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118 years of ornithological knowledge of a forgotten region of the Atlantic Forest near the largest city in South America

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ABSTRACT—The Atlantic Forest in eastern South America harbors 849 bird species, of which 216 are endemic and 122 threatened with extinction. It is also one of the 25 biodiversity hotspots recognized throughout the world. Within this biome, the Serra do Mar stands out as an important area of endemism in South America. Nonetheless, ornithological knowledge of the Serra do Mar remains underestimated and incomplete. One lacunae of information for the Serra is a region called Curucutu, which is adjacent to the largest urban area in South America. The avifauna of Curucutu has been sampled occasionally since 1900, but all of the available data have yet to be published. Therefore, we compiled ornithological data published on Serra do Mar over the last 118 years and undertook a 16-year-long field inventory using 3 methods of data collection simultaneously (visual observations, point counts, and mist nets) for a total of 395 field days. Sampling was performed in forest and natural grasslands along an elevational gradient from 5 to 850 m.a.s.l. A total of 422 species of birds, 128 of which are endemic to the Atlantic Forest and 29 that are threatened with extinction, were documented, thereby illustrating the importance of this region. Of this total, 382 species occur in Núcleo Curucutu do Parque Estadual da Serra do Mar, demonstrating the importance of this reserve to the regional avifauna. We made several significant additions to the avifauna of the region, with only one species, the Black-necked Aracari (*Pteroglossus aracari*), being considered regionally extinct because of a lack of records since 1900—thus representing a kind of poorly studied extinction that has yet to be investigated and may be happening with much greater frequency in large forested areas of Serra do Mar. Even though the region is partially protected, being a state reserve, its proximity to the largest urban area in South America automatically puts the area under threat, especially considering the disorganized urban growth that has been encroaching upon natural areas of the region. The expansion of current reserves, and the establishment of new protected areas in this region of Serra do Mar is essential for guaranteeing the integrity of this very rich and threatened bird community of the Atlantic Forest. *Received 12 February 2018. Accepted 23 December 2018.*

Key words: Brazil, elevational distribution, endangered species, ornithological inventory, São Paulo

118 anos de conhecimento ornitológico de uma região esquecida da Mata Atlântica localizada ao lado da maior área urbana da América do Sul

RESUMO (Portuguese)—A Mata Atlântica possui 849 espécies de aves, sendo 216 endêmicas e 122 ameaçadas de extinção, sendo considerada um dos vinte e cinco *hotspots* do mundo. A Serra do Mar se destaca dentro desta região por ser uma importante área de endemismo da América do Sul, mas seu conhecimento ornitológico continua subestimado, com muitas lacunas de informações. Diante deste cenário, fizemos uma compilação histórica de 118 anos e um levantamento de campo de 16 anos em uma região denominada Curucutu, localizada na Serra do Mar do estado de São Paulo, próxima da maior área urbana da América do Sul, no sudeste do Brasil. Foram utilizados métodos simultâneos de observação, ponto de contagem e rede-de-neblina, totalizando 395 dias de campo. As amostragens foram realizadas em ambientes florestais e campos naturais localizados em um gradiente altitudinal entre 5 e 850 m a.n.m. Um total de 422 espécies de aves foram registradas na região do Curucutu, sendo 128 endêmicas da Mata Atlântica e 29 ameaçadas de extinção, mostrando a importância desta região para a conservação das aves. Deste total, 382 espécies foram registradas para o Núcleo Curucutu do Parque Estadual da Serra do Mar, uma reserva importante para a proteção das aves desta região. Foram feitos vários acréscimos à avifauna regional, mas apenas o araçari-de-bico-branco (*Pteroglossus aracari*) foi considerado extinto, pois não é registrado desde 1900, representando um tipo de extinção pouco conhecida e estudada, que pode estar acontecendo com alguma frequência em grandes áreas florestais da Serra do Mar. Embora a região esteja parcialmente protegida, sendo uma reserva estadual, sua proximidade com a maior área urbana da América do Sul, a coloca automaticamente como uma área ameaçada, especialmente considerando o crescimento urbano desordenado que vem aumentando rapidamente em direção as áreas naturais da região. A expansão das reservas atuais e a criação de novas áreas protegidas legalmente nesta região da Serra do Mar é essencial para garantir a integridade desta comunidade de aves tão rica e ameaçada da Mata Atlântica.

Palavras-chave: Brasil, distribuição altitudinal, espécies ameaçadas, inventário ornitológico, São Paulo

The Atlantic Forest is home to a significant portion of Brazil's biological diversity, with very high levels of species richness and endemism. It is also one of the 25 global biodiversity hotspots, one of the most threatened biomes of the world, and an important biogeographic region of South America (Fonseca 1985, Myers et al. 2000, Silva et al. 2004). A total of 849 species of birds are currently recognized as occurring in the Atlantic Forest, of which 216 are endemic and 122 threatened with

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extinction due to high levels of environmental degradation (Tabarelli et al. 2003, Bencke et al. 2006, MMA 2014). Even given the significant amount of current knowledge regarding the avifauna of the Atlantic Forest, gaps remain regarding its biology, ecology, and distribution. Furthermore, a considerable portion of the knowledge that exists remains unpublished and awaiting analysis and appropriate disclosure. The absence of detailed compilations, which retrieve and combine historical and recent data, compromise the general and regional evaluation of this knowledge, resulting in an underestimation of the biodiversity of many regions of the Atlantic Forest (Stotz et al. 1996, Pacheco and Bauer 1999, Straube and Urben-Filho 2005).

