



Bird Extinctions in Brazil's Atlantic Forest and How They Can Be Prevented

Pedro F. Develey^{1*} and Benjamin T. Phalan^{2*}

¹ SAVE Brasil (BirdLife in Brazil), São Paulo, Brazil, ² Centre for Conservation of Atlantic Forest Birds, Instituto Claravis, Parque das Aves, Foz do Iguaçu, Brazil

OPEN ACCESS

Edited by:

Çagan H. Sekercioglu,
The University of Utah, United States

Reviewed by:

Miguel Alfonso Ortega-Huerta,
National Autonomous University
of Mexico, Mexico
Jonah Henri Ratsimbazafy,
Madagascar Primate Study
and Research Group, Madagascar

*Correspondence:

Pedro F. Develey
pedro.develey@savebrasil.org.br
Benjamin T. Phalan
benjamin@parquedasaves.com.br

Specialty section:

This article was submitted to
Conservation and Restoration
Ecology,
a section of the journal
Frontiers in Ecology and Evolution

Received: 31 October 2020

Accepted: 16 April 2021

Published: 13 May 2021

Citation:

Develey PF and Phalan BT (2021)
Bird Extinctions in Brazil's Atlantic
Forest and How They Can Be
Prevented.
Front. Ecol. Evol. 9:624587.
doi: 10.3389/fevo.2021.624587

Bird species extinctions in the Atlantic Forest of Brazil have been predicted since the early 1990s, but it has become accepted wisdom that none have yet been documented. We revisit this question in light of updates to the global Red List, and conclude that between five and seven bird species have likely been driven to extinction in the wild in this biome in recent decades, plus a further two species that occurred elsewhere in Brazil. These extinctions were the result of habitat loss in combination with other threats. A further nine Atlantic Forest bird species are Critically Endangered, plus six from elsewhere in Brazil. We review growing efforts to help these species avoid extinction using a range of tools including multi-stakeholder planning, advocacy, habitat protection and restoration on public and private land, focussed research, and intensive population management, drawing on examples from the most threatened Atlantic Forest endemics. Conservation organisations, local communities, government agencies, zoos, international funders, universities and others are working together to prevent these species from disappearing. While the political environment in Brazil has rarely been more hostile to conservation, there are also some positive trends. Rates of deforestation in the Atlantic Forest have fallen, forest restoration and recovery is increasing, and an unprecedented number of ordinary people are taking an interest in birds and participating in citizen science. With dedication, collaboration, sufficient resources, and a focus on evidence-informed solutions, we are hopeful that many of the Critically Endangered species can be pulled back from the brink of extinction.

Keywords: bird conservation, species extinction, forest restoration, collaborative conservation, intensive population management, Atlantic Forest biodiversity hotspot

INTRODUCTION

We are in the midst of a biodiversity crisis. International biodiversity targets have been missed, species continue to decline, and extinctions, previously concentrated on small islands, are increasingly occurring on continental islands and land-masses (Szabo et al., 2012; CBD, 2020; WWF Living Planet Report, 2020). Although the evidence for this crisis is overwhelming, extinction predictions have been questioned (Rennie, 2002). Brazil is the second country in the world in number of globally threatened birds (166) (BirdLife International, 2021), more than half of which

are found in the Atlantic Forest (Pizo and Tonetti, 2020; Develey, 2021). The endemic birds of Brazil's Atlantic Forest – more than 210 species and growing as taxonomic revision unveils new species (Lima, 2013; Vale et al., 2018) – have long been held up as a test case for predictions of extinctions from habitat loss, including a prediction of > 80 eventual bird extinctions (Brown and Brown, 1992; Brooks and Balmford, 1996; Brooks et al., 2002). These early studies considered that there had been no Atlantic Forest bird extinctions, but that the number of threatened species was consistent with predictions given that species are committed to go extinct after a time lag.

Questions about these predictions remain. They were based on an estimate that 7.5% of the biome retained primary forest (Brooks et al., 2002), but a more recent estimate that 28% of the biome retains native vegetation may be more appropriate (Rezende et al., 2018). However, much of the remaining forest is in small, degraded fragments; 73% is within 250 m of an edge, and < 8% is more than 1 km from an edge (Ribeiro et al., 2009; Banks-Leite et al., 2010). Some endemics tolerate degraded habitats, and there may be a rescue effect of forest recovery and conservation interventions, through which species otherwise committed to extinction can be saved from that fate (Brooks et al., 2002; Lira et al., 2012; Pizo and Tonetti, 2020; Bolam et al., 2021; but see Harris and Pimm, 2004). Nevertheless, some species extinctions in Brazil's Atlantic Forest would be expected.

We use recently updated information from the Global Red List (BirdLife International, 2021), supplemented by the National Red List (ICMBio, 2018) to revisit the assertion that there have been no documented extinctions of birds in the Atlantic Forest (Brown and Brown, 1992; Brooks and Balmford, 1996; many later citations). We examine the conservation situation for globally Extinct, Extinct in the Wild and Critically Endangered birds in Brazil to provide an update on extinctions, possible extinctions, and species on the brink of extinction. We describe conservation actions being implemented for Critically Endangered species, focussing primarily on Atlantic Forest endemics, and end with the question: what will it take to save these species from extinction?

