Biota Neotropica
ISSN: 1676-0611
ea@biotaneotropica.org.br
Instituto Virtual da Biodiversidade
Brasil

Cavarzere, Vagner; Silveira, Luis Fabio; Rodrigues Tonetti, Vinicius; Develey, Pedro; Kulaif Ubaid, Flávio; Bonatti Regalado, Luciano; de Andrade Figueiredo, Luiz Fernando

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Biota Neotropica, vol. 17, núm. 4, 2017, pp. 1-18
Instituto Virtual da Biodiversidade
Campinas, Brasil

Available in: http://www.redalyc.org/articulo.oa?id=199154653003

Museum collections indicate bird defaunation in a biodiversity hotspot

Vagner Cavarzere[1*], Luis Fabio Silveira[2], Vinicius Rodrigues Tonetti[3], Pedro Develey[4], Flávio Kulaif Ubaid[5], Luciano Bonatti Regalado[6] & Luiz Fernando de Andrade Figueiredo[7]

[1]Universidade Tecnológica Federal do Paraná, Prolongamento da Rua Cerejeira, 85892-000, Santa Helena, PR, Brazil

[2]Universidade de São Paulo, Museu de Zoologia, Seção de Aves, Avenida Nazaré, 04263-000, São Paulo, SP, Brazil

[3] Universidade Estadual Paulista, Departamento de Ecologia, Campus de Rio Claro, Avenida 24a, 13506-900, Rio Claro, SP, Brazil

[4]BirdLife/SAVE Brasil, São Paulo, SP, Brazil

[5]Universidade Estadual do Maranhão, Departamento de Química e Biologia, Morro do Alecrim, Caxias, MA, Brazil

[6]Instituto Chico Mendes de Conservação da Biodiversidade, Floresta Nacional de Ipanema, Caixa Postal 217, Centro, CEP 18190-000, Araçoiaba da Serra, SP, Brazil

[7]Centro de Estudos Ornitológicos, São Paulo, SP, Brazil

**Corresponding author: Vagner Cavarzere, e-mail: vagnera@utfpr.edu.br*

CAVARZERE, V., SILVEIRA, L. F., TONETTI, V. R., DEVELEY, P., UBAID, F. K., REGALADO, L. B., FIGUEIREDO, L. F. A. **Museum collections indicate bird defaunation in a biodiversity hotspot**. Biota Neotropica. 17(4): e20170404. http://dx.doi.org/10.1590/1676-0611-BN-2017-0404

Abstract: Ipanema National Forest, southeastern Brazil, once contained 340 bird species. Forest cover suffered for centuries from log exploitation and, as a result, most of the remaining forests are now an impoverished subset of the original vegetation. We show how the bird community changed over time by comparing historical and recent records. Currently, 228 species can be recorded, for a compilation of 410 species, of which 359 are documented. Some 89 forest species with historical records failed to be detected in recent surveys. Of the 72 Atlantic Forest or Cerrado endemic species, no more than 29 (40%) are still found. The bird community changed from one which used to be related to coastline rain forests to another, which relates more to drier semideciduous forests of the interior.

Keywords: *Atlantic Forest, Cerrado, hierarchical cluster analysis, multivariate analysis, semideciduous forests.*

Coleções de museus indicam defaunação de aves em um hotspot de biodiversidade

Resumo: A Floresta Nacional de Ipanema, sudeste do Brasil, já abrigou 340 espécies de aves. Sua cobertura florestal sofreu por séculos com a exploração de madeira e, desse modo, a maior parte da vegetação remanescente é uma sub-representação daquela original. Neste artigo é demonstrado como a comunidade de aves foi modificada com o passar do tempo por meio da comparação entre registros históricos e recentes. Atualmente, 228 espécies podem ser registradas, para um total de 410 espécies, das quais 359 possuem documentação. Das espécies registradas historicamente, 89 não foram mais detectadas. Das 72 espécies endêmicas da Mata Atlântica ou do Cerrado, apenas 29 (40%) ainda podem ser encontradas. A comunidade de aves, outrora similar à de florestas ombrófilas costeiras, atualmente é mais relaciona à comunidade de matas semideciduais mais secas do interior.

Palavras-chave: *Análise hierárquica de cluster, Análise multivariada, Cerrado, Floresta Semidecidual, Mata Atlântica.*

Introduction

Defaunation, i.e., the process of losing animal species, has been accelerated in the last five centuries, a fact by which some authors have contended that earth is experiencing a "sixth extinction wave" (Barnosky et al. 2011, Pimm et al. 2014, Ceballos et al. 2015, 2017). Besides extinctions, abundance of vertebrates is sharply declining, leading to functional extinction of several species (Butchart et al. 2010, Ceballos et al. 2017). Among different causes of this phenomenon (e.g. hunting, pollution, impacts from invasive species and climate change), habitat loss is one of the main drivers, especially in tropical regions, where deforestation rates are high (Dirzo et al. 2014, Johnson et al 2017). Among the different vertebrate groups suffering species loss and population decline, birds, which suffer population decline worldwide (especially accentuated in tropical regions, Ceballos et al. 2017), play important roles in ecosystems, such as pollination, pest control and seed dispersal (Whelan et al. 2008). In addition to the loss of important

services, the local extinction and population decline of birds can cause changes in evolutionary processes (Galetti et al. 2013).

Although one can infer bird species loss of a given degraded area by comparing its community to nearby areas, where species composition is assumed original, few studies have documented the disappearance of species over time at a same locality (but see Blake & Loiselle 2015, 2016). Curtis & Robinson (2015) resurveyed sites in Oregon from a 60-year-old historic dataset, comparing bird communities of the same sites between this time interval. In Neotropical regions, due to rare long-term data or earlier surveys, researchers have tried to assess extinction rates by comparing the composition of pre- and post-fragmentation bird assemblages (Willis 1974, 1979, Leck 1979, Bierregaard & Lovejoy 1989). Few authors compared censuses separated by long time intervals. These are from little-surveyed sites at time lags of: 200 years in eastern Amazonia (Moura et al. 2014), 167 years in southwestern Amazonia (Silveira & D'horta, 2002), 130 years in eastern Brazil (Christiansen & Pitter 1997) and 100 years in Singapore (Sodhi et al. 2005). There are also examples of less than a century separating surveys, such as Barro Colorado Island, Panama (85 years, Robinson 1999), San Antonio, Colombia (80 years, Kattan et al. 1994), and the Viçosa region, Brazil (70 years, Ribon et al. 2003).

At Ipanema National Forest (hereafter INF), interior São Paulo state, almost 200 years of continuous and severe deforestation led to conspicuous habitat change. Many naturalists visited this iron foundry, including Johann Baptist von Spix and Karl Friedrich Philip von Martius (Spix & Martius 1824), Friedrich Sellow and Ignaz Franz Werner Maria von Olfers (Stresemann 1948), Baron Georg Heinrich von Langsdorff, Peter Wilhelm Lund and Johannes Reinhardt and Johann Christian Mikan (Mikan 1820, Reinhardt 1870, Pinto 1979, Krabbe 2007). No other naturalist, however, contributed more to the knowledge of this locality than Johann Natterer, whose zoological work has no parallel in the history of scientific expeditions in Brazil (Pinto 1979). Thus, the site's well-documented (as museum specimens collected by naturalists) original avifauna provides a singular opportunity to evaluate how habitat loss has changed this Atlantic Forest bird community over time.

We compiled all bird records from the INF. We searched for both historical (museum specimens acquired during the nineteenth century naturalists' expeditions) and recent records, which included field data we have been gathering since 1986 and publications. We specifically addressed the question whether recent bird species composition in a highly surveyed biodiversity hotspot differed from that of ~200 years ago by comparing species recorded in the 1800s to species recorded in recent surveys. We used similarity indices and cluster analysis comparing species richness at the INF to other well-surveyed rain and semideciduous forests wishing to determine to which of these forests the INF used to be more closely related. We then conducted these same analyses only with the species we recently recorded at the INF to determine whether species richness changed over time. We hypothesized species richness changed considerably from one closely related to rain forests to another, which is more similar to semidecidual forests.

