ZOOLOGIA 42: e24019
ISSN 1984-4689 (online)
scielo.br/zool

RESEARCH ARTICLE

Temporal variation in the detection of endangered birds in the Northern Atlantic Forest

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https://zoobank.org/F01CC6F7-EEBD-42DC-8440-C28D33C26E56

ABSTRACT. The detectability of birds may shift seasonally in response to changes in environmental conditions and social interactions. Seasonal variation in bird behavior may influence the findings of avifaunal inventories, by making it difficult to detect some species, especially the rarest ones. We investigated how variation in rainfall patterns affects the detection of bird species in a fragment of tropical forest in the most threatened region of the Brazilian Atlantic Forest, in its northern extreme. The data were collected between January and September 2018, and October to December 2019, during which, two observers walked transects within a forest fragment. Considering the complete set of species studied, detection correlated negatively with rainfall, with a decrease in detection of bird species two months before the onset of the rainy season, between February and June. We identified distinct patterns of variation in bird detection. While 10 bird taxa were detected throughout the year, others were detected more frequently during the dry season, or at the onset of the rainy season. A positive correlation was found between rainfall and the detection of *Momotus momota marcgravianus* Pinto & Camargo, 1961, *Xiphorhynchus atlanticus* (Cory, 1916), and *Xenops minutus alagoanus* Pinto, 1954. Negative correlations, with reduced detection, were found in relation to the onset of the rainy season in the detection of *Hemitriccus griseipectus naumburgae* (Zimmer, 1945) and *Chiroxiphia pareola* (Linnaeus, 1766). The combined detection of these species was more frequent between the peak of the dry season and the onset of the rainy season. We recommend scheduling future surveys in the study region during this period to maximise the likelihood of detecting the greatest number of species.

KEYWORDS. Behavior, cross-correlation, detection, Pernambuco Center of Endemism, rainfall, tropical forest.

INTRODUCTION

Variation in bird detection can affect the reliability of bird surveys, and influence the definition of priority areas for conservation, the identification of rare species, the assessment of extinction risk, and other conservation strategies (Parker III 1991, Antunes 2008, Anderson et al. 2015). This variation in detection is associated with seasonal shifts in the vocal activity of birds, and may affect the probability of recording, in particular, rare species (Anderson et al. 2015). Birds may often adjust their vocal activity to seasonal changes in environmental conditions and associated shifts in patterns of social interaction. Seasonal fluctuations in bird vocal activity are related to reproduction (mating calls) (Amrhein et al. 2002), territorial defense, and environmental conditions, including habitat type, food availability, the abundance of predators, the photoperiod, temperature, and rainfall levels (Gahr 2014).

At low latitudes, there is relatively little seasonal variation in temperature and day length (Ricklefs 1993, Dawson et al. 2001, Moore et al. 2005), although in most tropical regions, there is marked seasonal variation in rainfall (Peres 1994). This variation in rainfall in the tropics is considered to be the key factor determining primary productivity (Ricklefs 1993, Ahumada 2001), plant phenology and fruit production (Van Schaik et al. 1993), insect abundance and activity (Vasconcellos et al. 2010, Osborne 2012), and bird reproductive phenology (Wolda 1980, Blake and Loiselle 1991, Poulin et al. 1992, Araujo et al. 2017). The rainfall-driven variation in these parameters can influence the vocal behavior of birds, which can also impact their detection. For example, Vokurková et al. (2018) recorded higher bird detection rates between the end of the dry season and the onset of the rainy season in humid tropical forests in Cameroon, west Africa.

In tropical regions, few studies have attempted to identify the main patterns of seasonal variation in bird detection (Karr 1976, Chiver et al. 2015, Brawn et al. 2017, Vokurková et al. 2018, Pérez-Granados and Schuchmann 2021). In addition to the importance of understanding these patterns in the case of rare and endangered species, this knowledge can be used to determine the optimal period for scheduling bird counts (Best 1981). Censuses of endangered species are crucial for diagnosis of the real risk of extinction, as well as for identifying priority areas for conservation and defining effective population management actions (Kamino et al. 2012, Tonetti and Pizo 2016, ICMBIO 2018).