GONE OR MISSING: BIRDS THAT ARE EXTINCT OR WITHOUT RECENT RECORDS

Seven Brazilian birds are now listed as globally Extinct, Extinct in the Wild, or Critically Endangered (Possibly Extinct), of which five were from the Atlantic Forest (Table 1). For a further two species, both Atlantic Forest endemics, there are no documented records (i.e., with photos, sound recordings, or other concrete evidence) from this century, and they too may be extinct (Pacheco and Fonseca, 2001; Butchart et al., 2018; Lees et al., 2021). Of this total of seven to nine lost species, two have been saved through captive breeding programmes (ICMBio, 2018; Francisco et al., 2020). The greatest concentration of these species was in the Pernambuco Centre of Endemism in northeast Brazil (Silveira et al., 2003), with four species (Supplementary Figure 1). Further

species might have been lost before ever being described (Lees and Pimm, 2015).

For all nine species, habitat loss to agriculture was an important threat (BirdLife International, 2021). All species also suffered from additional threats, including hunting/trapping (five species), logging (three species), and increases in fire frequency/intensity (three species). Historical waves of land clearance and degradation in the Atlantic Forest were caused by extraction of wood and charcoal, planting of crops such as coffee, cocoa, sugarcane and vegetables, establishment of eucalyptus plantations, expansion of cattle pasture, and urbanisation. In the northeast, an important cause of deforestation was a programme started in 1975 to promote production of ethanol from sugarcane (De Almeida Medeiros and Froio, 2012). Sugarcane and cattle pasture have since replaced most of the forests of the Pernambuco Centre of Endemism.

Most of the species from Atlantic Forest were tied to specific food sources or microhabitats, which likely increased their vulnerability to extinction: Cryptic Treehunter *Cichlocolaptes mazarbarnetti* was specialised at foraging in bromeliads (Mazar Barnett and Buzzetti, 2014); Alagoas Foliage-gleaner *Philydor novaesi* was a dead-leaf-searching specialist (Mazar Barnett and Buzzetti, 2014); Glaucous Macaw *Anodorhynchus glaucus* likely depended on Yatay Palms *Butia yatay* (Pittman, 1993); and Purple-winged Ground-dove *Claravis geoffroyi* was closely associated with *Guadua* bamboos (Areta et al., 2009).

As well as global extinctions and probable extinctions, there have also been many local extirpations, which are relevant to testing predictions of species-area models at finer scales. These include Red-and-green Macaw *Ara chloropterus*, Chestnut-fronted Macaw *Ara severus*, Red-throated Caracara *Ibycter americanus* and Great-billed Seed-finch *Sporophila maximiliani* from most or all of the Atlantic Forest; Cinereous Antshrike *Thamnomanes caesius* and Spot-backed Antshrike *Hypodaleus guttatus* from Pernambuco and Alagoas; Black-fronted Piping-guan *Aburria jacutinga* from Bahia and Espírito Santo; Banded Cotinga *Cotinga maculata* and Double-toothed Kite *Harpagus bidentatus* from Rio de Janeiro; and Blue-winged Macaw *Primolius maracana* from Rio Grande do Sul (Lima, 2013). While extirpations can be reversed through habitat restoration and reintroductions, local losses such as these have cascading impacts on ecosystem function, and might indicate global extinctions in other, less-well-studied taxa such as plants or invertebrates (Siqueira Filho and Tabarelli, 2006).

ON THE BRINK: OTHER CRITICALLY ENDANGERED BIRDS

Among the 15 remaining Critically Endangered species with recent records, nine are found in the Atlantic Forest and eight are Atlantic Forest endemics (Table 1). The greatest concentration is again in the Pernambuco Centre of Endemism, where three species occur together at Murici in Alagoas (Figure 1). Another three species are found in the south of Bahia, although the ranges of all three do not intersect. Outside the Atlantic Forest, two species occur in the Cerrado, and four are endemic to the

TABLE 1 | Bird species of Brazil listed as globally Extinct (EX), Extinct in the Wild (EW), or Critically Endangered (CR), including birds that are Possibly Extinct (PE) or Possibly Extinct in the Wild (PEW) (BirdLife International, 2021).

