



ECOSYSTEMS

Endangered bird species of one of the last remnants of lowland Atlantic Forest in Rio de Janeiro state, Brazil: pressures and preservation measures

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Abstract: The lowland Atlantic Forest, at altitudes of below 500 m, is highly fragmented, and is home to many threatened species of birds. The Brazilian state of Rio de Janeiro has a high concentration of threatened birds in the Americas and is an important residual of the dense ombrophilous formations of the Atlantic Forest, which includes the Reserva Biológica União, a high priority area for conservation of Atlantic Forest birds. This study compiled empirical and secondary records of threatened birds in this reserve and discusses potential factors determining their local occurrence. Since 2008, regular observations, including transect surveys and mist-netting, in addition to secondary data, have provided records of 306 bird species, of which 49 appear on red lists at some level (state, national or global), including 34 listed as endangered, of which 13 are listed globally, eight of them dependent on well-conserved lowland rainforest. Future studies should include new areas of the reserve, with the aim of confirming the presence of additional threatened species. The long-term conservation of this fauna will depend not only on the adequate management of the reserve, but also the reestablishment of its connectivity with adjacent forest fragments and upland areas in the state.

Key words: Dense ombrophilous lowland forest, avifauna conservation, protected area, southeastern Brazil.

INTRODUCTION

The Brazilian Atlantic Forest is one of the most threatened biomes on the planet, and has long been considered to be a biodiversity hotspot (Myers et al. 2000, Marchese 2015). Only 28% of the original forest cover of this conservation priority region now remains standing (Rezende et al. 2018), and this biome has the largest number of threatened species and subspecies found anywhere in Brazil, including 75.6% of the country's threatened endemic species. Dense Ombrophilous Lowland Forest is a vegetational physiognomy occurring in coastal plains (up to approx. 50 m elevation), from Amazon, over

Northeast region up to the proximities of São João river Basin in Rio de Janeiro State (IBGE 2012). The lowland forests and submontane forest (from about 50m to 500m elevation) (IBGE 2012) of southeastern Brazil have the largest number of threatened species, which represent almost half of the threatened taxa found in this biome (Marini & Garcia 2005).

The entire Brazilian state of Rio de Janeiro lies within the Atlantic Forest domain. While it is the country's third smallest state, covering only 0.5% of its total area (IBGE 2012), the diversity of bird species in Rio de Janeiro is among the greatest found anywhere in the Americas. In fact,

the 806 species found in this state represent 41% of the total number of bird species known to occur in Brazil (Gagliardi & Serpa 2022, Pacheco et al. 2021). Rio de Janeiro state is also considered to be the territory that has the greatest concentration of threatened passerines in the Americas (Manne et al. 1999). The low-lying forests of Rio de Janeiro state potentially contain the largest number of threatened bird species in this region, primarily in areas at elevations of less than 300 m on the southern and eastern slopes of the Serra dos Órgãos, Macaé de Cima, and Desengano mountain ranges (Jenkins et al. 2011). These areas combine lowland forests, at elevations of up to approximately 50 m above sea level (asl) and submontane forests, at 50–500 m asl (IBGE 2012). The lowland and submontane forests below 300 m asl have been the most impacted by deforestation, and are, proportionately, the areas mostly excluded of legal protection in the state (Costa et al. 2009).

The Reserva Biológica União (REBIO União) is one of the few remaining areas of lowland Atlantic Forest in the state of Rio de Janeiro that is under legal protection. Models of potential distribution indicate that this reserve is one of the areas with the largest number of threatened bird species in the state, according to any one of the three pertinent red lists, that is, the global IUCN list, the national list of the Brazilian Environment Ministry (MMA), and the Rio de Janeiro state list (Harris et al. 2005, Jenkins et al. 2011). Previous studies have highlighted the importance of the REBIO União for the conservation of the regional biota (Whitney & Pacheco 1995, Alves et al. 2000, 2009, Pacheco et al. 2010, Harris et al. 2005, Jenkins et al. 2011), and this area is considered to be an important bird area (IBA) by BirdLife International (Bencke et al. 2006). However, while many ornithological field studies have been conducted in the REBIO União since 1989 (Collar et al. 1992), few empirical

data are available, and most are hidden in publications that focus on more general topics. The principal source of data on the birds found in the reserve is the management plan for this protected area (ICMBIO/MMA 2008), although this document does not contain a complete list of the species reported in the existing publications. The present study reviews the available data on the threatened and near-threatened bird species (based on global, national, and state red lists) found in the REBIO União, including records collected by our team between 2008 and 2018 (primary data) and the secondary data published up to May 2023. The study also aims to approach the pressures on the threatened birds at the study area and to indicate preservation measures. Additionally, it discusses the potential factors that determine the unique features of the bird fauna of this reserve, in comparison with those of other, nearby forest fragments.