An important region of the Atlantic Forest is Serra do Mar, a hilly landscape located in the Southeast and South regions of Brazil. It is characterized as the edge of a plateau (seaward slope) facing the Atlantic Ocean, with an average 800 m of unevenness, a level top at elevations of 800–1,200 m, and a maximum peak of 2,275 m.a.s.l. in Serra dos Órgãos, Rio de Janeiro (Almeida and Carneiro 1998). It is recognized as one of the main areas of endemism within the Atlantic Forest and a priority for conservation of endemic and threatened species of this biome (Haffer 1974, 1985; Cracraft 1985, Stattersfield et al. 1998). Bencke et al. (2006) highlighted a region of Serra do Mar called Curucutu, located in the state of São Paulo, as one of the least ornithologically known regions in the Southeast Region of Brazil, due to the absence of information published in scientific journals. Nonetheless, there have been non-systematic studies conducted in Curucutu since 1900, but the resultant knowledge has never been organized, analyzed, and disseminated with due care (Willis and Oniki 2003). Based on this disconcerting scenario, and on the importance of having historical and current data compiled for use in conservation, we organized the ornithological information produced over the last 118 years and conducted a 16-year-long field study in this preserved region of Atlantic Forest, which happens to be located next to the largest urban area in South America. The main objective of this study was to characterize the bird community of Curucutu in Serra do Mar by comparing historical and current data, while emphasizing species that are endemic, threatened with extinction, or potentially locally extinct.

Methods

Study area

Curucutu is located in Southeast Brazil, in the municipalities of Itanhaém, Mongaguá, São Vicente, São Paulo, and Juquitiba in the eastern part of the state of São Paulo (Fig. 1). In this region the Núcleo Curucutu (23°56′S, 46°39′W) is part of Parque Estadual da Serra do Mar (PESM), a reserve created in 1977 that currently encompasses 332,290 ha divided into 10 independent administrative centers (subregions named "núcleos"). It ranges in elevation from 0 to 1,200 m.a.s.l., and is the largest protected area in the state of São Paulo and one of the largest protected areas of Atlantic Forest in Brazil. Núcleo Curucutu encompasses 36,134 ha with an elevational gradient ranging from 5 to 1,050 m.a.s.l. It is located in the southern part of PESM, between the metropolitan regions of São Paulo and Baixada Santista, which together contain 32.2 million human inhabitants (12% of the population of Brazil) and represent the first macro-metropolis of the Southern Hemisphere (IBGE 2014; Fig. 1). The region possesses a mosaic of habitats including upper-montane forest, montane forest, submontane forest, lowlands forest, flooded area (including flooded forest), natural montane grassland, and human-altered habitat (Garcia and Pirani 2003, Pessenda et al. 2009). According to Tarifa and Armani (2000), the climate of the region is Tropical Super Humid, on the reverse of the Atlantic Plateau, and Tropical Oceanic Super Humid, on the eastern facade of the Atlantic Plateau. Temperatures vary between 0 °C (winter) and 34 °C (summer), with annual rainfall ranging from 3,497 to 4,435 mm between 2008 and 2011 (data from the local meteorological station; Malagoli 2013).

Study sites

Ten areas within Núcleo Curucutu (A–J, plus the headquarters of the reserve) were systematically studied along with 10 other areas that were randomly visited once (Fig. 1; Supplemental Table S2).