Material and Methods

1. Study area

INF (23°26' S, 47°36' W) is located in the state of São Paulo, southeastern Brazil, within the municipalities of Araçoiaba da Serra, Capela do Alto and Iperó, ca 120 km west of the city of São Paulo (Figure 1). The region is predominantly inserted within the Atlantic Forest domain with some Cerrado enclaves. These two domains are biodiversity hotspots that, despite harboring several endemic and threatened species have suffered from intense habitat loss (Ribeiro et al. 2009, Strassburg et al. 2017). INF is drained by the Sapucaí River to the west and Ipanema River to the east, with elevations ranging from 550-970 m asl. According to Spix & Martius (1824:52), during the 1800s the vegetation cover was "almost everywhere covered with thick woods (…) The forests, which stand more luxuriant and thicker in the hollow than in the higher parts, are uncommonly rich in the most various kinds of wood". Currently, it encompasses ~ 5,000 ha, of which 75% are covered by semideciduous (90% of all forests) and rain forests in several successional stages (~ 2,800 ha), secondary growth and savannas, including ecotones between semideciduous forests and Cerrado *sensu lato* (~ 540 ha), water reservoirs and dams (~ 250 ha) and native reforestations (~ 220 ha, Radambrasil [1983]). The current vegetation is composed of secondary forests due to the extensive exploitation of tree species in the last two centuries to fuel the iron foundry furnaces (Saint-Hilaire 1976). Climate is considered as Cfa in Koeppen's classification, with defined wet (September-February) and dry (March-August) seasons. Annual mean rainfall is 1,400 mm, whereas mean annual temperature is 20.4 °C, with a minimum of 11.6 C° in July and reaching 29.8 C° in February (MMA 2003). The land cover surrounding forests comprise water reservoirs and dams, regrowth, recovery of degraded areas, settlements of rural workers, the administrative headquarters and preserved historical sites, such as ruins of the foundry (MMA 2003).

The vegetation at INF suffered from tree exploitation since the beginning of the iron foundry (Saint-Hilaire 1976). Intensive deforestation began during the nineteenth century, when metal craft was transformed into a metallurgical industry at the cost of large-scale exploitation of mines at the Araçoiaba Mountain between 1811-1833 (Menon 1992). Due to Brazilian governmental orders, as much as 2,764 tons of charcoal fueled auto-ovens during the Brazil-Paraguay war in 1878 (Dupré 1885). Between 1926 and 1943, the Araçoiaba Mountain suffered from apatite extraction; during the 1950s the dominant activity was the production of cement, still produced today. It was only in May 1992, when the area was legally declared a National Forest (which still allows the selective use of natural resources according to Brazilian law), that deforestation stopped within the INF and ~ 350 hectares were destined for fast growing *Eucalyptus* plantations (~ 200 ha) and reforestations with native species (~ 150 ha, MMA 2003).

2. Bird records

2.1. Historical survey

At that time naturalists provided few details on bird collection data. Species collected by Natterer are museum specimens that are predominantly deposited at the Naturhistorisches Museum in Vienna, Austria. Refer to Appendix I.

2.2. Recent survey

We surveyed forest birds using point counts (Bibby et al. 2000) ever three months from May 2001-February 2002 and from August 2009-May 2013. We determined three unlimited-radius 10-min point counts at least 200 m apart on two existing trails (north and south) inside mature forest within the INF, which we visited on four consecutive days following the same sequence of points. Therefore, each campaign consisted of 12 point counts (if inclement weather did not impede us from surveying). Although there are representative portions of the forest block outside the limit of the INF, all point counts lay within this protected area. We also used eight mist nets (12 m x 3 m x 32 mm) inside forests to record secretive species during 3 consecutive days on the 2001 and 2002 campaigns. Nets touched bottom and remained open from 06:00-17:00 h. We checked nets at 1-hr intervals and released captured birds after identification. We performed non-systematic surveys with transect counts (Bibby et al. 2000) on

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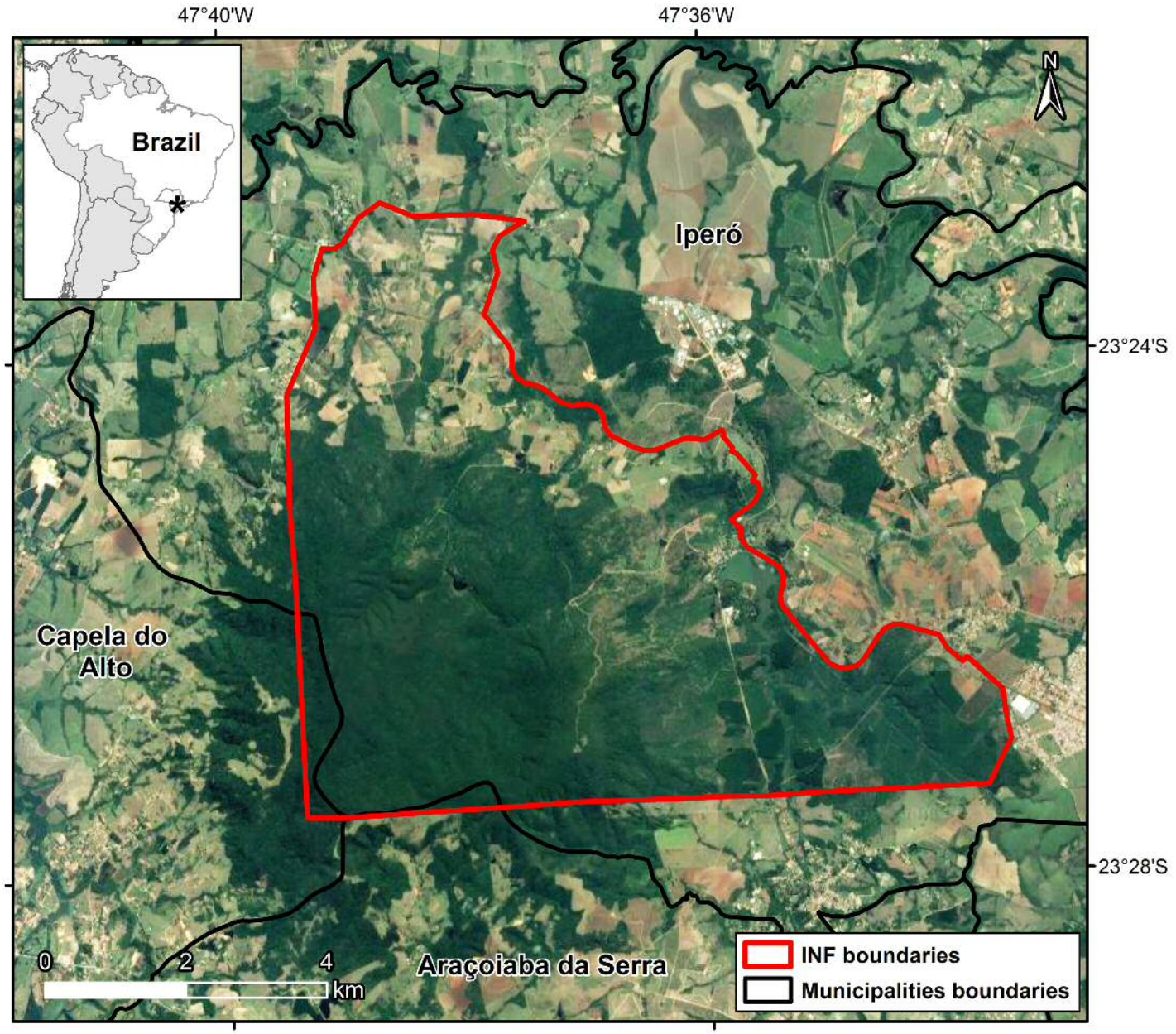

Figure 1. Location of the Ipanema National Forest (limited by a continuous line) within three municipalities in the state of São Paulo, southeastern Brazil.