With more than 1971 bird species, Brazil has one of the richest avifaunas on the planet (Pacheco et al. 2021), of which 13% (n = 257) are threatened with extinction (MMA 2022). The northern extreme of the Brazilian Atlantic Forest, which is located in northeastern Brazil, is the most fragmented portion of this biome, and is also home to the largest number of endangered bird species in the entire Atlantic Forest (Araujo et al. 2023). Extensive deforestation in this region, primarily for sugar cane plantations, has left only 12% of the original forest cover (Ribeiro et al. 2009). Two birds, Alagoas Foliage-gleaner, *Philydor novaesi* Teixeira & Gonzaga, 1983, and Cryptic Treehunter, *Cichlocolaptes mazarbarnetti* Buzzetti, 2014, from the Northern Atlantic Forest (NAF) have been added to the global list of extinct species, and others, such as Alagoas Antwren, *Myrmotherula snowi* Teixeira & Gonzaga, 1985, are critically endangered (Araujo et al. 2023). The most recent Brazilian list of threatened species (ICMBio 2023) has added Pernambuco Pygmy-Owl, *Glaucidium mooreorum* Silva, Coelho & Gonzaga, 2003, to the list of extinct species. In this context, understanding how environmental factors may influence the detection of threatened species will be crucial for the effective monitoring of birds in the study region.

In the present study, we investigated (i) how fluctuations in rainfall influence the detection of birds, including endangered species, in a fragmented tropical forest in the Northern Atlantic Forest, (ii) whether bird detection peaks during the transition period between the dry and rainy seasons, and (iii) whether species detection is heterogeneous, given that different species respond differently to local seasonal variation.

MATERIAL AND METHODS

Study area

We conducted the present study in the Guaribas Biological Reserve (REBIO Guaribas) (6°43'26"S; 35°10"44"W, Fig. 1), a fully-protected federal conservation unit. The reserve is located in the municipalities of Mamanguape and Rio Tinto, on the northern coast of the Brazilian state of Paraíba. The REBIO Guaribas covers a total area of 4,028.55 ha, divided into three sectors – SEMA I, with 673.64 ha, SEMA II (3,016.09 ha), and SEMA III (338.82 ha), in accordance with federal decree number 98,884, of January 25th, 1990 (Ibama 2003). Most of the vegetation in this protected area is lowland seasonal semi-deciduous forest (RADAMBRASIL 1981). The local landscape can be divided into forest, tableland forest, and open areas, and the REBIO Guaribas is surrounded by sugarcane plantations, highways, settlements, indigenous lands, and urban areas (Ibama 2003, Pereira and Barbosa 2004).

The local climate is tropical and humid, with dry summers and rainy winters (Ibama 2003, Köppen 1936). The mean temperature in the protected area is 24–26 °C, with an absolute annual maximum of 36 °C. Annual rainfall varies between 1,750 and 2,000 mm, with the rains beginning in February and lasting until July, with dry months between August and January (Ibama 2003). The study area is located on fluvial and marine plains, and also tablelands, with elevations between 60 m and 204 m above sea level, with the highest altitudes in the SEMA II sector (Ibama 2003, Melo and Vieira 2017).

We collected the data in SEMA II (Fig. 1), within a semi-deciduous seasonal forest, with a canopy of 15–20 m in height, medium to large trees, with some emergents that may reach up to 30 m (Ibama 2003). The forest canopy is dominated by trees such as *Ocotea canaliculata* (Rich.) Mez (Lauraceae), *Paubrasilia echinata* (Lam.) Gagnon, H.C. Lima & G.P. Lewis (Fabaceae), *Protium heptaphyllum* (Aubl.)