MATERIALS AND METHODS

The present study was conducted in the REBIO União, which is located between the municipalities of Casimiro de Abreu, Rio das Ostras, and Macaé, in northern of Rio de Janeiro state, in southeastern Brazil. When the study began, in 2008, the reserve encompassed an area of 3,216 hectares, of which 2,400 ha were covered by native forest (Bencke et al. 2006), while the remaining 816 ha consist of abandoned eucalypt plantations in varying stages of succession and other degraded habitats dominated by grass (ICMBio/MMA 2008). The region's climate is tropical hot and humid, with a rainy summer from November to March, and a dry winter from May to August. Mean annual rainfall is 1,658 mm and the mean annual temperature is 24.3°C (ICMBio/MMA 2008). The native vegetation of the REBIO União consists of a mosaic of dense

lowland rainforest (*Floresta Ombrófila Densa de Terras Baixas*) at altitudes of below 50 m, located primarily on floodplains, valley bottoms, and low-lying hillsides (ICMBio/MMA 2008, IBGE 2012). Beginning in 2012, portions of the abandoned eucalypt plantations were subject to forestry management, with the eucalypt trees

being replaced by native species. On the 5th of June 2017, the total area of the reserve was expanded to 7,756.76 ha, more than twice its original size (Figure 1), through the publication of a federal ordinance published on June 5th 2017 (http://www.planalto.gov.br/ccivil_03/_ato2015-2018/2017/dsn/Dsn14474.htm). This also