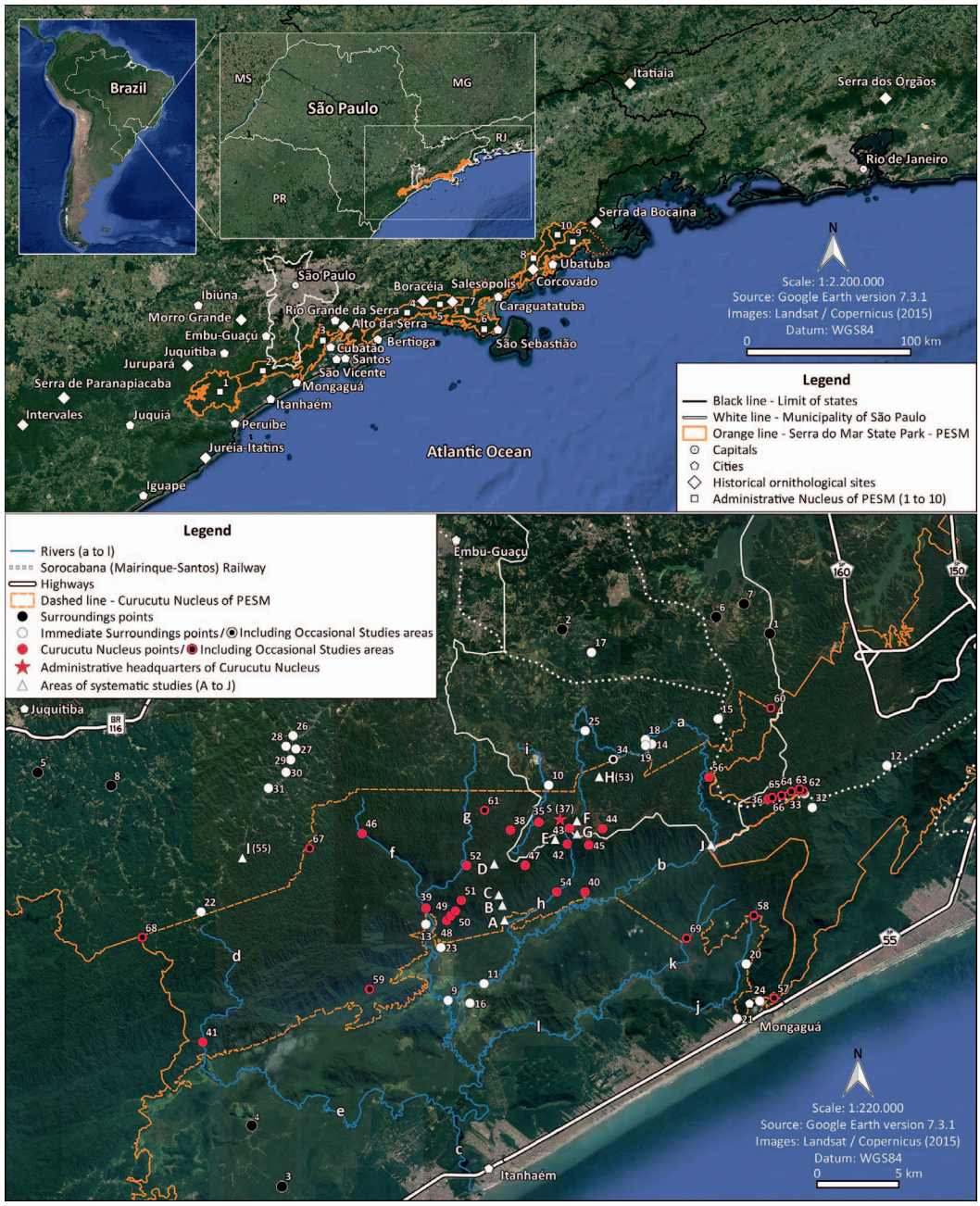

Figure 1. General map of the region of Curucutu. Administrative nucleus of PESM: 1. Itarirú, 2. Curucutu, 3. Itutinga-Pilões, 4. Bertioga, 5. Padre Dória, 6. São Sebastião, 7. Caraguatatuba, 8. Santa Virgínia, 9. Picinguaba, 10. Cunha. Rivers of the Curucutu region: a. Capivari, b. Branco, c. Itanhaém, d. Itarirú, e. Preto, f. Macacos, g. Mambú, h. Camburi, i. Embu-Guaçú, j. Bichoró, k. Mineiro, l. Aguapeú. Areas of systematic studies: A. Cota 30, B. Cota 200, C. Cota 400, D. Cota 700, E. Mirante 2, F. Mata dos 80, G. Campos, H. Rua sem Nome, I. Fazenda Stihl, J. Capivari. Areas of occasional studies and historical localities are in the Supplemental Tables S2 and S3.

Fieldwork

The present study gathered information continuously collected in the field by one of the authors (F.S.) between 2003 and 2018, for a total of 395 effective days of data collection (Supplemental Table S3). Furthermore, 16 exploratory visits were made to Núcleo Curucutu between 2003 and 2007, with some additional data collection (visual observations only). A systematic and standardized study was also undertaken between May 2007 and June 2011 in 10 areas spread across an elevation gradient from 15 to 880 m.a.s.l., plus the reserve headquarters. This study involved 18 campaigns—4 per area per year (1 per season of the year)—for 3 days per area, with the simultaneous use of 3 different survey methods (point counts, mist nets, and visual observations), for a total of 306 field days. Nine additional "visual observation only" samplings were made during this period. Seven summer campaigns (one per year) were carried out between 2012 and 2018 in the "campos" area (upper part of the Serra) using the same methods as used in the standardized sampling, for a total of 39 field days, with the only difference in sampling from year to year being the number of mist nets used (between 20 and 40) and the number of field days (between 5 and 6). During this period another 25 days of additional visual observation was carried out in a variety of locations, including areas that had not been sampled in the systematic study (Fig. 1; Supplemental Table S3).

The 10 areas selected for the systematic and standardized study were sampled by 5 point-counts, separated spatially by 100 m and temporally by 10 min, which added 1,244 point counts (samples) for a total of 207 census-hours (100 points and 16.5 census-hours during the extra campaigns). Twenty mist nets (30 mm mesh; 12 × 2 m, 4 bags) were distributed along 2 lines with 10 nets each, and were left open all day for a total of 115,717 net-hours (8,381 net-hours during the extra campaigns). Captured birds were marked with metal bands from CEMAVE/ICMBio (National Center for Research and Conservation of Wild Birds) and released after biometric measurements and ectoparasite evaluation (the latter data to be the subject of another paper).

Birds were voice-recorded when possible using either a Sony TCM 5000EV or a Marantz PMD660 recorder, but always with a Sennheiser ME66 shotgun microphone. All recordings were archived with one of the authors (F.S.), although some were made available online through the Xeno-Canto collection (www.xeno-canto.org). Likewise, most mist-netted individuals were photographed in hand, as were some free-ranging birds; the photographs are available throught the WikiAves online database (www.wikiaves.com.br).

Secondary data compilation

Secondary data (i.e., not collected in the field by the present study) came from scientific articles, catalogs, institutional documents, books, and the gazetteer of Paynter and Traylor (1991), as well as information from the scientific collections of Museu de Zoologia da USP (MZUSP), Field Museum of Natural History (FMNH), and Naturhistorisches Museum Wien (NMH). Gray literature included in the study comprised technical reports and bird lists made available by colleagues. We also consulted digital databases from Centro de Estudos Ornitológicos-CEO (an NGO in the city of São Paulo that performs ornithological surveys; www.ceo.org.br), Ornis (www.ornisnet.org), SpeciesLink (www.splink.cria.org.br), eBird (www.ebird.org), WikiAves, and Xeno-Canto (last accessed in June 2017). The words used in searches were Curucutu, Serra do Mar, Itanhaém, Mongaguá, and São Paulo. Secondary records were pre-evaluated before inclusion in the database resulting in some information not being used because it was deemed unreliable. The geographical coordinates of the historical sites were confirmed by consulting Paynter and Traylor (1991) and Willis and Oniki (2003), with some adjustments.

Some records for the Curucutu region published by Hasui et al. (2018)—the largest and most recent database on Atlantic Forest ornithological research—were discarded due to the presence of errors and because we consulted the information in the original sources.