	Species	Global Red List	National Red List	Atlantic Forest	
Gone or missing	Cryptic Treehunter <i>Cichlocolaptes mazarbarnetti</i>	EX	EX	Endemic	
	Alagoas Foliage-gleaner <i>Philydor novaesi</i>	EX	EX	Endemic	
	Alagoas Curassow <i>Mitu mitu</i>	EW	EW	Endemic	
	Spix's Macaw <i>Cyanopsitta spixii</i>	EW	CR (PEW)		
	Eskimo Curlew <i>Numenius borealis</i>	CR (PE)	EX		
	Pernambuco Pygmy-owl <i>Glaucidium mooreorum</i>	CR (PE)	EX	Endemic	
	Glaucous Macaw <i>Anodorhynchus glaucus</i>	CR (PE)	EX	Native	
	Purple-winged Ground-dove <i>Paraclaravis geoffroyi</i>	CR	CR (PE)	Endemic	
	Kinglet Calyptura <i>Calyptura cristata</i>	CR	CR (PE)	Endemic	
	On the brink	Marsh Antwren <i>Formicivora paludicola</i>	CR	CR	Endemic
		Alagoas Antwren <i>Myrmotherula snowi</i>	CR	CR	Endemic
		Orange-bellied Antwren <i>Terenura sicki</i>	CR	CR	Endemic
		Stresemann's Bristlefront <i>Merulaxis stresemanni</i>	CR	CR	Endemic
Araripe Manakin <i>Antilophia bokermanni</i>		CR	CR	Endemic	
Banded Cotinga <i>Cotinga maculata</i>		CR	CR	Endemic	
Alagoas Tyrannulet <i>Phylloscartes ceciliae</i>		CR	CR	Endemic	
Cherry-throated Tanager <i>Nemosia rourei</i>		CR	CR	Endemic	
Brazilian Merganser <i>Mergus octosetaceus</i>		CR	CR	Native	
Belem Curassow <i>Crax pinima</i>		CR	CR		
Blue-eyed Ground-dove <i>Columbina cyanopis</i>		CR	CR		
Black-winged Trumpeter <i>Psophia obscura</i>		CR	CR		
Tristan Albatross <i>Diomedea dabbenena</i>		CR	CR		
Rio Branco Antbird <i>Cercomacra carbonaria</i> *		CR	LC		
Hoary-throated Spinetail <i>Synallaxis kollari</i> *		CR	EN		

We divide species into two groups: "gone or missing" and "on the brink" (see text), and then order by Red List category, Atlantic Forest endemism (species indicated as native also occur in other biomes), and taxonomic order. National categories are included (from ICMBio, 2018), but additional species listed nationally in the same categories have not been added. *Discrepancies between the national and global assessments arise because these two species are not country endemics, and global assessments are based on modelled predictions of future habitat loss.

Amazon, with two in the Belém Centre of Endemism and another two in the extreme north of Brazil and adjacent Guyana (the Roraima-Rupununi region).

For the nine Atlantic Forest species, the most important threats are agriculture (nine species), logging and urbanisation (both seven species), fire (five species), and climate change (four species) (BirdLife International, 2021). Some threats are quite specific, such as water abstraction affecting Araripe Manakin *Antilophia bokermanni*, and invasion of wetlands by non-native plants reducing habitat quality for Marsh Antwren *Formicivora paludicola*.

As a result of these threats, remaining populations of some Atlantic Forest species are very small; they are truly on the brink of extinction. Stresemann's Bristlefront *Merulaxis stresemanni* is now known from just one individual, although as-yet-unconfirmed reports from another site offer hope of a second population. Intensive surveys have encountered only eleven individuals of Cherry-throated Tanager *Nemosia rourei*, and the global population is unlikely to be much greater. Just 17 Alagoas Antwrens were found during two years of dedicated fieldwork, and again, the global population cannot be much greater than that number (Vilela, 2020, in litt.). Other species have suffered serious declines. Banded Cotinga has disappeared from even the largest remaining

forest blocks in Espírito Santo, for reasons that are not understood (BirdLife International, 2021). Araripe Manakin declined by 22% between 2013 and 2018 (ICMBio, 2020). Reduced to very low numbers, populations become more vulnerable to additional threats such as disease, genetic problems, and stochastic events (Newton, 1998), but we have virtually no information on these potential threats for the species mentioned here.

CONSERVATION EFFORTS TO PREVENT A WAVE OF EXTINCTIONS

The situation for Brazil's most threatened species is worrying, but there is much being done to help them. Here, we review some of the most important actions being taken, with a focus on the Critically Endangered birds of the Atlantic Forest. Global analyses indicate that conservation interventions have been effective in avoiding at least some extinctions, including several of the species highlighted here (Bolam et al., 2021). In Brazil, conservation interventions have helped at least three bird species to be downlisted from Critically Endangered to Endangered – Red-billed Curassow *Crax blumenbachii*, Lear's Macaw *Anodorhynchus leari* and

On the brink



1. Hoary-throated Spinetail (CR) and Rio Branco Antbird (CR) are threatened by fire, and conversion of riverine forests in northern Brazil into ricefields