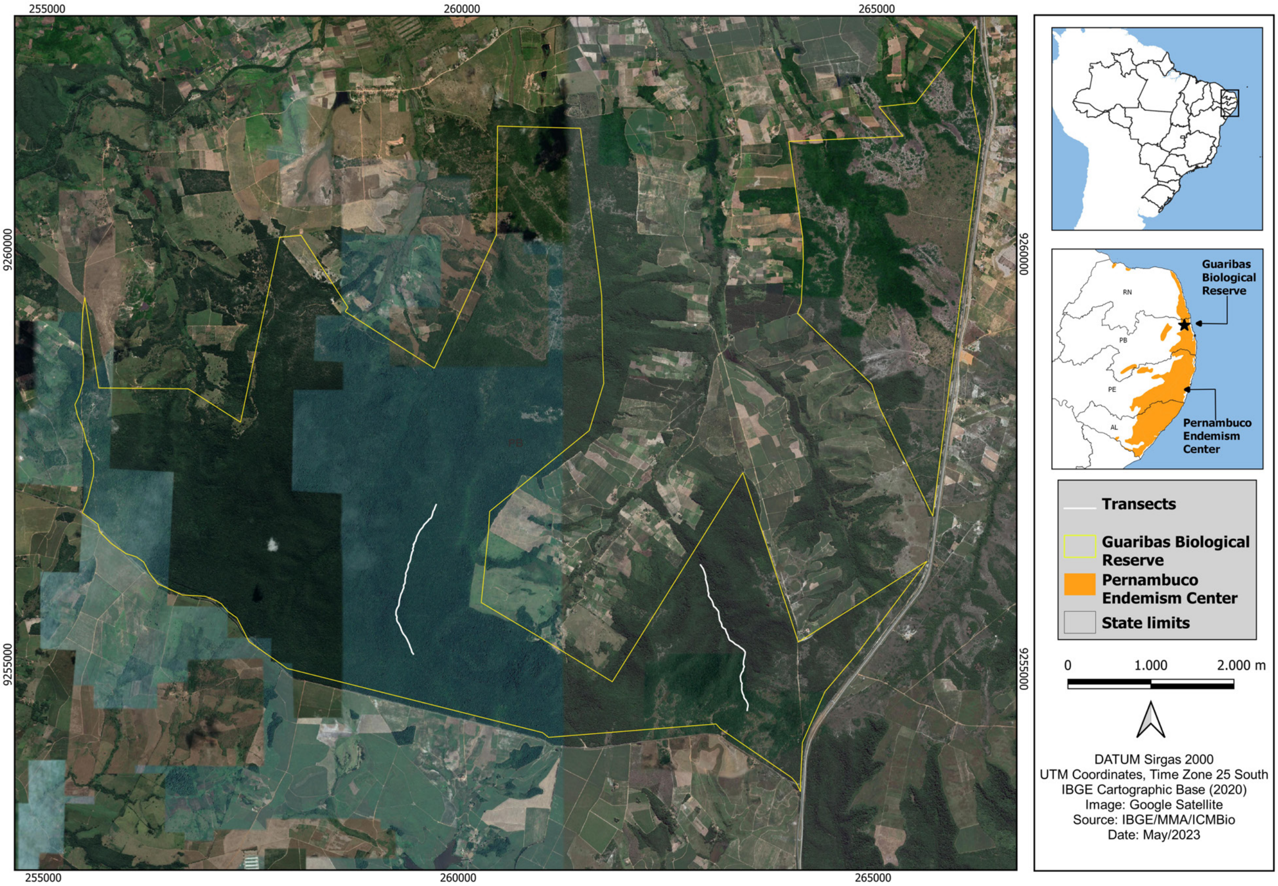

Figure 1. Transects surveyed in the present study at REBIO Guaribas, Paraíba, Brazil, between January and September 2018, and October to December 2019.

Marchand (Burseraceae), and *Inga blanchetiana* Benth. (Fabaceae) (Ibama 2003). There is also a number of other tropical hardwood species, including *Manilkara salzmannii* (A.DC.) H.J.Lam (Sapotaceae), *Tabebuia* spp. (Bignoniaceae), *Apuleia leiocarpa* (Volgel) J.F. Macbride (Fabaceae), *Bowdichia virgilioides* Kunth (Fabaceae), *Brosimum guianense* (Aubl.) Huber (Moraceae), *Cariniana legalis* (Mart.) Kuntze (Lecythidaceae), and *Eschweilera ovata* (Cambess.) Mart. ex Miers (Lecythidaceae).

Rainfall

We obtained daily rainfall data for the study between January and September 2018 directly from the administration of the REBIO Guaribas. Rainfall is measured on site, every day, using an analog rain gauge (accuracy of 2.5 mm), which is installed at the headquarters of the reserve. For the period between October and December 2019, we obtained daily rainfall data for the municipality of Mamanguape (municipality in the study area) from the online historical database provided by PROCLIMA/CPTEC (http://proclima.cptec.inpe.br). Based on these data, we calculated the monthly rainfall for the study period.