Data were classified geographically: "Surroundings" = up to 15 km from Núcleo Curucutu (comprising habitats similar to, and different from, those in the reserve; localities 1 to 8); "Immediate Surroundings" = surroundings within ~5 km (comprising habitats similar to those in the reserve; localities 9 to 34); and "Núcleo Curucutu" = the officially defined limits of this nucleus of PESM (localities 35 to 70; Fig. 1). The objective of this

classification was to determine which species occur within the official limits of the reserve (Núcleo Curucutu) and which occur outside, thus facilitating a more careful evaluation for the creation of new protected areas in the surroundings. This classification was based on the damping area of the Núcleo Curucutu and experience of the authors (F.S. and V.S.). Most of the ornithological compilations made for the Atlantic Forest—including 2 of the 4 compilations available for Serra do Mar of São Paulo (Cavarzere et al. 2010 and Simpson et al. 2012)—did not make this political–geographical distinction, and thus considered all available information as being of a reserve, or simply did not cite which species were within a protected area, thereby making it difficult to evaluate the efficiency of reserves for the protection of the regional avifauna.

Analysis

Chronological species accumulation curves were constructed for the period of 1900 to 2018 using year as the sampling unit, and for the period of 2007 to 2018 using data from the 3 sampling methods used employing the number of records as the sampling unit. The order of samples was randomized 100-fold in order to eliminate any random effect in the order in which the species were recorded (Colwell 2016). The respective standard deviations were considered for the data collected between 2007 and 2018. Estimated species richness for the study area was calculated using the first-order jackknife estimator based on 100 data randomizations. The analyses were performed using the Poolacum function of the Vegan package (Oksanen et al. 2013) of the program R (R Development Core Team 2016).

The status of occurrence of the species recorded in the field was determined through Frequency of Occurrence (F.O.: number of records divided by the number of systematic visits), based only on the 18 systematic campaigns carried out between 2007 and 2011, and adopting the criteria of Donatelli et al. (2011): VC [very common], recorded in at least 75% of the samples; C [common], recorded in 50–74% of the samples; U [uncommon], recorded in 15–49% of the samples; R [rare], recorded in less than 14% of the samples, and O [occasional], species with only one record. The rare category may only be the result of the low number of records of a respective species in the general context of field sampling, being a group that needs further studies to determine the true status of occurrence in the Curucutu region. Two other categories were also considered: R for residents (for VC, C, and U) and M for species considered migratory by Sick (1997), Willis and Oniki (2003), and Somenzari et al. (2018), with some adjustments. The conservation status of species at the global, national, and regional levels followed IUCN (2018), MMA (2014), and São Paulo (2018), respectively. Atlantic Forest endemics were determined following Bencke et al. (2006), whereas habitat associations (e.g., "forest species") followed Parker et al. (1996), with some adjustments. The nomenclature and taxonomy used follow the Brazilian Ornithological Records Committee-CBRO (Piacentini et al. 2015). Maps were produced using the free software QGis for Windows (v. 2.14.3) and Photoshop CS6. In the map, the "I" locality appears outside the current limits of the Núcleo Curucutu, but it is an area that has been attached to this reserve recently.

Results

A total of 422 species of birds were recorded for the region of Curucutu between 1900 and 2018 by different researchers, which represents 22% of the bird species of Brazil, 53% of the state of São Paulo, and 50% of the Atlantic Forest (Bencke et al. 2006, Silveira and Uezu 2011, Piacentini et al. 2015). Of this total, 338 were recorded between 1900 and 2007, but only 278 of these were published in scientific articles, books, congress abstracts, institutional documents, or museum catalogs (Hellmayr and Conover 1942, Pinto 1944, 1945; Collar et al. 1992, Whitney and Pacheco 1995, Buzzetti 1996, Willis and Oniki 2003, and São Paulo 2010; Fig. 2, Supplemental Tables S1 and S3).

The Núcleo Curucutu of PESM, the main protected area of the region, had 382 species recorded between 1940 and 2018. Up until 2007, 273 species had been recorded, but only 148 of these were published (Pinto 1944, Collar et al. 1992, Whitney and Pacheco 1995, Willis and Oniki 2003, São Paulo 2010)—although not in conventional media—making it difficult to access and use these data. Of the 382 species, 373 were

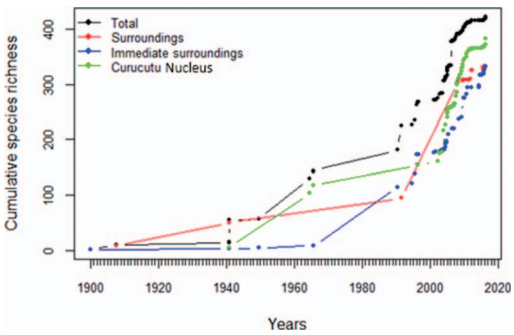

Figure 2. History of ornithological knowledge of the Curucutu region. The red line represents data of the surroundings, the blue line represents the immediate surroundings, the green line represents Núcleo Curucutu of PESM, and the black line represents all of the data combined.

recorded in the field by our study and only 9 were historical records that were not detected again, possibly because they were species that were vagrant, migratory, or even rare in this region of Serra do Mar, such as the Brown-crested Flycatcher (*Myiarchus tyrannulus*) and warbling-finch (*Microspingus* sp.). However, other species that fall into these categories were recorded in the present work in unique and random observations, such as the White-rumped Hawk (*Parabuteo leucorrhous*), the Great Horned Owl (*Bubo virginianus*), the Plush-crested Jay (*Cyanocorax chrysops*), and the Screaming Cowbird (*Molothrus rufoaxillaris*) (Supplemental Tables S1 and S3).

Until 2018, a total of 391 species of birds had been recorded for the surroundings of Núcleo Curucutu (Surroundings and Immediate Surroundings), with 2 localities being particularly noteworthy: Estação Ferroviária Evangelista de Souza and the Rio Preto region, located in the upper and lower part of the seaward slope of the Serra do Mar, with 258 and 294 species, respectively. Of this total, 29 species have not yet been recorded within the limits of Núcleo Curucutu, and only the Red-tailed Parrot (*Amazona brasiliensis*) and the Pied Lapwing (*Vanellus cayanus*) do not have suitable habitats for potential occurrence within this reserve. On the other hand, 28 species have been recorded to date only within the reserve (Fig. 1, Supplemental Tables S1, S3).