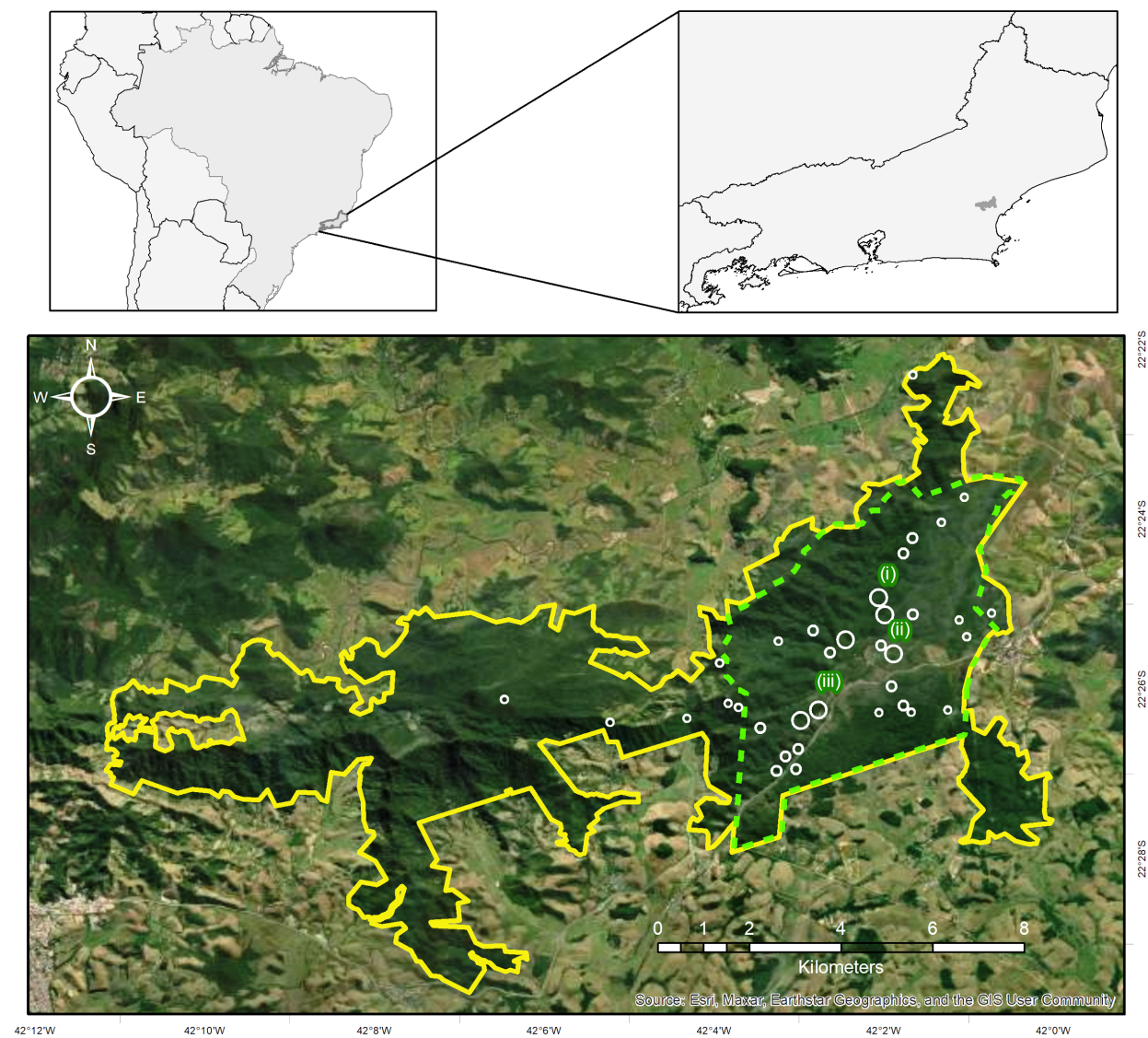


Figure 1. Study areas in the Reserva Biológica União, indicated in Brazil (above left) and in the Rio de Janeiro state (above right). The yellow outline indicates the current limits of the reserve, while the dashed green indicates its previous limits (1998-2017). White circles indicate points of primary data collection, according to the sampling effort: small circles – one to five days of sampling; middle circles - five to ten days of sampling, covering dry and rainy season; large circles - more than 20 days of sampling in different years and seasons, usually including transects and mist nets sampling.

increased the maximum elevation of the reserve from 340 m to 925 m asl, while the proportions of dense sub-montane and montane forest also increased.

All the primary data presented here were collected from three sites located within the original area of the reserve – (i) an area of native forest, including lowland and dense sub-montane forest (22° 24' 45"S, 42° 02' 06"W), (ii) a eucalypt plantation with an understory of native vegetation (22° 25' 28"S, 42° 02' 00"W), and (iii) a eucalypt plantation with negligible native vegetation (22° 26' 07"S, 42° 02' 50"W) (Figure 2). While the present study focuses specifically on threatened species, a full list of birds is given

in Supplementary Material - Table SI. At each of the three sites, an observer walked a fixed 500 m transect each month between December 2008 and April 2010, with a total sampling effort of 56 hours over the 17-month monitoring period. The duration of this period ensured the observation of seasonal migrants. The transects (Develey 2003) were walked during the morning, and all the birds encountered within 50 m of the transect line were recorded and identified. Each transect was also sampled twice in the early evening during the rainy season.

We followed the Brazilian Ornithological Records Committee for bird taxonomy (CBRO, Pacheco et al. 2021). We also considered