26 July 2009, 14 November 2010, 21-22 July 2012 and 01 May 2013. To detect border and canopy species or flying-over birds (Robinson 1999) we further considered qualitative records conducted during *ad libitum* observations during the mornings and while moving between point counting. We walked randomly through different types of habitats, such as reed beds, marshes, pastures, *capoeiras* (early successional forests) and forest edges during mornings and afternoons (15:00-19:00 h). We surveyed different successional stages of vegetation, such as early succession, 5- to 10-year-old regrowth and mature secondary forests. We detected birds 15 min before sunrise with the aid of binoculars and/or by vocalizations for both the point count method and random observations, accumulating 624 point counts (104 h), approximately 540 h of random observations and 600 mist-netting hours, more than any recent bird censuses (Table 1).

To complement our results, we searched for birds recorded within the INF in Web of Science (https://www.webofknowledge.com) and Google Scholar (http://scholar.google.com.br) and included a few recent records from colleagues (Appendix II). In addition, we searched for "Floresta Nacional de Ipanema" archived digital vouchers on the internet on Wiki Aves (www.wikiaves.com.br) and on the global avian sound library Xeno-canto (www.xeno-canto.org). We did not consider misidentifications (records of species which do not conform to expected range) of published records. These included the record of counterparts from different biogeographic regions and the absence of the species which would occur in southern Brazil: Rusty-margined Flycatcher *Myiozetetes cayanensis*, Pied Water-Tyrant *Fluvicola pica*, and Cinereous Becard *Pachyramphus rufus* certainly correspond to the Social Flycatcher *M. similis*, Black-backed Water-Tyrant *F. albiventer* and the White-winged Becard *P. polychopterus*, respectively. Both the Blue-back Grosbeak *Cyanoloxia cyanoides* and the Red-breasted Blackbird *Sturnella militaris* were mistaken for their southern counterparts, the Ultramarine Grosbeak *C. brissonii* and the White-browed Blackbird

Table 1. Source of historical bird records and detailed information on recent bird records at Ipanema National Forest, São Paulo, southeastern Brazil. For question marks, refer to Results. An asterisk indicates three misidentified species.

Source	Date	Time spent	Number of species
J. B. Spix and K. P. F. Martius	Jan 1818	–	13?
J. C. Mikan	1816-1817	–	?
F. Sellow and I. F. W. M. Olfers	Dec 1819 - Jan 1820	–	4?
J. Natterer	Feb 1819 - Jul 1820 / Sep 1821 - Sep 1822	–	340
J. H. Langsdorff	1825	–	?
P. W. Lund and J. T. Reinhardt	Mar 1834	–	7
C. Silva and L. B. Regalado	January 1995	–	1
L. B. Regalado	1991–1996	128 h	39
Y. Oniki & E. O. Willis	1986	2 h	45
C. Silva	1993–2003	350 h	186*
Present authors	1986–2015	1,244 h	228

Table 2. Characteristics of seven localities with which the Ipanema National Forest was compared. Boraceia Biological Station (BBS), Barreiro Rico Farm (BRF), Carlos Botelho State Park (CBSP), Caetetus Ecological Station (CES), Intervales State Park (ISP), Lençóis Paulista (LP), Serra do Mar State Park (SMSP). Evidences are museum specimens (S), photographs (P) and sound recordings (R).

	Habitat	Elevation (m)	Area (ha)	Surveys (yr)	Evidence	Species richness
BBS	Ombrophylous forest	800	96	1945-2010	S,P,R	323
BRF	Semidecidous forest	450-586	1451	1957-2002	S,P,R	359
CBSP	Ombrophylous forest	20-1000	37,644	2006-2009	S,P,R	331
CES	Semidecidous forest	500-680	2,180	1976-2006	P,R	293
ISP	Ombrophylous forest	60-1010	38,000	1988-2015	S,P,R	338
LP	Semidecidous forest	570	1,600	1989-2002	P,R	300
SMSP	Ombrophylous forest	0-1200	300,000	1898-2012	S,P,R	417

S. superciliaris. For the most part, museum specimens identified by Pelzeln (1868) collected by nineteenth century naturalists accounted for our "historical records". Taxonomic arrangements follow the Brazilian Committee of Ornithological Records (Piacentini et al. 2015). Atlantic Forest endemic species are according to Parker et al. (1996) and Cerrado endemic species follow Silva & Bates (2002).

3. Analysis

To investigate to which protected forests in São Paulo the INF were most similar regarding its historic bird species richness (presence/absence) we performed a hierarchical cluster analysis using Euclidean distance within the R environment (R Development Core Team 2015). We then ran this analysis with the current species richness of the INF. We chose Ward´s minimum variance criterion as the objective function, defining which clusters merge at each step (Ward-Jr 1963). We also calculated Jaccard Dissimilarity Index (package vegan, function vegdist()), in which case lower values suggest higher similarities. We decided to compare INF with sufficiently well surveyed protected forests at least 250 km away. These included well surveyed (1) semideciduous forest with Cerrado enclaves in Lençóis Paulista (Donatelli et al. 2004), (2) semideciduous forests without Cerrado enclaves in Barreiro Rico Farm (Magalhães 1999) and Caetetus Ecological Station (Cavarzere et al. 2009) and (3) rain forests to the east of the INF – Boraceia Biological Station (Cavarzere et al. 2010), Serra do Mar State Park (Simpson et al. 2012) and to the west of the INF – Intervales State Park, (Vielliard & Silva 2001) and Carlos Botelho State Park (Antunes et al. 2013; Table 2; Figure 2).

Results

1. Recent records

Compared to the 340 bird species INF once harbored, we recorded 228 species of 21 orders and 51 families. The compilation of all records from the INF resulted in a list of 410 species of 23 orders and 68 families, of which 359 are documented in the form of museum vouchers, photographs or recordings. No novel records came from e-vouchers, which contained 25 species on the Wiki Aves, and nine species on the Xeno-canto databases until 24/02/2017. The only species we failed to detect whose recent recording is available at those sites is the Rufous-breasted Leaftosser *Sclerurus scansor* (Ménétriès 1835). Of the 69 Atlantic Forest endemic species, 40 have no recent records; of the three Cerrado endemic species, two have no recent records; five, of all species, are under threat categories. One is threatened at the global level and one is critically endangered in Brazil (Table 3).

We show a cluster analysis of the bird community similarity in Figure 3. There are two distinct groups composed of (1) rain forests (Serra do Mar State Park, Boraceia Biological Station, Intervales and Carlos Botelho State Parks) and (2) semideciduous forests (Barreiro Rico Farm, Caetetus Ecological Station and Lençóis Paulista). When accounting for historical bird records, INF (INF1 in Figure 3) is most similar to the first rain forests cluster. However, when we incorporated only recent bird community composition (INF2 in Figure 3), INF nested within semideciduous forests. Dissimilarity indexes showed the same pattern (Table 4).

Discussion

1. Changes in species richness

Overall, 410 species of birds are reported for the INF, but 89 forest species and another 16 typical Cerrado/wet grassland species may no longer occur there. Of the 202 species recorded both during the nineteenth century and recent surveys, most resident species are widespread in the Atlantic Forest (Del Hoyo et al. 1992-2011). Approximately 60% of the bird community of the INF is still found. Of this, 87 (43%) are forest species. However, another 72 (36%) forest species collected by Natterer seem absent, i.e. we did not detect 45% of forest species over the last 29 years.

Our multivariate analyses suggest modifications resulting from severe forest loss as INF changed its bird species richness from one closely related to rain forests running parallel to the coastline to another, which resembles drier semideciduous forests of the interior. The savannization of moist forests in Colombia has been previously suggested due to deforestation and land practices (Cavelier et al. 1998). This suggestion linked human induced-fire damaging soils dating as far as Pre-Columbian times. The 200 years span shown in this paper may prove to drive similar results in the Atlantic Forest vegetation.