Of the 373 species of Núcleo Curucutu, 258 (69%) occur in the lower part of the seaward slope of the Serra do Mar, between 5 and 100 m.a.s.l. (6 localities); 211 (57%) at mid-elevations, between 200 and 650 m.a.s.l. (13 localities); and 299 (80%) in the upper part, between 650 and 850 m.a.s.l. (13 localities); in addition, there are 143 (38%) species that are present throughout the elevational gradient from 5 to 850 m.a.s.l. (Supplemental Table S1). Of the 3 field methods used, visual observation recorded 364 species, point counts 214 species, and mist nets 180 species. A total of 5,114 individual birds were captured, of which 4,832 were banded.

A total of 128 bird species endemic to the Atlantic Forest have been recorded in the Curucutu region (124 for Núcleo Curucutu), 45 of which are migratory species (38 for the nucleus) and 29 that are threatened with extinction (24 for the nucleus): 13 at the global level (12 for the nucleus), 11 at the national level (9 for the nucleus), and 27 at the state level (22 for the nucleus; Supplemental Table S1). A total of 252 species (68%) recorded by the field study were considered "Residents," while only 47 (13%) were considered "Occasional." Of this total, 281 were of forest habitat (majority of the area of the reserve), 31 of natural montane grasslands (restricted habitat), and 39 of flooded areas (restricted habitats situated mainly in the lower part of the seaward slope). The remaining species did not have an exclusive habitat preference, and occur in various vegetation types including human-altered and recovering areas (Supplemental Table S1).

The avifauna of this region is typical of the Atlantic Forest of southeastern Brazil; however, it is located close to the border between the 2 distinct regions of the Serra do Mar in the state of São Paulo—a northern forest block close to the coast (also called Serra do Mar) and a southern forest block more distant from the coast called Serra de Paranapiacaba—which leaves some distribution patterns poorly understoood. For example, the Gray-bellied Hawk (*Accipiter poliogaster*), Black-eared Fairy (*Heliothryx auritus*), Saffron Toucanet (*Pteroglossus bailloni*), Cinnamon-vented Piha (*Lipaugus lanioides*), and Half-collared Sparrow (*Arremon semitorquatus*) are all typical birds of Serra de Paranapiacaba but with rare records in the northern region and near the coast.

The cumulative species curve exhibited a tendency toward stabilization with the data collected in the field between 2007 and 2011 in the 10 locations studied systematically, but it

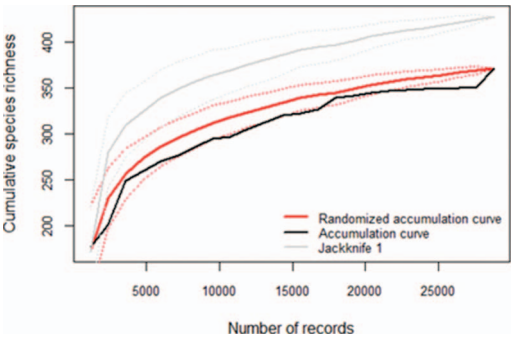

Figure 3. Species accumulation curve for the field study undertaken in the Núcleo Curucutu of PESM. The red line represents the species accumulation curve as a function of the number of records (of the 3 methods used), produced through 100 randomizations. The black line is the same curve without randomizations. The gray line represents the estimated number of species according to the first-order jackknife estimator. Dotted lines represent the respective standard deviations.

exhibited a second increase with the addition of data collected from new locations between 2012 and 2018 (Fig. 3).

Historical results

The Curucutu region has been visited by naturalists, collectors, and ornithologists since the end of the 19th century (see Supplemental Table S3 for a detailed account of all surveys ever made). The first bird record is a skin of a Black-necked Aracari, currently deposited in the Naturhistorisches Museum Wien (NMW 55565), which had possibly been collected between the late 19th and early 20th centuries in the region of the lower Rio Mambú, Itanhaém [Locality 9; hereafter numbers in brackets refer to the map] (Willis and Oniki 2003; H.M. Berg, pers. comm.). The first dated collections were traced to August and September 1907, when A. Wachsmund, collecting also for the museum in Wien, acquired specimens of 8 species in a region named Curucutu [1], including the Least Pygmy-Owl (*Glaucidium minutissimum*) (Hellmayr and Conover 1942). Museum collections were made again in the 1940s by the staff of Museu Paulista (currently the Museu de Zoologia da Universidade de São Paulo, MZUSP), when 44 species were collected (see Pinto 1944, 1945). These expeditions include the first location to be scientifically collected within what is now the current limits of the Núcleo Curucutu of PESM: Cabeceiras do Rio Embu-Guaçu [35].

In 1964 and 1965, A. M. Ollala and his team collected at 2 locations within the PESM: Estação Ferroviária Engenheiro Ferraz [36], located within the current limits of Núcleo Curucutu, and Estação Ferroviária Pai Matias [12], located in Núcleo Itutinga-Pilões (both in São Vicente). The first-mentioned locality is at an elevation of 605 m.a.s.l. and produced about 1,000 specimens of 115 species, and featured birds from both the upper and lower parts of the Serra, such as the Hooded and Black-headed berryeaters (*Carpornis cucullata* and *C. melanocephala*). These were the last large collections made around the Curucutu region.

Beginning in the 1980s, most "modern" surveys within Curucuru region relied on visual and aural records, without documentation, eventually leading to some obvious mistakes and other questionable records. On the other hand, some noteworthy records were also gathered recently. For example, a study carried out between 1987 and 1995 in the region of Rio Preto (Loteamento Bopiranga, Itanhaém) [3] recorded 225 species, of which only 48 were published, including the endemic and threatened Red-tailed Parrot (Buzzetti 1996, 2005; Minns et al. 2009, Lima 2010a).