Bird detectability

We assessed the detectability of the local birds through monthly surveys representing each of the 12 months of the year (between January and September 2018, and in October and December 2019). We collected data using a perpendicular distance sampling approach (Buckland et al. 1993, Cullen and Rudran 2004), based on two 2 km transects within the forest (Fig. 1). We walked the transects once a month at a constant speed (1–1.5 km/h) during the period of peak bird activity between 5:30 am and 9:00 am. Each survey was conducted by two trained observers, with a minimum interval of 10 days between monthly visits. The birds were detected either visually, using binoculars, or from their vocalizations (we consider songs and calls). Each detection, whether by vocalization or visual contact of an individual, was considered as a contact. Finally, we added all contacts, recorded in the two transects, for each taxon in the month.

The surveys focused on 10 bird taxa, including six considered to be at some risk of extinction in Brazil (MMA 2022) and four non-threatened species. The threatened species were Rusty-margined Guan, *Penelope superciliaris alagoensis* Nardelli, 1993 (Critically Endangered – CR), *Momotus momota marcgravianus* Pinto & Camargo, 1961 (Endangered – EN), Ceara Gnateater, *Conopophaga cearae* Cory, 1916 (EN), Golden-tailed Parrotlet, *Touit surdus* (Kuhl, 1820) (Vulnerable – VU), *Xiphorhynchus atlanticus* (Cory, 1916) (VU) and *Xenops minutus alagoanus* Pinto, 1954 (VU). The non-threatened (Least Concern) species were *Chiroxiphia pareola* (Linnaeus, 1766), Pale-bellied Tyrant-Manakin, *Neopelma pallescens* (Lafresnaye, 1853), *Hemitriccus griseipectus naumburgae* (Zimmer, 1945) and Black-cheeked Gnateater, *Conopophaga melanops nigrifrons* Pinto, 1954 (Near Threatened). However, two of these species (*P. superciliaris alagoensis* and *T. surdus*) were excluded from the individual analyses due to insufficient numbers of records (< 13 records).

Data analysis

To evaluate the relationship between rainfall and bird detection rates, we used the Cross-Correlation Function (CCF) and lagged regressions (Brockwell and Davis 1991, Cryer and Chan 2008). The CCF identifies possible patterns in a time series that can be used to explain the variation in the series over time. For example, here we use this approach to identify the time lag of the precipitation variable (x) that may be a potential predictor of bird detection (y).

The CCF between two time series (xt and yt) (e.g., in this work, precipitation and records species per month) is defined as the set of sample correlations between xt+h and yt for h = 0, -1, -2, -3, etc. (Armenteras et al. 2016). Correlations with a negative lag in h indicate a relationship between the first series and the values of the preceding periods in the second series (Armenteras et al. 2016). In this case, when x is a predictor of y and the lag is negative, x leads y. When there is a positive lag in h, the y series leads the x series. The values of the Autocorrelation Function (ACF) indicate the coefficient of autocorrelation of h at each lag. To understand the relationship between the rainfall and detection of the birds, we applied the lag indicated by the CCF plots to a lagged regression, to obtain the P and R^2 values. A significance level of $p = 0.05$ was used in all the analyses, which were run in R program, version 4.2.3, using the ACF function available in the basic software package.

RESULTS

Rainfall varied considerably among the months of the study period (Fig. 2). The months between August and December had the lowest rainfall, with total monthly rainfall not exceeding 37 mm. February (242 mm) and March (227 mm) were the rainiest months, with monthly rainfall

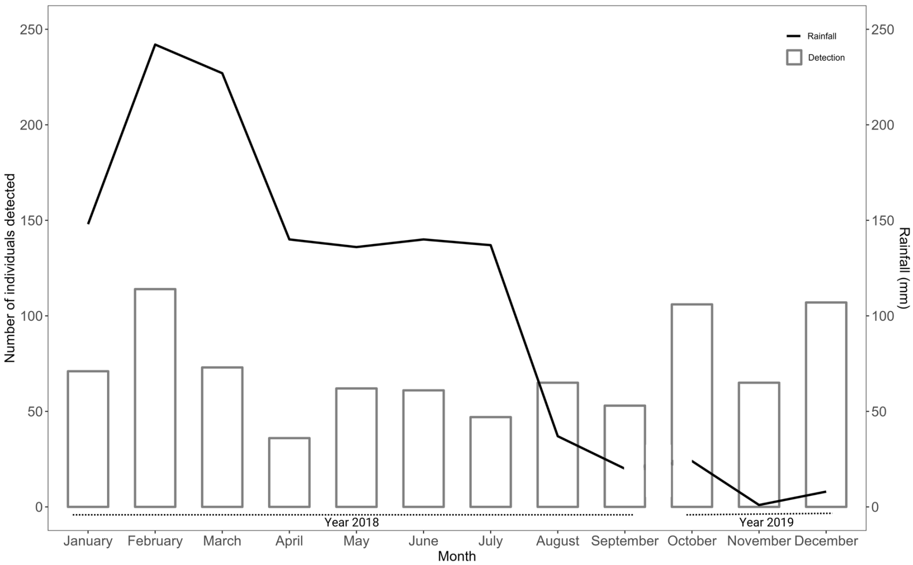

Figure 2. Temporal variation in rainfall (columns) and the detection (line) of the 10 study species monitored in the REBIO Guaribas, between January and September 2018, and October to December 2019.