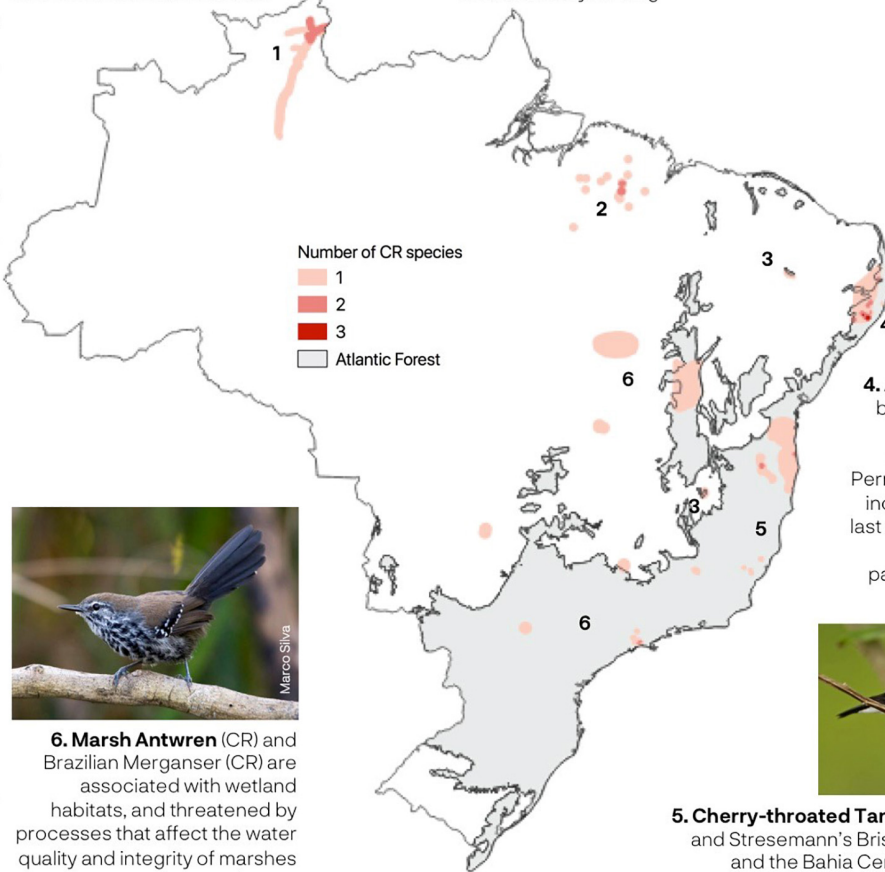


2. Belém Curassow (CR) and Black-winged Trumpeter (CR) are now restricted to a few remaining fragments of forest in the Belém Centre of Endemism, and are threatened by hunting



3. Araripe Manakin (CR) and Blue-eyed Ground-dove (CR) have extremely restricted ranges, the first in a naturally isolated oasis of Atlantic Forest in the Caatinga, and the second in the Cerrado, where both are vulnerable to stochastic events such as fires, as well as habitat loss and degradation

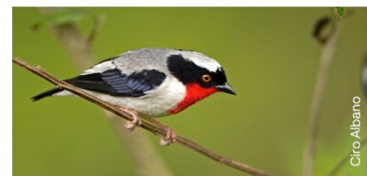
Map data: BirdLife International and Handbook of the Birds of the World (2019); Muylaert et al. (2018); Belém endemics: ICMBio (2018)



6. Marsh Antwren (CR) and Brazilian Merganser (CR) are associated with wetland habitats, and threatened by processes that affect the water quality and integrity of marshes and rivers



4. Alagoas Antwren (CR), Orange-bellied Antwren (CR) and Alagoas Tyrannulet (CR) are confined to remnant forest fragments in the Pernambuco Centre of Endemism – including ESEC Murici, which is the last site with all three species – after most forest was converted to pastures, sugarcane and bananas



5. Cherry-throated Tanager (CR), Banded Cotinga (CR) and Stresemann's Bristlefront (CR) from Espírito Santo and the Bahia Centre of Endemism have declined because of deforestation for coffee and eucalyptus, fragmentation, and uncontrolled fire

FIGURE 1 | Distributions of globally Critically Endangered bird species of Brazil, except for those already included as possibly extinct (see **Table 1**). Map data: Muylaert et al. (2018), BirdLife International, and Handbook of the Birds of the World (2019), Belém endemics: ICMBio (2018).

Grey-breasted Parakeet *Pyrrhura griseipectus* (BirdLife International, 2021). In most cases, multiple interventions are needed, ideally defined through collaborative, multi-stakeholder planning, such as the National Action Plans coordinated by ICMBio.

Policy, Governance, and Advocacy

The current political climate in Brazil is unfavourable for conservation, with a federal administration hostile to environmentalists, non-governmental organisations, and environmental protection. Nevertheless, Brazil has a legacy of

strong environmental laws, and there continue to be possibilities for progress at municipal and state levels. The 2006 Atlantic Forest Law protects all mature Atlantic Forest from clearance except in special circumstances (Calmon et al., 2011). The 2012 Native Vegetation Protection Law requires landowners to protect 20% of their property as native vegetation and conserve vegetation along watercourses and on steep slopes (Metzger et al., 2019). These laws are only as strong as their implementation and enforcement, and while deforestation in the Atlantic Forest has decreased over the last decade (SOS Mata Atlântica/INPE, 2020), continued efforts are needed to end deforestation and forest degradation in some key states.