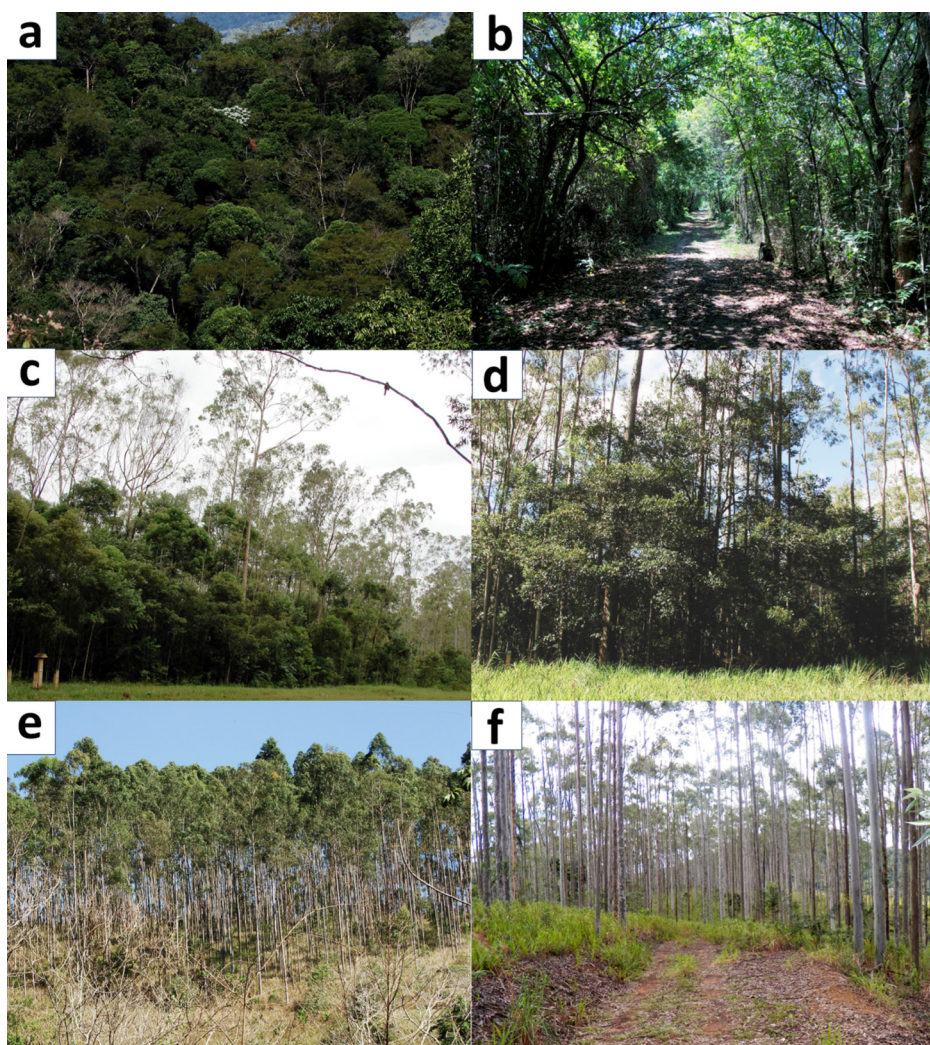


Figure 2. Overview of three habitats of the Reserva Biológica União systematically sampled by transects between December 2008 and April 2010. a-b - native forest, including lowland and dense sub-montane forest; c-d - eucalypt plantation with an understory of native vegetation, and e-f - eucalypt plantation with negligible native vegetation. Photographs: Edvandro A. Ribeiro (a, c, d, e) Andressa C.S.S. Pinto (b), Luiz Freire (f).

Figueiredo et al.'s (2021) species lists for the Atlantic Forest, including endemic species, and their adjustments to the CBRO taxonomy. We adopted Parker et al.'s (1996) classification of indicator species, while the trophic guilds were based on Wilman et al. (2014) and Tobias et al. (2022), adjusted in accordance with our experience in the field.

Birds were also captured by mist-netting at each of the three study sites every two months between January 2009 and April 2012. At each site, 10 nets (AFO Mistnets: 12 m x 2.5 m, with a 32 mm mesh) were set in the understory, with an additional four nets of similar size being suspended in the canopy by a rope and pulley system (see Vecchi & Alves 2015). Each capture session began at sunrise and lasted for seven consecutive hours, with a total of 26,400 net-h/m² per site. Between 2013 and 2016, monthly mist-netting sessions were conducted at alternative native forest sites with the original reserve, for a total sample of 160,000 net-h/m² over 76 sampling days.

In addition to this systematic sampling, the principal trails of the original reserve were walked during the first three hours of the morning and the final three hours of the afternoon (when bird activity is most intense) during both rainy and dry seasons. The vocalizations of the threatened and endangered species encountered during these walks were recorded. Some of the species listed here were recorded only during this non-systematic sampling.

In addition to the primary data collected during the present study, secondary data were extracted from the literature available for the original reserve, including the management plan (ICMBio/MMA 2008), published papers and books, presentations at scientific meetings, and academic monographs. We also considered personal communications and citizen science data available at the Wikiaves (www.wikiaves.com.br)

ornithological platform (WikiAves 2023), of which we critically evaluate each record, disregarding probable errors and confirming information with the respective authors, when necessary.

We categorized all the listed species according to forest dependence based on BirdLife International (2023) and trophic guilds based mostly on Wilman et al. (2014). Additionally, we pointed the Atlantic Forest endemics (Figueiredo et al. 2021). The lowland Atlantic Forest indicator species were based on Parker et al. (1996), migrant and altitudinal migrants were based on Somenzari et al. (2018) and Barçante et al. (2017), respectively.

RESULTS

According to the combined primary and secondary data, 13 threatened bird species listed by the IUCN (2023) are found in the REBIO União, including two Endangered, 11 Vulnerable, and 12 Near Threatened taxa (Table I). When the other red lists (Alves et al. 2000, MMA 2022) are added, the total number of threatened, or near-threatened species found in the REBIO União rises to 49 (34 endangered and 15 near-threatened), although 20 of these species were absent from the management plan (ICMBio/MMA 2008). Based on the Rio de Janeiro state red list (Alves et al. 2000), the REBIO União has a total of 27 threatened species (one Critically Endangered, four Endangered, and 22 Vulnerable) and 12 species that are probably threatened.