Among the undocumented records made in a list of 108 species in the lower part of the Rio Manbu [13] in May 1990 (SABESP 1990), 2 call particular attention: the Mouse-colored Tapaculo (*Scytalopus speluncae*) and the Ochre-faced Tody-Flycatcher (*Poecilotriccus plumbeiceps*), which are both rare species, or may even be absent, in the foothills of the Serra do Mar (Willis and Oniki 2003). Records that are most likely mistakes and were discarded in the present work pending adequate documentation include Tropical Mockingbird (*Mimus gilvus*), which has never been documented in the state of São Paulo (Silveira and Uezo 2011), but was mentioned for Estação de Tratamento de Água do Rio Branco [16] (SABESP 2001); the Scaled Dove (*Columbina squammata*), Gilded Hummingbird (*Hylocharis chrysura*), White-eyed Parakeet (*Psittacara leucophthalmus*), Pale-breasted Spinetail (*Synallaxis albescens*), and the Mouse-colored Tyrannulet (*Phaeomyias murina*), all of which are not known to occur in eastern São Paulo (Curucutu region) but included in a list of 142 species from a 13-day survey in January

and February 2004 by G. Cabanne and I. Roesler (unpublished) around the headquarters of Núcleo Curucutu [37]; and Spot-breasted Antvireo (*Dysithamnus stictothorax*), Salvadori's Antwren (*Myrmotherula minor*), and Scaled Antbird (*Drymophila squamata*), of the same G. Cabanne and I. Roesler survey, which are species almost exclusive to the tall forests of the lowlands and their documentation over 750 m.a.s.l. still need documentation (both decisions agreed upon by Cabanne and Roesler themselves).

In 1994, a team from the prefecture of the municipality of São Paulo (Depave-3 team) began to make ornithological inventories in the southern region of the municipality, such as at Estação Ferroviária Evangelista de Souza [15] (São Paulo 2010, Melo et al. 2016), Fazenda Capivari (SABESP) [14], Sítio Bordin [17], and Núcleo Curucutu [37], with the inventory of this last location being the first since the 1965 collections (São Paulo 2010). In 2002 and 2003 the Centro de Estudos Ornitológicos-CEO undertook 3 expeditions to Núcleo Curucutu [37], recording 87 species, most notably the Speckle-breasted Antpitta (*Hylopezus nattereri*), with one of us (F.S.) participating in the 2003 expedition (CEO 2014). Between 2003 and 2007, this same author (F.S.) and collaborators started making reconnaissance expeditions to the park and its direct surroundings, recording some interesting species like Black-fronted Piping-Guan (*Aburria jacutinga*). In March of 2005, 138 species were recorded at 4 localities of Núcleo Curucutu [40–43] during an inventory to support the Plano de Manejo do PESM (PESM Management Plan), and included the Brown-backed Parrotlet (*Touit melanonotus*) (Buzzetti 2005).

In the last decade (in addition to the samplings of the present study), only one inventory was undertaken (2012), which recorded 118 species for 4 highland localities [37o, 37p, 38c, and 56] (Ambiens 2013). Further records were obtained through occasional surveys and isolated records made by photographers and birdwatchers in areas of the surroundings and direct surroundings (Fig. 1, Supplemental Table S3).

Noteworthy records

*Blue Ground-Dove (*Claravis pretiosa*)*—A single record made in October 2005 at the locality "Campos," in a small patch of upper-montane forest with the presence of the bamboo (*Chusquea longispiculata*), remains the only documented record of this species for PESM. Its presence in the eastern region of the state of São Paulo has always been associated with just a few localities, such as Iguape and Juquiá (Willis and Oniki 2003), Juréia-Itatins (Develey 2004), and Ubatuba (Goerck 1999, Simpson et al. 2012). In recent years it has been photographed at other coastal locations such as Bertioga, São Sebastião, and Caraguatatuba, indicating an occurrence associated with the hottest months of the year, but with some records also having been made in winter (WikiAves 2018). On the other hand, the Purple-winged Ground-Dove (*C. geoffroyi*) continues to lack recent information, with the only documented record for Serra do Mar being made in August of 1899 in Alto da Serra (Pinto 1938), ~35 km northeast of Curucutu. This species is considered likely extinct due to the absence of recent, reliable, and documented records.

*Black-billed Scythebill (*Campylorhamphus falcularius*)*—Recorded once at the locality Mirante 2 [E] (2008) and twice at Cota 400 [C] (2009), both of which were auditory records. This species has never been captured during the 11 years of mist-netting (115,717 net-hours), as have all other species of the family Dendrocolaptidae, which are considered rare in this region. There is a record for the locality Sítio Bordin [17], located ~7 km from the northern limit of the Núcleo Curucutu (São Paulo 2010), indicating its presence near the nucleus. This bird is rare throughout the mid-south region of Serra do Mar of São Paulo, and there is a gap of information for the area between Curucutu and the region of Salesópolis, farther to the northeast (Cavarzere et al. 2010, WikiAves 2018).

*Black-headed Berryeater (*Carpornis melanocephala*)*—This species was collected in May 1964 by the team of A.M. Ollala in the region of Estação Ferroviária Engenheiro Ferraz (without elevation being determined) and recorded in the Rio Preto region [3 and 4] in the lower part of the Seaward slope by Buzzetti (1996) and Lima (2010a). Between 2007 and 2011, we recorded this species in 16 of the 18 samples taken at the locality of Cota 30 [A], in 2 of the 3 trips made to the locality Capivari [J], and 1 record at the locality of Cota 200 [B], indicating a common occurrence in the

lowland forests of this region. However, in June 2015, an individual (a female or young male) struck a building at the administrative headquarters of the park [37], 750 m.a.s.l., and was photographed and released by the reserve manager. Based on the small montane forests and human-made habitats around this site, this atypical record may indicate a possible unknown regional movement of this species. In October 2015, we recorded an individual in tall forest at about 770 m.a.s.l. in Juquitiba, near the reserve. The nearest records to this locality are about 21 and 31 km to the northwest in P.E. Jurupará, Ibiúna (Beyer et al. 2010, Godoy 2010, WikiAves 2018). Its presence in the upper part of the seaward slope of Serra do Mar of São Paulo was known only from Rio Grande da Serra and Alto da Serra (35 km to the northeast of Núcleo Curucutu) (Hellmayr 1929, Pinto 1944), where it is no longer recorded according to Silveira (2009) and WikiAves (2018). It has recently been recorded in the region of Juquitiba and Ibiúna, probably due to the less rugged relief, which facilitates the occurrence of many species typical of the lower part of the seaward slope, and the tall vegetation, similar to lowland forests.