1.1. Vegetation

Part of the remarkable historical species richness is also due to a Cerrado (tropical savanna) enclave, which increased substantially the diversity of the bird community with typical Cerrado species, such as

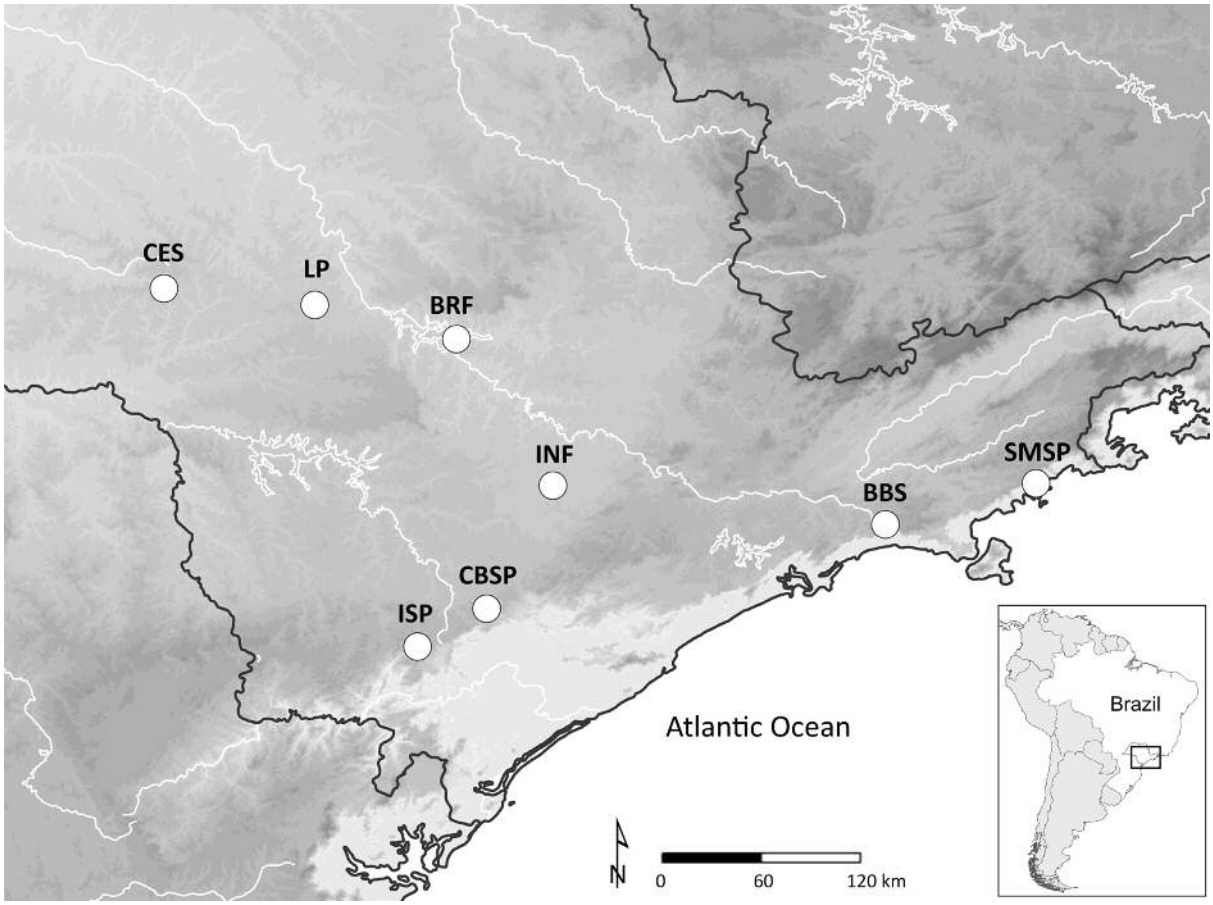

Figure 2. Locations between which we compared bird species richness. BBS – Boraceia Biological Station, CES – Caetetus Ecological Station, BRF – Bacury Farm, INF – Ipanema National Forest, LP – Lençóis Paulista, CBSP – Carlos Botelho State Park, ISP – Intervales State Park, SMSP – Serra do Mar State Park.

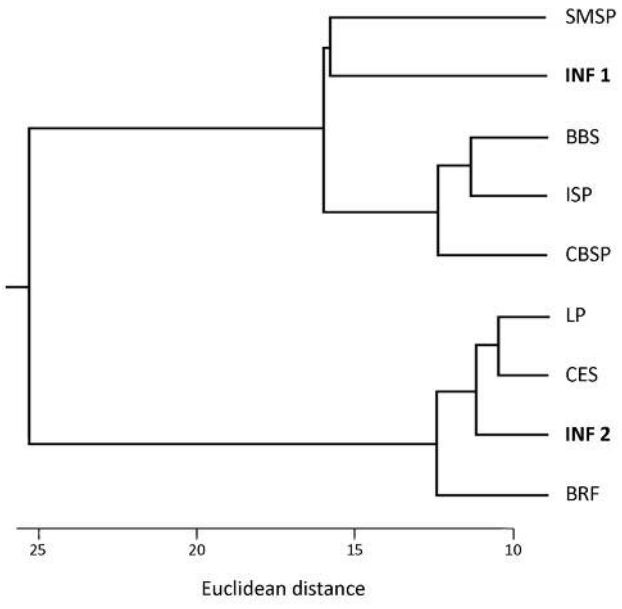

Figure 3. Cluster analysis of bird species richness similarity between eight Atlantic Forest remnants in São Paulo, southeastern Brazil. BBS – Boraceia Biological Station, CES – Caetetus Ecological Station, BRF – Bacury Farm, INF – Ipanema National Forest, LP – Lençóis Paulista, CBSP – Carlos Botelho State Park, ISP – Intervales State Park, SMSP – Serra do Mar State Park. INF 1 refers to historical species richness, whereas INF 2 refers to recent species richness.

Geositta poeciloptera (Wied 1830), *Alectrurus tricolor* (Vieillot 1816), *Cistothorus platensis* (Latham 1790) and *Coryphaspiza melanotis* (Temminck 1822). Although this enclave still exists, these species seem no longer present. Currently, no more than 29 Atlantic Forest and one Cerrado endemic species are detected in this area.

1.2. Fragmentation

The INF, where pristine forests once contained as much as 340 species of birds, currently has ca. 50% of forest birds and several (69) invaders, i.e. species that did not occur at the INF and benefited from several years of deforestation (Table 3). Most species demanding high-quality forests or that are sensitive to human presence seem absent. These include *Tinamus solitarius* (Vieillot 1819), *Aburria jacutinga* (Spix 1825), *Spizaetus ornatus* (Daudin 1800), *Triclaria malachitacea* (Spix 1824), *Trogon* spp., *Ramphastos* spp. and *Pteroglossus aracari* (Linnaeus 1758), Helmeted Woodpecker *Celeus galeatus* (Temminck 1822), Short-tailed Antthrush *Chamaeza campanisona* (Lichtenstein 1823), Antpittas *Grallaria varia* (Boddaert 1783) and *Hylopezus nattereri* (Pinto 1937). Ipanema is the type locality of *Phylloscartes eximius* (Temminck 1822), a species without recent records. It is a sensitive mid-story flycatcher which requires riverine forests and occurs at low densities (Tonetti & Pizo 2016). The species richness decline witnessed in the Psittaciformes and Trogoniformes is quite remarkable. Currently, one species of forest-dwelling parrot *Pionus maximiliani* (Kuhl 1820) is infrequent, and no *Trogon* sp. species remains. Because these species play essential ecological roles

Table 3. List of bird species (indicating those we consider forest dwellers) recorded within the Ipanema National Forest, São Paulo, southeastern Brazil. Sources: 1 (Pelzeln 1868), 2 (Reinhardt 1870), 3 (Hellmayr 1906), 4 (Stresemann 1948), 5 (Krabbe 2007), 6 (Silva & Regalado 1998), 7 (Regalado 1999), 8 (Willis & Oniki 2003), 9 (Silva 2010), 10 (present authors), WA (Wiki Aves), XC (Xeno-canto). Atlantic Forest (AF) and Cerrado (CE) endemic species are according to Parker et al. (1996) and Silva & Bates (2002), respectively. Evidences acquired in this study are aural (A) or visual (V) undocumented records, or photographed (P), audio-recorded (R) or mist-netted (MN). Skins collected during the nineteenth century (sources 1-5) represent museum vouchers. A question mark denotes a probable misidentification or typographic error (see Lopes et al. 2017). Threat status: Critically Endangered (CR), Endangered (EN), Vulnerable (VU). IUCN = globally threatened taxa; BR = taxa threatened in Brazil; SP = taxa threatened is São Paulo. Invader species are indicated as [inv] on the recent records column.