These 49 threatened or near threatened bird species represent 16% of the total of 306 species whose occurrence in the REBIO União we confirmed based on our empirical data and the secondary data (Table SI). Overall, 62 (20.3%) of the species in this assemblage are endemic to the Atlantic Forest, and represent 28.4% of the 218 endemic species of the Atlantic Forest,

Table I. List of the globally threatened or near threatened bird species recorded in the Reserva Biológica União, Rio de Janeiro state, Brazil. The nomenclature and taxonomical order followed the Brazilian Ornithological Records Committee (Pacheco et al. 2021). Threat status based on global (IUCN 2023), Brazilian (MMA 2022), and Rio de Janeiro state (Alves et al. 2000) red lists, respectively. Atlantic Forest endemics based on Figueiredo et al. (2021); lowland Atlantic Forest indicator species based on Parker et al. (1996); forest dependence based on BirdLife (2023); Trophic guilds based mostly on Wilman et al. (2014). EN = Endangered; VU = Vulnerable; NT = Near (or Probably) Threatened.

Species	Threat status			Endemic/ Indicator	Forest dependence	Trophic guild
	Global	National	Regional			
<i>Tinamus solitarius</i>	NT		EN	Ind	High	Omnivore
<i>Penelope superciliaris</i>	NT				Medium	Frugivore
<i>Amadonastur lacernulatus</i>	VU	VU	VU	End,Ind	High	Vertivore
<i>Urubitinga coronata</i>	EN	EN	DD		Low	Vertivore
<i>Pseudastur polionotus</i>	NT		NT	End	High	Vertivore
<i>Ramphastos vitellinus</i>	NT			Ind	High	Frugivore
<i>Touit melanonotus</i>	NT	VU	VU	End	High	Frugivore/Granivore
<i>Touit surdus</i>	VU	VU	VU	End,Ind	High	Frugivore/Granivore
<i>Amazona rhodocorytha</i>	VU	VU	VU	End,Ind	High	Frugivore/Granivore
<i>Amazona aestiva</i>	NT				Low	Frugivore/Granivore
<i>Pyrrhura cruentata</i>	VU	VU	EN	End	High	Frugivore/Granivore
<i>Pyrrhura leucotis</i>	VU	VU	VU	End	Medium	Frugivore/Granivore
<i>Primolius maracana</i>	NT				Medium	Frugivore/Granivore
<i>Myrmotherula minor</i>	VU	VU	VU	End,Ind	High	Invertivore
<i>Myrmotherula urosticta</i>	VU	VU	VU	End,Ind	High	Invertivore
<i>Carpornis melanocephala</i>	VU	NT	VU	End,Ind	Medium	Frugivore
<i>Procnias nudicollis</i>	NT		NT	End	High	Frugivore
<i>Laniisoma elegans</i>	NT	EN	NT	End	High	Omnivore
<i>Iodopleura pipra</i>	EN	EN	NT	End,Ind	Medium	Frugivore
<i>Hemitriccus orbitatus</i>	NT			End,Ind	High	Invertivore
<i>Phyllomyias griseocapilla</i>	NT			End	Medium	Invertivore
<i>Dacnis nigripes</i>	NT		NT	End	Medium	Omnivore
<i>Sporophila frontalis</i>	VU	VU	EN	End	Medium	Granivore
<i>Sporophila falcirostris</i>	VU	VU	EN	End	Medium	Granivore
<i>Stilpnia peruviana</i>	VU	NT	NT	End	Medium	Frugivore

as defined by Figueiredo al. (2021), following our adjustments to the CBRO taxonomy (Pacheco et al. 2021) and other corrections (Table S1). Thirty-one of the 306 bird species recorded in the REBIO União are migrants, according to Somenzari et al. (2018), and 39 are altitudinal migrants or probable altitudinal migrants (Table S1).

Seven of the 13 globally threatened species in the REBIO União feed primarily on fruit, and 12 are endemic to the Atlantic Forest. With the exception of *Urubitinga coronata*, all these species are highly or moderately dependent on forest, and seven are indicators of lowland forest (Table I).