*Cinnamon-vented Piha (*Lipaugus lanioides*)*—Collected in 1964 (May) and 1965 (September) by the team of A.M. Ollala in the region of the railway stations Engenheiro Ferraz and Pai Matias [36 and 12], separated by about 8 km, although the elevations are not reported in the respective specimens. The only field record was an auditory observation made in November 2007 in an area of medium forest at the top of the seaward slope in the region of Rio Mambú [52], ~8 km southeast of the headquarters and 20 km from the Estação Engenheiro Ferraz [36]. It is a rare bird in the mid-south region of Serra do Mar of São Paulo and, as well as *C. falcularius*, is lacking information between Curucutu and Núcleo Santa Virgínia (to the northeast), occurring with a regular frequency only in Serra da Bocaina (on the border with Rio de Janeiro), where it also occurs in lowland areas (Willis and Oniki 2003, Mallet-Rodrigues et al. 2015).

*Brown-breasted Pygmy-Tyrant (*Hemitriccus obsoletus*)*—Recorded on 9 and 10 March 2010 at the locality Mirante 2 [E], at the top of the seaward slope, when a single individual was observed feeding and vocalizing sporadically, but documentation was not possible. The region of Curucutu lies precisely in the existing gap between the current distributions of the 2 recognized taxa of *H. obsoletus*, with the nominate subspecies occurring to the northeast of Serra do Mar of São Paulo and *H. o. zimmeri* in Serra de Paranapiacaba (Willis and Oniki 2003, Clock 2016). The collection of specimens is necessary to determine which taxon occurs in the region, as well as their status in this part of the Serra do Mar.

*Chilean Elaenia (*Elaenia chilensis*)*—Recorded at the locality Campos [G] in the upper montane region in March every year from 2009 to 2018, during the species' migration between its breeding range in southern South America and its wintering area in northeastern Brazil (Marini and Cavalcanti 1990, Jiménez et al. 2016). The birds stay for a few days in the Curucutu region, where they feed on fruits of trees and bushes in the upper montane forest. In total, 271 individuals were banded, but there have yet to be any recaptures.

*Warbling-Finch (*Microspingus *sp.)*—A single individual was observed near the headquarters of the reserve [37] in September 2002 and identified as *Microspingus lateralis* before this group of species was separated into two distinct species (CEO 2014). The region of Curucutu lies precisely in the gap between the distribution of *M. lateralis* (occurring to the north) and *M. cabanisi* (occurring to the south; Assis et al. 2007), making it difficult to determine which taxon was recorded at the time. New records are needed to more confidently determine which taxon occurs in the region.

Discussion

The region of Curucutu currently has the highest species richness of birds in Serra do Mar of the state of São Paulo with 422 species, surpassing Boracéia (323 species; Cavarzere et al. 2010), Ubatuba (417; Simpson et al. 2012), and Serra da Bocaina (407; Mallet-Rodrigues et al. 2015). This richness is also significant when compared to other regions of the Atlantic Forest, such as Itatiaia (457; MMA 2013, Mallet-Rodrigues et al. 2015) and Serra dos Órgãos (476; Mallet-Rodrigues et al. 2007, 2015). Even considering the varied compositions of these localities, and being aware of the problems comparing species lists of different areas (Remsen 1994), this region must be considered a

new ornithological reference for the Atlantic Forest and Serra do Mar, and an exemple of what can be expected with regard to species richness of a preserved region with varied habitats.

The fact that the historical data for the Curucutu region had only been partially and recently published has made this knowledge "forgotten" for more than a hundred years, and thus "biased" the basic literature that has been produced on the birds of the Atlantic Forest throughout the 20th and beginning of the 21st centuries, especially studies that mapped key areas for conservation, such as Wege and Long (1995), Cordeiro (2003), Bencke et al. (2006), and Tonetti and Cavarzere (2017). Until 1965, 144 species of birds had been collected in the region of Curucutu, about 14% more than the 124 species known at that time for Alto da Serra (Silveira 2009), one of the most well-known and important localities of the Atlantic Forest of southeastern Brazil, and which lies only 35 km from Núcleo Curucutu. The main differences between the 2 regions are that at Alto da Serra the collections were more intense between the end of the 19th and the beginning of the 20th centuries, and the data were published almost completely by Ihering (1898), Ihering and Ihering (1907), Pinto (1938, 1944), and Hellmayr and Conover (1942, 1949). The present compilation for the Curucutu region shows that this locality is among those at the frontiers of ornithological exploration of the Atlantic Forest of southeastern Brazil but, unfortunately, it is still only the fifth compilation of available data for a specific region of the Serra do Mar of the state of São Paulo, after Silveira (2009), Cavarzere et al. (2010), Simpson et al. (2012), and Schunck et al. (2018). Pacheco and Bauer (1999) and Straube and Urben-Filho (2005) highlighted the incomplete knowledge of the birds of the Atlantic Forest at the time and the need to make new compilations of historical data (including the gray literature) and field inventories (including research and publication of long-term data), yet little has changed in the last 18 years and the issue still remains a conservation priority for the birds of this very rich and threatened biome.

The 382 species of birds recorded at Núcleo Curucutu (373 by the present study) place it as the nucleus with the highest number of bird species among the 10 that form PESM, and among the other reserves located in Serra do Mar in the state of São Paulo, only behind Parque Estadual de Intervales (401 species) located in Serra de Paranapiacaba (Antunes et al. 2008). However, the list available for the latter reserve gathers information from a region greater than its official boundaries, making it difficult to accurately assess how many species are actually protected.