Engagement with authorities at state and municipal level has generated results. In the municipality of Guararema, for example, lobbying and advice by the NGO SAVE Brasil resulted in the municipal council designating a 2,373 ha Wildlife Refuge in 2019 to protect wetlands that shelter at least 50 Marsh Antwrens (SAVE Brasil, 2019). Other efforts have been less successful: attempts in collaboration with state government to declare a strictly protected area in the last remaining Cherry-throated Tanager site failed because of opposition by some farmers, a stark reminder of the crucial role of understanding and engaging with local stakeholders.

Habitat Protection and Management

Habitat protection is a cornerstone conservation strategy. Even where there are other threats, it is crucial to buy time to understand the ecological requirements of the species and plan other conservation interventions. Some 30% of remaining vegetation cover in the Atlantic Forest is in formal protected areas, of which 9% is strictly protected (IUCN Categories I-IV), including Estação Ecológica de Murici in Alagoas (Bencke et al., 2006; Rezende et al., 2018). Beyond these public protected areas, 231,730 ha of Atlantic Forest are conserved in private protected areas (Confederação Nacional de RPPNs, 2020). In Pernambuco, forests of the Serra do Urubu are protected by two private reserves and support populations of Orange-bellied Antwren *Terenura sicki* and Alagoas Tyrannulet *Phylloscartes ceciliae*.

In the state of Ceará, the entire range of Araripe Manakin is protected by a mosaic of nine public and private protected areas, but the species remains threatened by water abstraction and extreme climatic events. In the southeast, one of the two known groups of Cherry-throated Tanager is protected in a biological reserve; the other group occurs in a block of forest of less than 1,000 ha, part of which is protected in a private reserve. A local NGO is working with other national and international organisations to buy land for more private reserves.

Habitat Recovery and Restoration

In some parts of the Atlantic Forest, forest cover is increasing, as a result of both forest regrowth on abandoned land and active restoration. Between 2011 and 2015, c.700,000 ha of forest regrowth appeared in the 15 Brazilian Atlantic Forest states (Crouzeilles et al., 2019). While this is a positive trend,

it may be many decades before forest-dependent species return to secondary forests, and the process of habitat recovery may come too slowly for the most depleted populations. Given how little forest remains overall, and the vulnerability of remaining fragments to edge effects and degradation, some species could yet be committed to extinction (Uezu and Metzger, 2011). Nevertheless, this time lag between habitat loss and extinction, or extinction debt, provides a window of opportunity for other conservation actions to avert extinctions. In the case of the Marsh Antwren, habitat management and restoration are needed even within protected areas, as wetlands are prone to fluctuating water levels, siltation and consequent invasion of exotic plant species.

Intensive Population Management

While it is preferable to maintain species in their natural habitat where possible, other measures such as control of nest predators, translocations, or establishment of insurance populations for later reintroduction must be considered in extreme cases (Lees and Pimm, 2015). Alagoas Curassow was saved from extinction through captive breeding and detailed genetic study and management; the next challenge, already underway, is to re-establish a wild population (Francisco et al., 2020). Six of the nine Critically Endangered Atlantic Forest birds with known populations are small insectivorous passerines, for which little expertise in captive breeding exists. In the case of Alagoas Antwren, a programme aimed at developing the expertise needed for *ex situ* conservation, working initially with non-threatened model species, began at the end of 2019 through a partnership between the private zoo Parque das Aves and SAVE Brasil. If successful, these efforts open up the possibility of intensive management interventions for Alagoas Antwren and other small insectivores where those are deemed necessary. Such decisions must be made through consultation and dialogue with key stakeholders including government authorities, conservation organisations and researchers. In parallel, work is ongoing in the field on the reproductive biology of Alagoas Antwren in Murici to obtain the necessary data for captive breeding or *in situ* interventions.

Scientific Research

Field research programmes led by university biologists in partnership with NGOs have been developed for Alagoas Antwren, Araripe Manakin, Cherry-throated Tanager and Marsh Antwren. In the case of Alagoas Antwren, we suspect that interactions with other birds are key to their survival, since the species was commonly sighted foraging within mixed flocks (Teixeira and Gonzaga, 1985; Whitney and Pacheco, 1997; Mazar Barnett et al., 2005). Since the species was described in 1997, some of the key nuclear flock-forming birds have been greatly depleted within its range (Cinereous Antshrike *Thamnomanes caesius*, Red-crowned Ant-tanager *Habia rubica*). Large multi-species mixed flocks are no longer observed in the understorey and midstorey (H. Vilela, A. Andrade, pers. comm.). The loss of large mixed flocks may leave Alagoas Antwrens exposed to higher predation risk and/or lower foraging success (Develey and Peres, 2000). The two globally

Extinct species that occurred at the same site (Alagoas Foliage-gleaner and Cryptic Treehunter) also foraged with mixed flocks (Mazar Barnett and Buzzetti, 2014).