Based on the transect and mist-netting data collected between 2008 and 2012, threatened species were more common in the conserved native forest (site i) than the sites (ii and iii) with eucalypt plantations (Table II). Overall, 80 species were systematically recorded in the native forest, 66 in the plantation with understory (ii), and 41 in the plantation with no understory (iii). Of seven globally threatened species recorded, four were exclusive to the native forest, and two were exclusive to the eucalypt plantation with understory.

Eight of the indicator species of lowland Atlantic Forest were found exclusively in the forest (i), three occurred in both native forest and the eucalypt plantation with understory (ii), and only one (*Phaethornis idaliae*) was found in the plantation with no understory (iii). A total of 15 migratory species were recorded, with habitat (ii) having the highest number (14), especially between September and March, and six species each being recorded in the other two habitats (ii and iii). Invertivores birds (33 species) predominated in the native forest, followed by frugivores (16). Invertivores (27 species) also predominated in the eucalypt plantation with understory, followed by omnivores (20). In

the bare plantation (site iii), the predominant guild was the omnivores (16), followed by the invertivores (12).

DISCUSSION

Based on the full data set compiled here (primary and secondary data), approximately 13% of the threatened (Endangered and Vulnerable) bird species (IUCN 2023) found in the Atlantic Forest (n = 102) occur in the REBIO União, as well as 15.3% of the threatened terrestrial birds (n = 85) found in Rio de Janeiro state. The 13 globally threatened species identified in the present study are close to the 19 species recorded by Jenkins et al. (2011) using potential distribution modeling, which reinforces the effectiveness of their approach for the identification of conservation priority areas. The present study identified 27 species in the REBIO União that are on the Rio de Janeiro state red list, which is ten more than the 17 species reported by Alves et al. (2000), who had already highlighted the concentration of threatened species in the reserve.

Despite its relatively small size, the original REBIO União was the largest of the eight fragments identified by Harris et al. (2005) as priority areas for bird conservation in the state of Rio de Janeiro, considering the potential richness of threatened species and the level of threat to remnant habitat. Despite its size and (initial) isolation, Jenkins et al. (2011) concluded that the REBIO União was distinct from other fragments of Atlantic Forest in the state of Rio de Janeiro due to its concentration of threatened species (considering all red lists). This conclusion was further supported by the results of the present study. The general richness (306) and number of globally threatened or near threatened bird species (34) of REBIO União was higher than a considered pristine lowland forest (Saibadela,

(Alves et al. 2000). Of the 13 threatened species (excluding the Near Threatened category) on the IUCN red list that were recorded in the REBIO União, seven (54%) are indicators of tropical lowland evergreen forest, according to Parker et al. (1996), and depend on well-preserved forests for their survival. These seven species are *Amadonastur lacernulatus*, *Touit surdus*, *Amazona rhodocorytha*, *Myrmotherula minor*, *Myrmotherula urosticta*, *Carpornis melanocephala*, and *Idopleura pipra*. In addition, we only observed *A. lacernulatus* and five other species – *Crypturellus variegatus*, *Pyrrhura cruentata*, *Hemitriccus orbitatus*, *Sporophila frontalis*, and *Sporophila falcirostris* – in well-preserved forest, predominantly of the lowland type, a pattern also observed in *Myrmotherula minor* by J.F. Pacheco (*personal communication*). The globally Vulnerable *Amazona rhodocorytha* was encountered frequently in the REBIO União throughout the year, although this species has not been recorded in the Poço das Antas Biological Reserve (Pacheco et al. 2010), a second remnant of lowland forest, 30 km to the west.

In the present study, *A. lacernulatus* was recorded primarily during the rainy months, although it had not been seen in the REBIO União for at least 11 years (ICMBio/MMA 2008), and was considered to be Possibly Extinct from the site, based on this evidence (Bencke et al. 2006). The REBIO União is the only protected area in the state of Rio de Janeiro in which the four local *Myrmotherula* species (*M. minor*, *M. urosticta*, *Myrmotherula axillaris*, and *Myrmotherula unicolor*) are found in sympatry (Whitney & Pacheco 1995). With the exception of *M. axillaris*, these antwrens inhabit lowland forests preferentially, or even exclusively (Whitney & Pacheco 1995, Parker et al. 1996), being *M. minor* and *M. urosticta* listed as Vulnerable globally (IUCN 2023).

The REBIO União is also one of the few known locations at which the state's three *Nyctibius* species – *Nyctibius grandis*, *Nyctibius aethereus*, and *Nyctibius griseus* – are known to occur (G.D. Castiglioni & L.P. Gonzaga, unpublished data). While *N. grandis* is listed as Vulnerable in the state of Rio de Janeiro, *N. aethereus* is considered to be Endangered in Brazil (MMA 2022).

