WikiAves (2019) Birdwatching and citizen science. Available in https://www.wikiaves.com.br/ Accessed in December of 2019

WikiAves, Birdwatching and citizen science (2021).

Willis EO, Oniki Y (2002) Birds of a central São Paulo woodlot: 1. Censuses 1982–2000. Braz J Biol 62:197–210. https://doi.org/10.1590/S1519-69842002000200003

Zelt J, Courter J, Arab A, Johnson R, Droege S (2012) Reviving a legacy citizen science project to illuminate shifts in bird phenology. Int J Zool 2012:710710. https://doi.org/10.1155/2012/710710

Zimmer JT (1955) Studies of Peruvian birds. No. 66. The swallows (Hirundinidae). Am Museum Novit 1723:1–35