Araripe Manakin is perhaps the best-studied Critically Endangered bird from the Atlantic Forest. Fifteen articles published in the last 10 years have detailed its reproduction, diet and habitat use, providing a solid scientific basis for conservation action (ICMBio, 2020). For Cherry-throated Tanager, very little is known yet. Censuses are being conducted, including the use of passive acoustic recorders to estimate population size, but encounter rates are extremely low, making a robust estimate difficult. In the case of Marsh Antwren, research is ongoing on it and its sister species, Paraná Antwren *Formicivora acutirostris*, to understand its genetic structure and habitat needs. Passive acoustic recorders are being used to search for Purple-winged Ground-dove (Lees et al., 2021).

Awareness and Communication

Knowledge, appreciation and respect for species and their habitats can contribute to a culture of environmental conservation. As far as interest in birds is concerned, a positive civil society trend is the exponential growth in numbers of birdwatchers and bird photographers, now estimated at nearly 40,000 Brazilians and still growing (Develey, 2021). This movement contributes to knowledge of Brazilian birdlife through citizen science platforms including WikiAves and eBird. The question that emerges and still does not have a clear answer is the extent to which this interest translates into improved conservation outcomes for birds. Among citizens of ten countries rich in biodiversity, Brazilians scored relatively highly in terms of awareness of the term “biodiversity” and what it means, but very poorly in terms of positive attitudes toward biodiversity conservation and willingness to contribute to biodiversity conservation (SINUS Institute, 2019). This suggests that – while the growth in interest and awareness of birds is encouraging – there is still much to do to help the Brazilian public understand the biodiversity crisis, and to build greater popular support for conservation action.

CONCLUSION

It is no longer accurate to say that no bird extinctions have been documented in the Atlantic Forest. We consider that between five and seven bird species have been driven to extinction in the wild in this biome and others have been extirpated from large parts of it, because of habitat loss in combination with other threats. The number of extinctions is lower than the number of eventual bird extinctions predicted by Brooks et al. (2002), perhaps because more habitat remains than was previously estimated, protected areas and other conservation efforts were implemented as species became rarer, extinction debt takes many decades to be paid, and because some endemic species can occupy regrowing secondary forests. The historical legacy of deforestation and forest degradation means that some species have been depleted to tiny, fragmented populations

and continue to face a high risk of extinction in the near future. Many of the birds discussed in this paper have (or had) highly specific habitat requirements, such as associations with bamboos, bromeliads, palms and small wetlands. For such species, total forest area is a weak indicator of suitable habitat, and they will require targeted interventions to ensure population recovery, including intensive management interventions where appropriate.

What will it take for the most threatened Atlantic Forest birds to be saved from extinction? Certainly, continued and scaled-up investment in advocacy, habitat protection, restoration, intensive population management, targeted research, and public engagement are needed. Cases from Brazil and around the world have shown that in the right circumstances, species can be pulled back from what seems like a hopeless situation. A federal government more supportive of its conservation agencies, and willing to invest resources commensurate with the challenge of preventing extinction, would be an advantage, but much can be done even without this support. It is already too late for Alagoas Foliage-gleaner and Cryptic Tree Hunter, but other cases are more hopeful. With dedication, collaboration, sufficient resources, and a focus on evidence-informed solutions, species can be saved from the brink of extinction.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Both authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

ACKNOWLEDGMENTS

We thank Nigel Collar and Carmel Croukamp for comments on a draft, the photographers (Ciro Albano, Arthur Andrade, Gustavo Gonsioroski, Silvia Linhares, and Marcos Silva) for permitting use of their images, and the many people who are working hard to conserve the biodiversity of the Atlantic Forest. We also thank Mark Balman (BirdLife International) and Eduardo Barbosa (CEMAVE/ICMBio) for providing data on species distributions. Parque das Aves and SAVE Brasil supported the authors during the preparation of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2021.624587/full#supplementary-material>