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Tinamiformes						
Tinamidae						
Tinamus solitarius	1		AF			Forest
Crypturellus obsoletus	1					Forest
Crypturellus parvirostris	1	8, 10		A		
Crypturellus tataupa	1	10		A		Forest
Rhynchotus rufescens	1,3					
Nothura maculosa	1	8, 10		P		
Anseriformes						
Anhimidae						
Anhima cornuta	1					
Anatidae						
Dendrocygna viduata		10[inv]		V		
Cairina moschata	1	10		P		
Amazonetta brasiliensis	1	9, 10		V		
Nomonyx dominicus	1					
Galliformes						
Cracidae						
Penelope superciliaris	1	9, 10		P		Forest
Aburria jacutinga	1		AF		EN[BR]	Forest
Odontophoridae						
Odontophorus capueira	1		AF			Forest
Podicipediformes						
Podicipedidae						
Tachybaptus dominicus	1, 3	10		R,P		
Podilymbus podiceps	1	9, 10		V		
Suliformes						
Phalacrocoracidae						
Nannopterum brasilianus	1	9, 10		V		
Anhingidae						
Anhinga anhinga		9, 10[inv]		V		
Pelecaniformes						
Ardeidae						
Tigrisoma lineatum	1	10		V		
Ixobrychus exilis	1	8				
Nycticorax nycticorax	1	9, 10		V		
Butorides striata	1	9, 10		V		
Bubulcus ibis		9, 10[inv]		V		
Ardea cocoi	1	9, 10		V		
Ardea alba	1	9, 10		V		
Syrigma sibilatrix		9, 10[inv]		V		
Pilherodius pileatus	1					
Egretta thula	1	9, 10		V		
Egretta caerulea	1					
Threskiornithidae						
Plegadis chihi	1					
Mesembrinibis cayennensis	1	10		V		
Platalea ajaja	1					
Cathartiformes						
Cathartidae						
Cathartes aura	1	9, 10		P		
Coragyps atratus	1	8,9,10		P		
Sarcoramphus papa		6,9,10[inv]		P	EN[SP]	

Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Accipitriformes						
Accipitridae						
Leptodon cayanensis	1	10		P		Forest
Elanoides forficatus	1					
Elanus leucurus		8,9,10[inv]		P		
Harpagus diodon	1	10		V		Forest
Accipiter poliogaster	1					
Accipiter superciliosus	1					
Ictinia plumbea	1	9, 10		P		
Rostrhamus sociabilis		9, 10[inv]		V		
Heterospizias meridionalis	1	9, 10		V		
Urubitinga urubitinga		10[inv]		V		
Urubitinga coronata		9[inv]		V	EN[IUCN], EN[BR],CR[SP]	
Rupornis magnirostris	1	9, 10		P		
Geranoaetus albicaudatus	1	9, 10		V		
Pseudastur polionotus	1		AF			Forest
Buteo brachyurus		9[inv]		V		
Spizaetus tyrannus	1, 3					Forest
Spizaetus melanoleucus	1					
Spizaetus ornatus	1					Forest
Gruiformes						
Aramidae						
Aramus guarauna		9, 10[inv]		V		
Rallidae						
Aramides cajaneus		9, 10[inv]		V		
Aramides saracura	1	10	AF	P		Forest
Laterallus melanophaius		10[inv]		A		
Mustelirallus albicollis	1	9				
Pardirallus nigricans	1	9, 10		A		
Gallinula galeata	1	8,9,10		P		
Porphyrio martinicus	1	9				
Charadriiformes						
Charadriidae						
Vanellus chilensis	1	8,9,10		A,V		
Pluvialis dominica	1					
Recurvirostridae						
Himantopus melanurus	1					
Scolopacidae						
Gallinago paraguaiae	1					
Gallinago undulata	1					
Numenius borealis	1					
Actitis macularius	1					
Tringa solitaria	1					
Tringa flavipes	1					
Calidris alba	1					
Calidris fuscicollis	1					
Calidris melanotos	1					
Calidris subruficollis	1					
Jacanidae						
Jacana jacana	1	8,9,10		A,V		
Laridae						
Chroicocephalus maculipennis	1					
Sternidae						
Sternula superciliaris	1					
Rynchopidae						
Rynchops niger	1					

Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Columbiformes						
Columbidae						
Columbina talpacoti		8,9,10[inv]		A,V		
Columbina squammata		9, 10[inv]		A,V		
Claravis pretiosa	1					Forest
Claravis geoffroyi	1		AF		CR[BR]	Forest
Columba livia		9[inv]		V		
Patagioenas picazuro		9, 10[inv]		P		
Patagioenas cayennensis	1	9, 10		A,V		Forest
Zenaida auriculata	1	8,9,10		A,V		
Leptotila verreauxi	1	9, 10		MN,P		Forest
Leptotila rufaxilla	1	9, 10		A		Forest
Geotrygon violacea	1					Forest
Geotrygon montana	1	10		A		Forest
Cuculiformes						
Cuculidae						
Piaya cayana	1	9, 10		P		
Coccyzus melacoryphus	1					
Coccyzus euleri		10[inv]		P		
Crotophaga ani	1	8,9,10		P		
Guira guira	1	8,9,10		A,V		
Tapera naevia	1	9, 10		R,P		Forest
Dromococcyx phasianellus	1					Forest
Dromococcyx pavoninus		10[inv]		A		
Strigiformes						
Tytonidae						
Tyto furcata	1	10		V		
Strigidae						
Megascops choliba	1	9, 10		A		Forest
Pulsatrix koeniswaldiana	1	10	AF	A		Forest
Strix hylophila	1		AF			Forest
Strix virgata	1					Forest
Glaucidium brasilianum	1					
Athene cunicularia		8,9,10[inv]		A,V		
Asio clamator	1					
Asio flammeus	1					
Caprimulgiformes						
Nyctibiidae						
Nyctibius aethereus	1				EN[BR]	Forest
Nyctibius griseus	1	9, 10		A		Forest
Caprimulgidae						
Nyctiphrynus ocellatus	1					Forest
Antrostomus rufus		9, 10[inv]		R		
Antrostomus sericocaudatus	1					Forest
Lurocalis semitorquatus	1, 4	10		A,V		Forest
Nyctidromus albicollis	1	9, 10		A,V		
Hydropsalis parvula	1	10		A,V		
Hydropsalis anomala	1					
Hydropsalis maculicaudus	1					
Hydropsalis torquata	1	9, 10		P		
Hydropsalis forcipata	1		AF			
Podager nacunda	1, 4	10		V		
Chordeiles minor	1					

http://dx.doi.org/10.1590/1676-0611-BN-2017-0404

Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Apodiformes						
Apodidae						
Cypseloides fumigatus	1					
Cypseloides senex	1					
Streptoprocne zonaris	1	9, 10		V		
Streptoprocne biscutata	1					
Chaetura meridionalis	1	8,9,10		A,V		
Trochilidae						
Phaethornis squalidus	1		AF			
Phaethornis pretrei		9, 10[inv]		A,V		
Phaethornis eurynome	1	9, 10	AF	A,V		Forest
Campylopterus largipennis	1?					
Eupetomena macroura		9, 10[inv]		P		
Aphantochroa cirrochloris	1					Forest
Florisuga fusca	1	9, 10		A,V		
Colibri serrirostris	1	8, 10		P		
Anthracothorax nigricollis	1	9				
Lophornis magnificus	1					Forest
Lophornis chalybeus	1, 3					Forest
Chlorostilbon lucidus	1	9, 10		P		
Thalurania glaucopis	1	9, 10	AF	MN,P		Forest
Leucochloris albicollis	1	9, 10		P		Forest
Amazilia versicolor	1	10		A,V		Forest
Amazilia lactea		9, 10[inv]		A,V		
Heliodoxa rubricauda	1		AF			Forest
Heliothryx auritus	1					
Heliomaster squamosus	1	10		P		
Calliphlox amethystina	1					
Trogoniformes						
Trogonidae						
Trogon surrucura	1					Forest
Trogon rufus	1					Forest
Coraciiformes						
Alcedinidae						
Megaceryle torquata	1	9, 10		A,V		
Chloroceryle amazona	1	8,9,10		V		
Chloroceryle americana	1	9, 10		V		
Momotidae						
Baryphthengus ruficapillus	1	10		A,V		Forest
Galbuliformes						
Galbulidae						
Jacamaralcyon tridactyla	1, 3		AF			
Bucconidae						
Notharchus swainsoni	1		AF			Forest
Nystalus chacuru	1	9				
Malacoptila striata	1	9, 10		MN,P		Forest
Nonnula rubecula	1					Forest
Piciformes						
Ramphastidae						
Ramphastos toco	1	9, 10		V		
Ramphastos dicolorus	1		AF			Forest
Pteroglossus aracari	1					Forest

Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Picidae						
Picumnus cirratus	1	9, 10		A,V		Forest
Picumnus temminckii	1	9, 10	AF	A,V		Forest
Melanerpes candidus	1	8,9,10		A,V		
Melanerpes flavifrons	1					Forest
Veniliornis spilogaster	1	9, 10		A,V		Forest
Piculus aurulentus	1		AF			Forest
Colaptes melanochloros	1	9, 10		R		
Colaptes campestris	1	8,9,10		A,V		
Celeus galeatus	1		AF		EN[BR]	Forest
Celeus flavescens	1	9, 10		A,V		Forest
Dryocopus lineatus	1	9, 10		P		
Campephilus robustus	1		AF			Forest
Cariamiformes						
Cariamidae						
Cariama cristata		9, 10[inv]		A,V		
Falconiformes						
Falconidae						
Ibycter americanus	1					
Caracara plancus	1	9, 10		P		
Milvago chimachima	1, 3	9, 10		V		
Herpetotheres cachinnans	9	10		A		
Micrastur ruficollis	1					Forest
Micrastur semitorquatus		10[inv]		A		
Falco sparverius	1	9, 10		V		
Falco femoralis	1	9, 10		V		
Psittaciformes						
Psittacidae						
Primolius maracana	1					Forest
Psittacara leucophthalmus	1	10		A,V		
Aratinga auricapillus	1	10		R		
Pyrrhura frontalis	1					Forest
Forpus xanthopterygius	1	9, 10		A,V		
Brotogeris tirica		10[inv]	AF	A,V		
Pionopsitta pileata	1		AF			Forest
Pionus maximiliani	1	9, 10		A,V		Forest
Amazona vinacea	1, 3		AF		VU[BR]	Forest
Amazona aestiva		10[inv]		A,V		
Triclaria malachitacea	1		AF			Forest
Passeriformes						
Thamnophilidae						
Rhopias gularis	1					Forest
Dysithamnus mentalis		9, 10[inv]		A,MN,V		
Herpsilochmus rufimarginatus	1					Forest
Thamnophilus doliatus		10[inv]		P		
Thamnophilus ruficapillus	1	10		R		
Thamnophilus caerulescens	1	7,9,10		A,MN, V		Forest
Hypoedaleus guttatus	1, 3		AF			Forest
Batara cinerea	1					Forest
Mackenziaena leachii	1		AF			Forest
Mackenziaena severa	1	7,9,10	AF	A,MN,V		Forest
Biatas nigropectus	1		AF			Forest
Myrmoderus squamosus	1	10	AF	A		Forest
Pyriglena leucoptera	1	7,9,10	AF	A,MN,V		Forest
Drymophila ferruginea	1		AF			Forest
Drymophila ochropyga	1		AF			Forest
Drymophila malura	1	7,9,10	AF	R		Forest

http://dx.doi.org/10.1590/1676-0611-BN-2017-0404

Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Conopophagidae						
Conopophaga lineata	1	7,9,10		A,MN,V		Forest
Grallariidae						
Grallaria varia	1					Forest
Hylopezus nattereri	1		AF			Forest
Rhinocryptidae						
Eleoscytalopus indigoticus	1	9, 10	AF	A		Forest
Formicariidae						
Chamaeza campanisona	1					Forest
Scleruridae						
Sclerurus scansor	1	WA,XC	AF	R		Forest
Geositta poeciloptera	1		CE		EN[BR]	
Dendrocolaptidae						
Sittasomus griseicapillus	1	7,9,10		A,MN,V		Forest
Xiphorhynchus fuscus	1	7,9,10		A,V		Forest
Campylorhamphus falcularius	1	7,9,10	AF	A,V		Forest
Lepidocolaptes angustirostris		10[inv]		V		
Lepidocolaptes falcinellus	1	10	AF	V		Forest
Dendrocolaptes platyrostris	1	7,9,10		A		Forest
Xiphocolaptes albicollis	1					
Furnariidae						
Xenops minutus	1					Forest
Xenops rutilans	1	7, 10		A,V		Forest
Furnarius rufus		8,9,10[inv]		A,V		
Lochmias nematura	1	7,9,10		A,MN		Forest
Automolus leucophthalmus	1	7,9,10		A,MN		Forest
Anabazenops fuscus	1		AF			Forest
Anabacerthia amaurotis	1		AF			Forest
Anabacerthia lichtensteini	1		AF			Forest
Philydor atricapillus	1	8	AF			Forest
Philydor rufum	1					Forest
Heliobletus contaminatus	1	7, 9	AF			Forest
Syndactyla rufosuperciliata	1	9, 10		A,MN,V		Forest
Phacellodomus ferrugineigula		8, 10[inv]	AF	P		
Certhiaxis cinnamomeus	1	9, 10		A		
Synallaxis ruficapilla	1	7,9,10	AF	A,MN,V		Forest
Synallaxis cinerascens	1		AF			Forest
Synallaxis frontalis		9, 10[inv]		MN,P		
Synallaxis albescens		9[inv]		A		
Synallaxis spixi	1	9, 10		A		
Cranioleuca pallida	1	7,9,10	AF	A		Forest
Pipridae						
Neopelma chrysolophum	1		AF			Forest
Manacus manacus	1					Forest
Ilicura militaris	1					Forest
Chiroxiphia caudata	1	7,9,10	AF	A,MN,V		Forest
Tityridae						
Myiobius atricaudus	1					Forest
Schiffornis virescens	1, 5	10	AF	A		Forest
Laniisoma elegans	1	M. Cohn-Haft and A. Whittaker		R	VU[SP]	Forest
Tityra inquisitor	1	9				Forest
Tityra cayana	1	7, 9				Forest
Pachyramphus viridis	1	10		A		Forest
Pachyramphus castaneus	1					Forest
Pachyramphus polychopterus		9, 10[inv]		A,V		
Pachyramphus validus	1	9, 10		A,V		

Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Cotingidae						
Pyroderus scutatus	1	7			VU[SP]	Forest
Lipaugus lanioides	1		AF			Forest
Procnias nudicollis	1	9	AF		VU[SP]	Forest
Pipritidae						
Piprites chloris	1					Forest
Platyrinchidae						
Platyrinchus mystaceus	1, 5	7,9,10		A,MN,V		Forest
Rhynchocyclidae						
Mionectes rufiventris	1	7,9,10		A,V		Forest
Leptopogon amaurocephalus	1	7,9,10		A,MN,V		Forest
Corythopis delalandi	1	10		A,MN,V		Forest
Phylloscartes eximius	1		AF			Forest
Phylloscartes ventralis	1	10		R		Forest
Tolmomyias sulphurescens	1	7,9,10		A,V		Forest
Todirostrum poliocephalum		9, 10[inv]	AF	A,V		
Todirostrum cinereum		9, 10[inv]		A,V		
Poecilotriccus plumbeiceps	1	7,9,10		A		Forest
Myiornis auricularis	1	10	AF	P		Forest
Hemitriccus diops	1		AF			Forest
Hemitriccus orbitatus	1	10	AF	A		Forest
Hemitriccus nidipendulus	1		AF			Forest
Tyrannidae						
Hirundinea ferruginea	1	8,9,10		P		
Euscarthmus meloryphus	1					
Tyranniscus burmeisteri	1					Forest
Camptostoma obsoletum	1	9, 10		A,V		
Elaenia flavogaster	1	8, 10		A,V		
Elaenia spectabilis		10[inv]		P		
Elaenia parvirostris		10[inv]		P		
Elaenia mesoleuca	1	10		A,V		
Elaenia chiriquensis	1					
Elaenia obscura	1	10		A,V		
Myiopagis caniceps	1					Forest
Myiopagis viridicata	1	9, 10		A,V		Forest
Capsiempis flaveola	1	10		P		Forest
Phaeomyias murina	1					
Phyllomyias virescens	1	10	AF	R		Forest
Phyllomyias fasciatus	1	10		A,V		Forest
Culicivora caudacuta	1					
Serpophaga nigricans	1					
Serpophaga subcristata	1			A,V		
Attila rufus	1	7, 10	AF	A,V		Forest
Legatus leucophaius	1					
Myiarchus swainsoni	1	7,9,10		P		Forest
Myiarchus ferox		9, 10[inv]		P		
Myiarchus tyrannulus	1	10		A,V		
Sirystes sibilator	1	10		A		Forest
Pitangus sulphuratus	1	8,9,10		A,V		
Machetornis rixosa		8,9,10[inv]		A,V		
Myiodynastes maculatus	1	7,9,10		A,MN,V		
Megarynchus pitangua	1, 2	9, 10		A,V		
Myiozetetes similis	1	9, 10		A,V		
Tyrannus melancholicus	1, 5	8,9,10		A,V		
Tyrannus savana	1	8,9,10		P		
Empidonomus varius	1	9, 10		P		
Conopias trivirgatus	1					Forest

 http://dx.doi.org/10.1590/1676-0611-BN-2017-0404

Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Colonia colonus	1, 5	9, 10		A,V		
Myiophobus fasciatus	1	9, 10		A,V		
Pyrocephalus rubinus	1	9				
Fluvicola albiventer		9[inv]		A,V		
Fluvicola nengeta		9, 10[inv]		A,V		
Arundinicola leucocephala		8,9[inv]		V		
Gubernetes yetapa		8,9,10[inv]		V		
Alectrurus tricolor	1				VU[BR]	
Cnemotriccus fuscatus	1					Forest
Lathrotriccus euleri	1	7,9,10		P		Forest
Contopus cinereus	1	10		A,V		
Knipolegus cyanirostris	1	10		V		
Knipolegus lophotes		9, 10[inv]		V		
Satrapa icterophrys	1					
Xolmis cinereus	1	9, 10		V		
Xolmis velatus		8, 10[inv]		V		
Muscipipra vetula	1, 3	10	AF	V		
Vireonidae						
Cyclarhis gujanensis	1	9, 10		A,V		
Hylophilus amaurocephalus		10[inv]		A,V		
Hylophilus poicilotis	1	10	AF	A,V		Forest
Vireo olivaceus	1	7,9,10		A,V		
Corvidae						
Cyanocorax cristatellus	1	10	CE	A,V		
Hirundinidae						
Pygochelidon cyanoleuca	1	8,9,10		A,V		
Alopochelidon fucata	1					
Stelgidopteryx ruficollis	1	8,9,10		A,V		
Progne tapera		9, 10[inv]		V		
Progne chalybea	1	8,9,10		A,V		
Tachycineta albiventer	1					
Tachycineta leucorrhoa	1	9				
Troglodytidae						
Troglodytes musculus	1	9, 10		A,V		
Cistothorus platensis	1					
Donacobiidae						
Donacobius atricapilla		8,9,10[inv]		P		
Turdidae						
Turdus leucomelas	1	9, 10		A,MN,V		
Turdus rufiventris	1	9, 10		A,MN,V		
Turdus amaurochalinus	1	9, 10		A,V		
Turdus subalaris		10[inv]		A		
Turdus albicollis	1	7,9,10		A,MN,V		Forest
Mimidae						
Mimus saturninus	1	8,9,10		A,V		
Motacillidae						
Anthus lutescens		9[inv]		A,V		
Passerellidae						
Zonotrichia capensis	1	8,9,10		A,V		
Ammodramus humeralis	1	8,9,10		A,V		
Arremon semitorquatus	1	7, 10	AF	A,V		Forest
Parulidae						
Setophaga pitiayumi	1	7,9,10		A,V		Forest
Geothlypis aequinoctialis	1, 5	8,9,10		A,V		
Basileuterus culicivorus	1	7,9,10		A,MN,V		Forest
Myiothlypis flaveola		9, 10[inv]		MN,P		
Myiothlypis leucoblephara	1	7,9,10		A,MN,V		Forest
Myiothlypis rivularis	1					

Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Icteridae						
Psarocolius decumanus	1	10		A,V		Forest
Icterus pyrrhopterus		10[inv]		A,V		
Gnorimopsar chopi	1					
Agelasticus cyanopus		8, 10[inv]		P		
Chrysomus ruficapillus		9, 10[inv]		P		
Pseudoleistes guirahuro		9, 10[inv]		A,V		
Molothrus oryzivorus	1					
Molothrus bonariensis	1	9, 10		A,V		
Sturnella superciliaris		8,9[inv]		A,V		
Thraupidae						
Pipraeidea melanonota	1	10		V		Forest
Cissopis leverianus	1					Forest
Schistochlamys ruficapillus	1					
Tangara seledon	1		AF			Forest
Tangara cyanoventris	1		AF			Forest
Tangara sayaca	1	8,9,10		A,V		
Tangara palmarum		9, 10[inv]		A,V		
Tangara ornata	1		AF			
Tangara cayana	1	9, 10		A,V		
Nemosia pileata		10[inv]		A,V		
Conirostrum speciosum		9, 10[inv]		R		
Sicalis flaveola	1	10		A,V		
Haplospiza unicolor	1		AF			Forest
Hemithraupis ruficapilla	1	7, 10	AF	P		Forest
Volatinia jacarina	1	8,9,10		A,V		
Trichothraupis melanops	1	7,9,10		A,MN,V		Forest
Coryphospingus cucullatus	1	9, 10		A,V		
Tachyphonus coronatus	1	7,9,10		MN,P		Forest
Ramphocelus carbo		10[inv]		P		
Tersina viridis	1	10		A,V		
Dacnis nigripes	1		AF			Forest
Dacnis cayana	1	9, 10		A,V		
Coereba flaveola	1	9, 10		A,V		
Sporophila lineola		9, 10[inv]		A,V		
Sporophila caerulescens	1, 5	8,9,10		P		
Sporophila leucoptera		10[inv]		A,V		
Sporophila angolensis	1	10		A,V		
Coryphaspiza melanotis	1		CE		EN[BR]	
Emberizoides herbicola	1	10		A,V		
Saltator similis	1	7,8,9,10		A,V		Forest
Saltator fuliginosus	1	10	AF	A,V		Forest
Thlypopsis sordida		9, 10[inv]		A,MN,V		
Pyrrhocoma ruficeps	1	7,9,10		V		Forest
Cardinalidae						
Piranga flava	1	9				
Habia rubica	1	7,9,10		A,V		Forest
Cyanoloxia glaucocaerulea		10[inv]		P		
Cyanoloxia brissonii	1	9, 10		V		
Fringillidae						
Spinus magellanicus	1	9, 10		V		
Euphonia chlorotica	1	9, 10		A,V		
Euphonia violacea	1					
Euphonia chalybea	1		AF			
Euphonia cyanocephala	1	10		V		Forest
Euphonia pectoralis	1		AF			
Chlorophonia cyanea	1					

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Table 3. Continued...