of 137–148 mm being recorded in January, April, May, June and July.

The months with the lowest bird detection were April (n = 36) and July (n = 48). Some species had relatively high detection, in particular, *C. pareola*, which was recorded 45 times in October and 40 times in December. *Momotus m. marcgravianus*, *X. atlanticus* and *X. m. alagoanus* were detected most frequently in January and February, while *H. g. naumburgae* was detected least frequently between April and July, and most frequently between October and January. *Conopophaga cearae* and *C. m. nigrifrons* were detected at similar rates throughout the year.

Overall (Fig. 3), a significant negative correlation between bird detections and rainfall was observed two months before the rainfall peak (lag (h) = -2, autocorrelation coefficient = -0.559; R^2 = 0.55, p = 0.01). Bird detections decreased during this period when all species were considered together. However, when we analysed the correlograms recorded for each species, however, we identified three different patterns: (i) no significant correlation between detection and rainfall for *C. m. nigrifrons* and *C. cearae* (Fig. 4); (ii) detection correlated positively with rainfall in the same month and one month after the peak in rainfall, with continuous detection in the subsequent months, *M. m. marcgravianus* (lags (h) = 0, Autocorrelation Coefficient = 0.582; R^2 = 0.33, p = 0.04), *X. m. alagoanus* (lags (h) = 1, Autocorrelation Coefficient = 0.600; R^2 = 0.36; p = 0.04) and *X. atlanticus* (lags (h) = 1, Autocorrelation Coefficient = 0.598; R^2 = 0.35; p = 0.05), and (iii) bird detection was negatively correlated with rainfall, decreasing during the rainy season, one to two months prior to the peak in rainfall, and increasing detect in the third and fourth months after this peak., *H. g. naumburgae* (lags (h) = -2, Autocorrelation Coefficient = -0.600; R^2 = 0.50; p = 0.02) and *C. pareola* (lags (h) = -1, Autocorrelation Coefficient = -0.643; R^2 = 0.54, p = 0.01). *Neopelma pallescens* showed the same pattern (iii) in its detection, but it was not significant (Fig. 4).

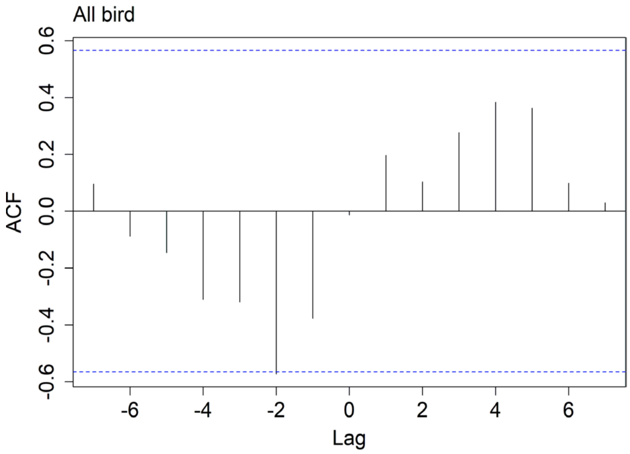

Figure 3. Cross-correlation function (CCF) of the number of birds detected during the present study in the REBIO Guaribas, Paraíba, Brazil, between January and September 2018, and October to December 2019. The correlation is significant when the value of the autocorrelation function (ACF) exceeds the dashed line (significance interval), and the lag (number of months, on the x-axis) when it is negative, the vocal activity responses precede the period of greatest rainfall and positive, it indicates that the vocal activity responses were more frequent during or follow the period of greatest rainfall.

DISCUSSION

Overall, the findings of the present study indicate that bird detection are not homogeneous over time, and tend to vary with seasonal fluctuations in rainfall. While the detection of some species was not associated with rainfall, others were detected more frequently during the first two or three months of the rainy season, or during the dry season, with a significant reduction in their detectability during the rainy season. Overall, the largest numbers of individuals were detected during the dry season, and at the onset of the rainy season in the NAF.