Sporophila frontalis and *S. falcirostris* are nomadic granivores that specialize in the exploitation of bamboo (Bambuseae) seeds (Areta et al. 2009), and these two species were only encountered in the REBIO União during the fruiting period of *Merostachys* spp., in the summer of 2009–2010 (E.A. Ribeiro, unpublished data). The degradation of the native forest in which these bamboo stands are located and the illegal trapping of these birds are the principal threats to these two species (Silva et al. 2018, Marques et al. 2018). In the REBIO União, *S. frontalis* and *S. falcirostris* have been seen feeding on the seeds of two unidentified bamboo species of the genus *Merostachys*, which may potentially be important resources for these birds.

The REBIO União may be an important wintering ground for altitudinal migrants, such as *Laniisoma elegans* (Bencke et al. 2006) and *Procnias nudicollis*, as well as winter migrants such as *Dacnis nigripes*, *Turdus flavipes*, and *Tersina viridis*. *Procnias nudicollis* was recorded in all the winter months sampled during the present study, but never during the summer months. The first arrivals in the winter months are the females and subadults (recorded by one of the authors, E.A. Ribeiro), possibly attracted by the fruiting of *Byrsonimia* trees. The males typically begin singing in mid-June, when a second food source, *Euterpes edulis*, begins to fruit.

Laniisoma elegans was captured in an understory mist net in April 2015, which indicates

that this species does not occur in the study region in periods that do not coincide with its breeding season. This is corroborated by the fact that nine of the 11 records in the REBIO União of this bird in WikiAves were obtained between June and August. This bird was only observed in well-preserved forests in the reserve, at all altitudes.

Dacnis nigripes was seen in the REBIO União at the end of the summer (mid-March), but primarily from April through July. This species was observed in aggregations of males, females, subadults, and juveniles, in a mixed flock together with *Dacnis cayana*, and occasionally with both *Cyanerpes cyaneus* and *D. cayana*. *Dacnis nigripes* was observed consuming the fruit of *Trema micrantha*. Further studies focusing of visitor species would provide important insights into the use of these lowland forest fragments by bird populations with poorly-known dispersal patterns.

Pressures on the threatened bird populations of the REBIO União and preservation measures

The total bird species richness of the REBIO União represents 38% of the total number (806) of species recorded in Rio de Janeiro state (Gagliardi & Serpa 2022), and the assemblage includes 60% (25) of the 42 species classified as indicators of lowland Atlantic Forest. The considerable number of threatened species and taxa sensitive to threats in the REBIO União indicates that the reserve's lowland forest is in good environmental condition (E.A. Ribeiro, unpublished data). However, the reserve faces a number of potential problems, such as the relatively reduced area of native forest (2,400 ha in the original reserve – Bencke et al. 2006), and the fact that it is traversed by the BR 101 federal highway and isolated from other forest remnants by extensive areas of pasture (ICMBio/MMA 2008). This habitat loss and fragmentation

is considered to be the principal threat to the survival of bird species (Pimm et al. 1995). Given this scenario, the long-term preservation of the species found in this protected area can only be guaranteed if the reserve is connected effectively to other nearby fragments of forest (Harris et al. 2005). Fortunately, initiatives toward this connectivity are well advanced, and the expansion of the area of the reserve has contributed to this process (Pimm & Jenkins 2019).

The decline and disappearance of some bird species from the REBIO União had been noted in a number of previous studies (Bencke et al. 2006, ICMBio/MMA 2008). In particular, we did not record *Tinamus solitarius*, *Chlorestes notata*, *Myrmotherula urosticta*, *Myrmotherula minor*, *Carpornis melanocephala*, *Iodopleura pipra* or *Thamnomanes caesius* during the present study. As we did not find any recent secondary records of these species, it seems reasonable to conclude that they have been absent from the REBIO União for at least 30 years. This is likely a consequence of the fragmentation of the reserve prior to its recent expansion and connection to the neighboring fragment in 2017 (Pimm & Jenkins 2019). While we did not record the Critically Endangered *Cotinga maculata* in the REBIO União, this species was recorded in the basin of the São João River, within which the REBIO União is also located, in the 19th century in (Descourtilz 1834 *apud* Pacheco et al. 2010). In this case, the REBIO União would represent one of the last remnants of habitat suitable for this species.