REFERENCES

- Areta, J. I., Bodrati, A., and Cockle, K. (2009). Specialization on *Guadua* bamboo seeds by three bird species in the Atlantic Forest of Argentina. *Biotropica* 41, 66–73. doi: 10.1111/j.1744-7429.2008.00458.x
- Banks-Leite, C., Ewers, R. M., and Metzger, J.-P. (2010). Edge effects as the principal cause of area effects on birds in fragmented secondary forest. *Oikos* 119, 918–926. doi: 10.1111/j.1600-0706.2009.18061.x
- Bencke, G. A., Maurício, G. N., Develey, P. F., and Goerck, J. M. (2006). *Áreas Importantes para a Conservação das Aves no Brasil, Parte I – Estados do Domínio da Mata Atlântica*. São Paulo: SAVE Brasil.
- BirdLife International (2021). *IUCN Red List for birds*. Cambridge: BirdLife International.
- BirdLife International, and Handbook of the Birds of the World (2019). *Bird species distribution maps of the world. Version 2019.1*. Cambridge: BirdLife International.
- Bolam, F. C., Mair, L., Angelico, M., Brooks, T. M., Burgman, M., Hermes, C., et al. (2021). How many bird and mammal extinctions has recent conservation action prevented? *Conserv. Lett.* 14:e12762. doi: 10.1111/conl.12762
- Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., Rylands, A. B., Konstant, W. R., et al. (2002). Habitat loss and extinction in the hotspots of biodiversity. *Conservat. Biol.* 16, 909–923.
- Brooks, T., and Balmford, A. (1996). Atlantic forest extinctions. *Nature* 380:115. doi: 10.1038/380115a0
- Brown, K. S. Jr., and Brown, G. G. (1992). "Habitat alteration and species loss in Brazilian forests," in *Tropical deforestation and species extinction*, eds T. C. Whitmore and J. Sayer (London, UK: Chapman & Hall), 129–142.
- Butchart, S. H. M., Lowe, S., Martin, R. W., Symes, A., Westrip, J. R. S., and Wheatley, H. (2018). Which bird species have gone extinct? A novel quantitative classification approach. *Biol. Conservat.* 227, 9–18. doi: 10.1016/j.biocon.2018.08.014
- Calmon, M., Brancalion, P. H. S., Paese, A., Aronson, J., Castro, P., da Silva, S. C., et al. (2011). Emerging threats and opportunities for large-scale ecological restoration in the Atlantic forest of Brazil. *Restorat. Ecol.* 19, 154–158. doi: 10.1111/j.1526-100X.2011.00772.x
- CBD (2020). *Global Biodiversity Outlook 5*. Montreal: Secretariat of the Convention on Biological Diversity.
- Confederação Nacional de RPPNs (2020). *Painel de Indicadores da CNRPPNs*. Brazil: RPPN.
- Crouzeilles, R., Santiami, E., Rosa, M., Pugliese, L., Brancalion, P. H. S., Rodrigues, R. R., et al. (2019). There is hope for achieving ambitious Atlantic Forest restoration commitments. *Perspect. Ecol. Conserv.* 17, 80–83. doi: 10.1016/j.pecon.2019.04.003
- De Almeida Medeiros, M., and Froio, L. (2012). Actors, interests and strategies of Brazilian foreign policy on biofuels. *Brazil. Politic. Sci. Rev.* 6, 37–52.
- Develey, P. (2021). Bird conservation in Brazil: challenges and practical solutions for a key megadiverse country. *Perspect. Ecol. Conserv.* 2021:5. doi: 10.1016/j.pecon.2021.02.005
- Develey, P. F., and Peres, C. A. (2000). Resource seasonality and the structure of mixed species bird flocks in a coastal Atlantic forest of southeastern Brazil. *J. Trop. Ecol.* 16, 33–53.
- Francisco, M. R., Costa, M. C., Azeredo, R. M. A., Simpson, J. G. P., Costa Dias, T., Fonseca, A., et al. (2020). Recovered after an extreme bottleneck and saved by ex situ management: Lessons from the Alagoas curassow (*Pauxi mitu* [Linnaeus, 1766]; Aves, Galliformes, Cracidae). *Zoo Biol.* 2020:zoo.21577. doi: 10.1002/zoo.21577
- Harris, G. M., and Pimm, S. L. (2004). Bird species' tolerance of secondary forest habitats and its effects on extinction. *Conserv. Biol.* 18, 1607–1616. doi: 10.1111/j.1523-1739.2004.00336.x-i1
- ICMBio (2018). *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção: Volume III - Aves*, in *Livro Vermelho da Fauna Brasileira Ameaçada de Extinção*. Brasília: ICMBio.
- ICMBio (2020). *Sumário executivo do Plano de Ação Nacional para a conservação do soldadinho-do-araripe - 2º ciclo*. Brasília: Instituto Chico Mendes de Conservação da Biodiversidade.
- Lees, A. C., and Pimm, S. L. (2015). Species, extinct before we know them? *Curr. Biol.* 25, R177–R180. doi: 10.1016/j.cub.2014.12.017
- Lees, A. C., Devenish, C., Areta, N., Phalan, B., and Silveira, L. F. (2021). Is the Purple-winged Ground-dove (*Claravis geoffroyi*) extinct? *Front. Ecol. Evolut.* 2021:624959. doi: 10.3389/fevo.2021.624959
- Lima, L. M. (2013). Aves da Mata Atlântica: riqueza, composição, status, endemismos e conservação. *São Paulo* 2013:91547.