While rainfall may not directly predict bird vocal activity, it serves as a trigger that regulates climatic conditions favorable for breeding and resource availability, which in turn can influence bird activity (Araujo et al. 2017) and vocal detection (Best 1981, Senapathi et al. 2011, Vokurková et al. 2018, Pérez-Granados and Schuchmann 2021). For example, the accumulation of rain in a tropical forest may reduce the availability of invertebrate prey, as they become less active during intense rainfall and seek shelter under the foliage and leaf litter, making them less visible to birds (Foste 1974). Furthermore, birds tend to reduce their displays and vocal activity during rains (Robbins 1981, Zuberogoitia et al. 2019), which may be due to air temperature (Garson and Hunter 1979, Strain and Mumme 1988), cloudy conditions (Bas et al. 2008) or rain noise (Ryan and Brenowitz 1985, Lengagne and Slater 2002). Phenology data indicate that flowers and fruits are available throughout the year in the NAF, although fruit availability is greater in the months preceding the annual peak in rainfall (Fortunato and Quirino 2016). The combination of these processes may explain for the higher detection rates recorded during the dry season and the onset of the rainy season in the REBIO Guaribas.

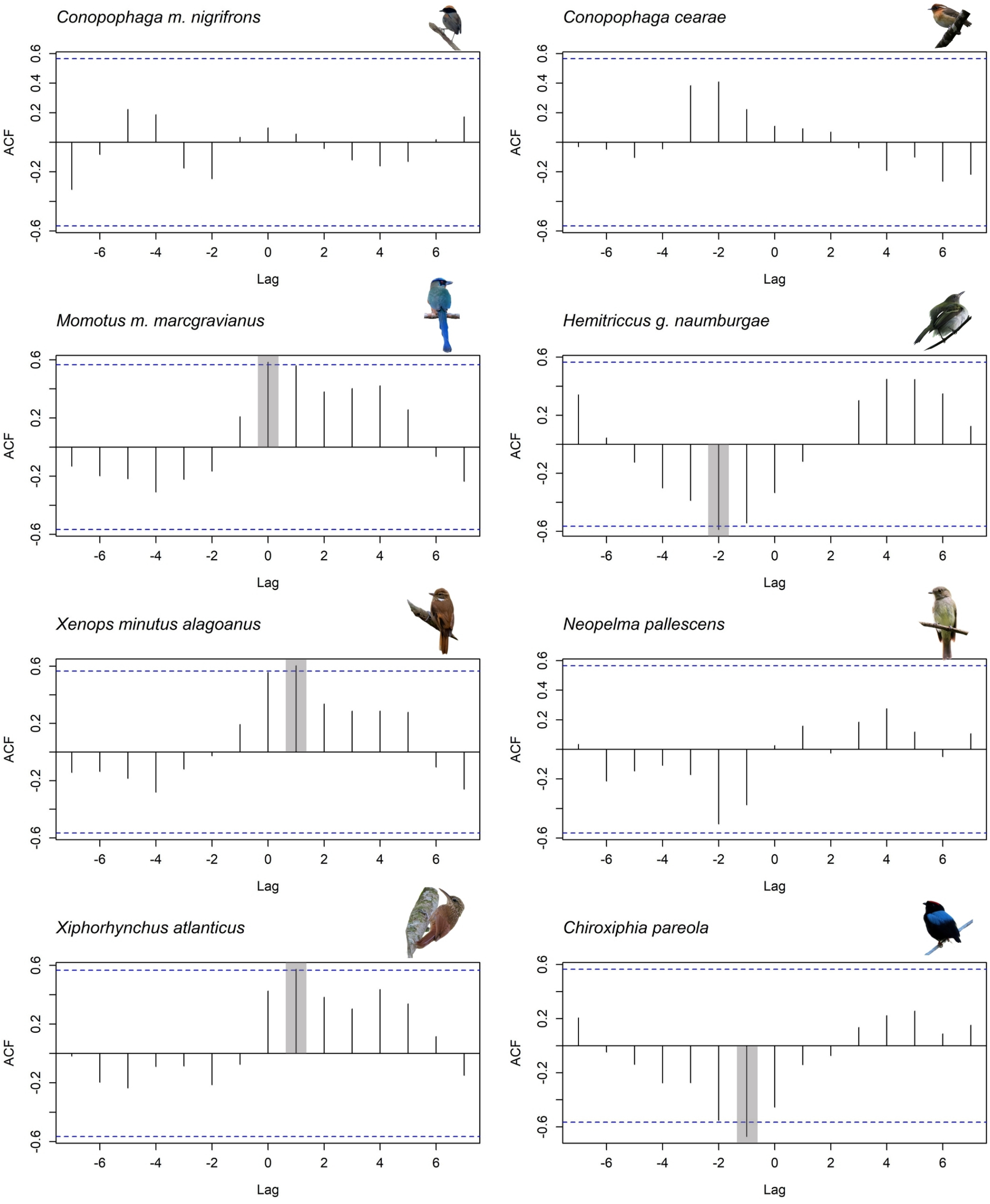

Figure 4. Cross-correlation of the number of birds of each of the study species detected during the present study in the REBIO Guaribas, Paraíba, Brazil, between January and September 2018, and October to December 2019. The correlation is significant when the value of the autocorrelation function (ACF) exceeds the dashed line (significance interval), and the lag (number of months, on the x-axis) when it is negative, the vocal activity responses precede the period of greatest rainfall and positive, it indicates that the vocal activity responses were more frequent during or follow the period of greatest rainfall. The values highlighted in gray are significant correlations ($p < 0.05$). Silhouette of birds: *M. m. marcgravianus* (author: Emanuel Barreto); *X. m. alagoanus* (author: Thiago Zanetti); *X. atlanticus* (author: Ciro Albano); *C. m. nigrifrons*, *C. cearae*, *H. g. naumburgae*, *C. pareola* and *Neopelma pallescens* (author: Diego Lima).

One of the main factors influencing bird detection is the length of the breeding season (Best 1981). Some studies have found that many tropical forest birds sing infrequently most of the year, but increase their vocal activity during the breeding period (Koloff and Mennill 2013, Chiver et al. 2015, Hill et al. 2015). While the considerable diversity of birds found in the Brazilian Atlantic Forest is reflected in an enormous variety of breeding strategies, there is a general tendency for breeding to occur between September and February (Sick 1997), the period in which we recorded the highest detection. However, it is important to note that detection patterns vary considerably between species, especially considering that their breeding behaviour may be synchronised with different biological and physiological factors within this time window (Staicer et al. 1996, Wiley 1996, Morais et al. 2012).