In the case of bird species that depend primarily on relatively large and well conserved forests, local extinction may occur many decades after the isolation of the fragments (Brooks et al. 1999). Despite the quality of its habitats, the REBIO União was, until recently, relatively small and isolated. These effects may

be accentuated in birds with limited dispersal capacity, or in species with cryptic behavior, that avoid exposure in open vegetation, such as *C. variegatus*, *M. urosticta*, and *M. minor*. Even the BR 101 highway may represent a barrier to dispersal for these species. While it was abundant in the lowland forest located to the north of this highway, we did not record *C. variegatus* on the southern margin of the highway, where the largest tract of lowland forest is located. Further observations are needed to confirm whether *C. variegatus* has in fact disappeared from the southern fragment, and whether this was related to the role of the highway as a barrier to dispersal. The impact of hunting pressure on the *C. variegatus* population cannot be ruled out as a contributing factor. Continued monitoring will be necessary to determine whether other species that have not been detected over the past few years will return to the REBIO União following its expansion and connection to the neighboring fragment.

Incentives for the creation of Private Natural Heritage Reserves (*Reservas Particulares do Patrimônio Natural* - RPPNs) on private properties could expedite the creation of ecological corridors in the area. The Chico Mendes Institute for Biodiversity Conservation (*Instituto Chico Mendes de Conservação da Biodiversidade* - ICMBio) removed eucalypts and other exotic species from the area between 2013 and 2016, and seedlings of native species were planted up until 2018 to reconstitute the vegetation of these and other degraded areas of the reserve. One other important conservation measure for the bird populations of the REBIO União would be to reduce the fragmentation of populations caused by the BR 101 federal highway in the reserve's most important tract of forest susceptible to flooding. The potential impact of this highway is likely to be exacerbated by its ongoing duplication. Potential strategies to

ensure the dispersal of terrestrial species, such as *C. variegatus*, between fragments include forested overpasses and under-road tunnels, which have been employed successfully in the Poço das Antas reserve to mediate the impact of the BR-101 highway in this protected area (Aroeira et al. 2021).

It is important to note here that, while the systematic sampling conducted during the present study was well distributed in time, it was restricted spatially to a portion of the original area of the REBIO União, and did not include the area incorporated during the recent expansion process. A systematic inventory covering the whole area of the updated reserve will now be necessary to ensure the long-term conservation of the bird fauna of this protected area. Connectivity with nearby protected areas should also be a priority (Alves et al. 2009). The best option was a fragment located one kilometer to the west of the REBIO União, which is separated from this protected area by cattle pasture (Harris et al. 2005), which has now been connected successfully (Pimm & Jenkins 2019). This reconnection and other possibilities, including higher-altitude fragments close to the area of expansion, will enable the dispersal of species between highland and lowland forests, contribute to the reestablishment of ecological processes, such as historical inter-species interactions or even new interactions with other elements of the local fauna and flora. This will be especially important for altitudinal migrants.

Ongoing efforts to expand forest cover in the protected area and ensure the long-term preservation of species, not only birds, but also other groups of fauna and flora, include the recent expansion of the REBIO União, the substitution of eucalypt plantations with native vegetation, the restoration and regeneration of native vegetation, and the implantation of ecological corridors to connect with neighboring

forest fragments. The latter process will be important to integrate the REBIO União with areas managed by the Golden Lion Tamarin Association. The recent expansion of the REBIO União will also enable the establishments of connections with larger, more well-preserved fragments and reserves, such as the protected areas of the central mountains of the state of Rio de Janeiro. In addition to these efforts, in particular, the restoration of the native vegetation in degraded areas within the reserve, increased patrolling and enforcement within the reserve will also be important to reduce hunting pressure, as well as initiatives to impede the duplication of the stretch of then BR 101 highway that traverses the reserve. If the highway is duplicated, compensatory measures will be necessary to establish corridors of dispersal for terrestrial birds and other fauna.

The findings of the present study reinforce the importance of the REBIO União for the conservation of the birds of the Atlantic Forest. Connectivity with nearby protected areas, in particular through the Central Fluminense Corridor, represent an opportunity for the recolonization of the REBIO União by bird species, as well as the reestablishment of ecological processes that were lost as a consequence of the habitat fragmentation that isolated the reserve. This will permit the conservation of the threatened species birds and other organisms that occur in the study area, and the recuperation of the interactions between species that will guarantee the continuity of the local ecosystems over the long term.

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SUPPLEMENTARY MATERIAL

Table S1.

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