The avifauna of Núcleo Curucutu is composed predominantly of forest birds (76%); however, among 191 species recorded at the "Campos" locality, 31 occur exclusively in natural montane grasslands, of which the Giant Snipe (*Gallinago undulata*) and Hellmayr's Pipit (*Anthus hellmayri*) occupy "clean natural grassland," with the first in wetter areas and the second in drier ones. The other species use "dirty natural grassland," with isolated low vegetation often forming small forest patches, usually in water drainages with a dominant presence of bamboo (*Chusquea longispiculata*). This high number of species may be the result of the natural montane grasslands of Curucutu being located between the forests at the top of the seaward slope and the plateau, with the presence of isolated fragments of upper montane and montane forests, which means that many forest species, such as Spot-billed Toucanet (*Selenidera maculirostris*), Swallow-tailed Manakin (*Chiroxiphia caudata*), and Pin-tailed Manakin (*Ilicura militaris*), use these areas to move between forest patches. Our study seems to be the first systematic one of montane grasslands in all of the Serra do Mar, which is one of the least known habitats of the mountains of southeastern Brazil (Vasconcelos and Rodrigues 2010).

The absence of some species typical of Serra de Paranapiacaba, such as Rusty-breasted Nunlet (*Nonnula rubecula*), Helmeted Woodpecker (*Celeus galeatus*), White-bearded Antshrike (*Biatas nigropectus*), Bay-ringed Tyrannulet (*Phylloscartes sylviolus*), and Magpie Tanager (*Cissopis leverianus*), attract much attention, mainly due to the significant field effort carried out over several years, reducing the possibility of failure of detectability. Only *N. rubecula* and *C. galeatus* seem to be truly restricted to Serra de Paranapiacaba (as well as areas in the interior of the state of São Paulo), with the others occurring in other areas to the north of the Curucutu region, and whose absence needs to be better investigated

since Curucutu is a continuous forest area with appropriate habitats.

Among all the species ever recorded in the Curucutu region between 1900 and 2018, only *Pteroglossus aracari*, collected around 1900, remains without current records, and is now considered by us as regionally extinct. According to Willis and Oniki (2003), this aracari was always rare on the coast of São Paulo, and the last report was made in Ubatuba in the 1990s (J.F. Pacheco, pers. comm.). These authors associate its disappearance from the interior of São Paulo and the municipality of Rio de Janeiro to deforestation, but its absence in preserved areas of Serra do Mar remains a mystery. This process of local extinction has already been documented in well-studied forest fragments in the interior of the state of São Paulo, where the loss of habitat has been intense and the quality of habitats declined year after year (Silva et al. 1992, Aleixo and Vielliard 1993). However, extinction processes in large, well-preserved forested areas of Serra do Mar are still unknown and not studied, with only speculative citation being made by Silveira (2009) for Alto da Serra, a region that suffered industrial pollution from the Petrochemical Complex of Cubatão (located near Santos) in the 1970s and 1980s. The passage of 118 years without records of this aracari may indicate a process of regional extinction of species in large natural areas of Serra do Mar still unknown. The same may also be true for Sickle-winged Nightjar (*Hydropsalis anomala*) and *Claravis geoffroyi*, both recorded over 100 years ago in Alto da Serra, and which are no longer recorded in any other region of Serra do Mar of São Paulo, despite their habitats being still available.

Conservation implications

This historical compilation and the production of robust data through long-term inventories is fundamental to improving the ornithological knowledge of the Atlantic Forest, even when dealing with areas located next to large urban centers such as São Paulo. All the other nuclei of PESM and several other important reserves of Serra do Mar still lack ornithological compilations or thorough field inventories, thereby compromising an understanding of the avifauna of the region, particularly with regard to new occurrences and possible local extinctions.

The Curucutu region harbors 29 bird species currently classified as threatened with extinction either at global (13), national (11), or regional (27) levels, therefore highlighting the importance of a protected area such as Núcleo Curucutu. Among the 333 species of birds recorded in the surroundings of the reserve, only *Amazona brasiliensis* and *Vanellus cayanus* have no potential for occurrence within this reserve due to the absence of their typical habitats, which are flooded forests of the coastal plain and sandy beaches of large rivers, respectively. An expansion of the reserve or the creation of new reserves in lowland areas, such as the Rio Preto (the main breeding area of this threatened parrot in its northernmost distribution), is fundamental for the conservation of the regional avifauna, which faces constant impacts by the uncontrolled urbanization in the surroundings of the Núcleo Curucutu, such as the municipalities of Mongaguá and Itanhaém. Likewise, the growth of urban areas in the upper parts of the Serra do Mar around Curucutu (e.g., Marsilac-Evangelista de Souza neighborhoods in São Paulo) has led to irregular occupation and deforestation in a zone that should be working as a buffer between PESM and the largest urban area in South America.

Unfortunatelly the problems are not restricted to the surroundings of Curucutu, as even within the reserve birds continue to be hunted (e.g., *Tinamus solitarius*, *Aburria jacutinga*) and trapped for the cage trade (e.g., seedeaters: *Sporophila frontalis*, *S. falcirostris*, *S. angolensis*). The reduced staff available for such a large area hinders the fight against the illegal persecution of birds and other animals, as well as the illegal collection of native plants for human consumption (e.g., *Euterpe edulis* palmheart) or gardening (e.g., *Geonoma* palms, ferns, and orchids), which are constant impacts to the reserve. Other conservation challenges for Curucutu are the conflicts of land ownership and the presence of exotic species such as *Pinus elliottii*, which are invading areas of natural grasslands. Proper land management and law enforcement, both within and around the Núcleo Curucutu of PESM, are thus imperative to the long-term conservation of biodiversity in one of the most species-rich regions of the Atlantic Forest hotspot.

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