Taxon	Record		Endemism	Evidence	Threat status	Habitat
	Historic	Recent				
Estrildidae						
Estrilda astrild		9[inv]		A,V		
Passeridae						
Passer domesticus		8,9,10[int]		A,V		

Table 4. Jaccard Dissimilarity Indices comparing bird species richness between eight protected forests in São Paulo, southern Brazil. INF 1 refers to historical species richness, whereas INF 2 refers to recent species richness. Ipanema National Forest (INF), Intervales State Park (ISP), Carlos Botelho State Park (CBSP), Caetetus Ecological Station (CES), Lençóis Paulista (LP), Serra do Mar State Park (SMSP), Boraceia Biological Station (BBS), Barreiro Rico Farm (BRF).

	ISP	CBSP	INF 1	INF 2	CES	LP	SMSP	BBS
CBSP	0.400							
INF 1	0.453	0.587						
INF 2	0.583	0.633	0.559					
CES	0.551	0.615	0.526	0.417				
LP	0.639	0.689	0.578	0.399	0.363			
SMSP	0.397	0.548	0.511	0.603	0.572	0.653		
BBS	0.320	0.416	0.470	0.581	0.571	0.647	0.462	
BRF	0.595	0.626	0.626	0.511	0.458	0.511	0.654	0.622

such as seed dispersal (Galetti et al. 2013), maintenance of the original vegetation structure may be seriously compromised at INF in the long term.

Pre- and post-isolation comparisons of tropical forests show the percentage of extinct species varies according to the time lag between isolation. It varies from 49% in a 4-ha fragment in Singapore over 100 years (Sodhi et al. 2005) to ca 30% after 50-90 years in Colombian forests (Kattan et al. 1994, Renfijo 1999) and Barro Colorado Island, Panama (Robinson 1999). For the Atlantic Forest, Aleixo & Vielliard (1995) noted that 54% of the forest avifauna of an isolated 251 ha southeastern Brazilian remnant was extinct after a 15-year interval. Authors who compared historical and recent data show a slightly better scenario. Christiansen & Pitter (1997) showed that almost 17% of all forest species were extinct from fragments in Lagoa Santa, southeastern Brazil (original data compiled from Krabbe [2007]), after 130 years. Willis & Oniki (2002), Ribon et al. (2003) and Silveira (2009) reported similar percentages (20.4-30%) of forest bird extinctions for Santa Teresa and Santo André, southeastern Brazil, after 50, 70 and 106 years separating deforestation time-lags, respectively.

1.3. Climate change

It is expected that habitat loss will act synergistically with climate change in the next decades, being major threats to biodiversity and human wellbeing (Pecl et al. 2017). Climate change has been suggested to reduce survival rates of Neotropical bird species (Blake & Loiselle 2015) and to reduce species richness and their current ranges both in the Atlantic Forest (Anciães & Peterson 2006) and Cerrado (Marini et al. 2009), as well as in several other regions in the planet (Şekercioğlu et al. 2012). Although the effects of climate change on species richness composition between periods must be considered, due to lack of detailed surveying methods during the 1800s, we cannot account for climatic changes on bird communities.

2. Changes in specific species

2.1. Extinctions

Although local extinction is quite probable, one cannot simply assume it (Scheffers et al. 2011) because three forest species collected by Natterer had no record until the second last survey we conducted at the INF in 2012. This is the case of a single recording of the Shrike-like Cotinga *Laniisoma elegans* (Thunberg 1823), and VC's aural and visual record of the Olivaceous Elaenia *Elaenia mesoleuca* (Deppe 1830). During our last visit, LFAF heard the Squamate Antbird *Myrmoderus squamosus* song, after a 190-year span. Robinson (1999) also reported similar re-encounters, although for a shorter (~25 years) time span.

It is also important to highlight one of the most important records at INF, the Eskimo Curlew *Numenius borealis* (Forster 1772). Once abundant, it has not been recorded with certainty since 1963, and none have been confirmed on wintering grounds since 1939 (BirdLife International 2015). The species exhibited an elliptical migratory route connecting its Arctic breeding grounds in North America to its wintering range in southern South America. Besides the specimen collected by Natterer at the INF, there are other specimens from the states of Mato Grosso and Amazonas, the only indications of its presence in Brazilian grounds (Straube 2008).

2.2. Recent records due to habitat change

It is intriguing that Natterer did not collect *Dysithamnus mentalis* (Temminck 1823) or *Todirostrum poliocephalum* (Wied 1831), both currently abundant at the INF. These forest edge species are quite common in early to medium successional stages of vegetation and are found, though more scantly, even in mature forests of the state as well. We suspect they must have been very rare hundreds of years ago, when pristine forests predominated the surroundings. A similar phenomenon was observed at Serra da Cantareira, where *Herpsilochmus rufimarginatus* (Temminck 1822) used to be rare and is suggested to be one of the most abundant species in a time span of only two decades (Tonetti et al. 2017). Another noteworthy absence during the nineteenth century is *Furnarius rufus* (Gmelin 1788), which probably began invading eastern parts of the country after large deforestation in western Brazil took place during the 1800s (Sick 1997).

In the case of some marsh birds, we assume there were no southern cattail *Typha domingencis* (Pers.) or bulrush *Scirpus californicus* (C. A. Mey) Steud marshes while Natterer stayed at the INF. Several typical marsh species such as *Laterallus melanophaius* (Vieillot 1819), *Phacellodomus ferrugineigula* (Pelzeln 1858), *Arundinicola leucocephala* (Linnaeus 1764), *Agelasticus cyanopus* (Vieillot 1819) and *Chrysomus ruficapillus* (Vieillot 1819) are missing from this period. Natterer probably would have collected these conspicuous species. Some species can help illustrate what kind of aquatic environments were present at the time. We suspect these were riverside

vegetation because of the presence of *Anhima cornuta* (Linnaeus 1766) and *Serpophaga nigricans* (Vieillot 1817), while wet or flooded grasslands must have been visited, as suggested by the several Herons, Ibises and migratory Sandpipers.

3. Museum collections

Within the climax of both digital and molecular century, we take great pleasure in highlighting the importance of traditional museum skin collections. A special issue on museum collections effects on bird diversity and extinction did detail reasons for continued growth of collections (Collar et al. 2003). In addition, natural history collections were evidenced as sources of data that can complement past surveys. They also comprise samples that span the period of accelerated anthropogenic habitat destruction and climate warming, reflecting baseline conditions (Lister 2011). There could not be a comparison to be made without Natterer's committed bird collections and Pelzeln's (1868) publication, rendering our study a rare opportunity to evaluate how bird species richness differed within the same site almost 200 years apart.

Supplementary material

The following online material is available for this article:
Appendix I - Historical survey
Appendix II - Recent literature

Acknowledgments

We wish to thank Holcim Brasil on behalf of L. C. B. Nepomuceno, who invited us to carry out this Fauna Monitoring Program. J. F. Pacheco shared with us crucial information about Langsdorff's voyages to Brazil. P. S. Tomkovich, curator of the Zoological Museum of the Moscow State University, generously detailed Langsdorff's Brazilian bird collections deposited under his care. A. Whittaker identified M. Cohn-Haft's recording of the Shrike-like Cotinga and both kindly agreed in sharing their remarkable record with us. G. Del-Rio, F. C. Straube, A. Zillikens, T. Putker and two anonymous reviewers contributed with important remarks. A. A. Kuniy (JGP Consultoria e Participações Ltda.) made this paper possible. VC thanks IdeaWild and LFS receives a grant from the Brazilian Council of Research (CNPq).

Author Contributions

Vagner Cavarzere: Substantial contribution in the concept and design of the study, contribution to data collection, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

Luís Fábio Silveira: Substantial contribution in the concept and design of the study, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

Vinicius Rodrigues Tonetti: Substantial contribution in the concept and design of the study, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

Pedro Ferreira Develey: Contribution to data analysis and interpretation, contribution to critical revision, adding intellectual content.

Flávio Kulaif Ubaid: Contribution to data collection, contribution to data analysis and interpretation, contribution to manuscript preparation, contribution to critical revision, adding intellectual content.

Luciano Bonatti Regalado: Contribution to data collection.

Luiz Fernando de Andrade Figueiredo: Contribution to data collection.

Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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Received: 10/07/2017
Revised: 13/09/2017
Accepted: 10/10/2017
Published online: 30/10/2017