- Lira, P. K., Ewers, R. M., Banks-Leite, C., Pardini, R., and Metzger, J. P. (2012). Evaluating the legacy of landscape history: extinction debt and species credit in bird and small mammal assemblages in the Brazilian Atlantic Forest. *J. Appl. Ecol.* 49, 1325–1333. doi: 10.1111/j.1365-2664.2012.02214.x
- Mazar Barnett, J., and Buzzetti, D. R. C. (2014). A new species of *Cichocolaptes* Reichenbach 1853 (Furnariidae), the 'gritador-do-nordeste', an undescribed trace of the fading bird life of northeastern Brazil. *Rev. Brasil. Ornitol.* 22, 75–94.
- Mazar Barnett, J., Carlos, C. J., and Roda, S. A. (2005). Renewed hope for the threatened avian endemics of northeastern Brazil. *Biodiv. Conserv.* 14, 2265–2274. doi: 10.1007/s10531-004-5290-8
- Metzger, J. P., Bustamante, M. M. C., Ferreira, J., Fernandes, G. W., Librán-Embid, F., Pillar, V. D., et al. (2019). Why Brazil needs its Legal Reserves. *Perspect. Ecol. Conserv.* 2019:002. doi: 10.1016/j.pecon.2019.07.002
- Muylaert, R., de, L., Vancine, M. H., Bernardo, R., Oshima, J. E. F., Sobral-Souza, T., et al. (2018). Uma nota sobre os limites territoriais da Mata Atlântica. *Oecol. Austral.* 22:3. doi: 10.4257/oeco.2018.2203.09
- Newton, I. (1998). *Population Limitation in Birds*. London: Academic Press.
- Pacheco, J. F., and Fonseca, P. (2001). The remarkable rediscovery of the Kinglet *Calyptura calyptura cristata*. *Cotinga* 16, 44–47.
- Pittman, T. (1993). Recent research on the *Anodorhynchus* macaws feeding habits. *AFA Watchbird* 20, 48–50.
- Pizo, M. A., and Tonetti, V. R. (2020). Living in a fragmented world: Birds in the Atlantic Forest. *Condor* 122:duaa023. doi: 10.1093/condor/duaa023
- Rennie, J. (2002). *A Response to Lomborg's Rebuttal*. New York, NY: Scientific American.
- Rezende, C. L., Scarano, F. R., Assad, E. D., Joly, C. A., Metzger, J. P., Strassburg, B. B. N., et al. (2018). From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. *Perspect. Ecol. Conserv.* 16, 208–214. doi: 10.1016/j.pecon.2018.10.002
- Ribeiro, M. C., Metzger, J. P., Martensen, A. C., Ponzoni, F. J., and Hirota, M. M. (2009). The Brazilian Atlantic Forest: How much is left, and how is the remaining forest distributed? *Implicat. Conserv. Biol. Conserv.* 142, 1141–1153. doi: 10.1016/j.biocon.2009.02.021
- SAVE Brasil (2019). *Relatório de Atividades 2019*. Brasil: SAVE Brasil.
- Silveira, L. F., Olmos, F., and Long, A. J. (2003). Birds in Atlantic Forest fragments in north-east Brazil. *Cotinga* 20, 32–46.
- SINUS Institute (2019). *Societal biodiversity awareness in Brazil, China, Colombia, Índia, Indonesia, Kenya, Mexico, Peru, South Africa, and Vietnam*. Heidelberg: Indicator calculation and socio-demographic characteristics.
- Siqueira Filho, J. A., and Tabarelli, M. (2006). Bromeliad species of the Atlantic forest of north-east Brazil: losses of critical populations of endemic species. *Oryx* 40, 218–224.
- SOS Mata Atlântica/INPE (2020). *Atlas dos remanescentes florestais da Mata Atlântica*. São Paulo: Fundação SOS Mata Atlântica e Instituto Nacional de Pesquisas Espaciais.
- Szabo, J. K., Khwaja, N., Garnett, S. T., and Butchart, S. H. M. (2012). Global patterns and drivers of avian extinctions at the species and subspecies level. *PLoS One* 7:e47080. doi: 10.1371/journal.pone.0047080
- Teixeira, D. M., and Gonzaga, L. P. (1985). Uma nova subespécie de *Myrmotherula unicolor* (Menétries, 1835) (Passeriformes, Formicariidae) do nordeste do Brasil. *Boletim do Museu Nacional* 310, 1–15.
- Uezu, A., and Metzger, J. P. (2011). Vanishing bird species in the Atlantic Forest: relative importance of landscape configuration, forest structure and species characteristics. *Biodivers. Conserv.* 20, 3627–3643. doi: 10.1007/s10531-011-0154-5
- Vale, M. M., Tourinho, L., Lorini, M. L., Rajão, H., and Figueiredo, M. S. L. (2018). Endemic birds of the Atlantic Forest: traits, conservation status, and

- patterns of biodiversity. *J. Field Ornithol.* 89, 193–206. doi: 10.1111/jfo.12256
- Vilela, H. (2020). *Seleção de habitat de Myrmotherula snowi Teixeira & Gonzaga, 1985 (Aves, Thamnophilidae), uma espécie criticamente ameaçada de extinção*. João Pessoa: CCEN.
- Whitney, B. M., and Pacheco, J. F. (1997). Behavior, vocalizations, and relationships of some *Myrmotherula* antwrens (Thamnophilidae) in eastern Brazil, with comments on the “Plain-winged” group. *Ornithol. Monogr.* 48, 809–819. doi: 10.2307/40157569
- WWF Living Planet Report (2020). *Bending the curve of biodiversity loss*. Gland: World Wildlife Fund.
- Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
- Copyright © 2021 Develey and Phalan. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.