We found at least three patterns in the detection of the study species monitored in the REBIO Guaribas, including threatened birds. The simplest pattern was observed for *C. m. nigrifrons* and *C. cearae*, whose detection remained consistent throughout the study period. This consistent detection pattern may be due to their very distinctive vocalizations, which are easily heard throughout the forest (Whitney and Juana 2020).

A second detection pattern was identified in *M. m. marcgravianus*, *X. m. alagoanus* and *X. atlanticus*. The detection of these species was significantly correlated with rainfall, often coinciding with the onset of the rainy season. In particular, *M. m. marcgravianus*, a rare species in the Atlantic Forest that typically vocalizes during the crepuscular hours before dawn, has a low probability of detection during early morning surveys for most of the year. However, this study revealed a shift in its vocal activity between January and March, when it vocalized intensely until 9 am.

The third pattern was recorded in *H. g. naumburgae*, *C. Pareola* and *N. pallescens*, which are relatively common in the study area. The detection of the first two species was correlated negatively and significantly with the onset of the rainy season, one to two months prior to the peak of the rains. *Neopelma pallescens* showed the same pattern (iii) in its detection, but it was not significant. This pattern may be associated with the end of the breeding season, which coincides with the peak of the dry season, between September and December (Clock 2004, Snow 2020a, 2020b), just prior to the onset of the rainy season. While *H. g. naumburgae*, for example, vocalizes frequently throughout the year (Schulenberg 2020), in our study, we recorded a peak in its detection rate between September and January. However, as data on breeding patterns are not available for most of the taxa in the study area, further research is needed to determine whether the higher detection rates recorded here actually correspond to breeding patterns.

The findings of the present study indicate that rainfall has a variable influence on bird species detection in the NAF. Detection patterns differed among species, with some being consistently detected year-round, while others peaked during the dry season or at the onset of the rainy season. Similar patterns have been observed in bird assemblages from humid African forests (Vokurková et al. 2018) and certain species in the Pantanal Matogrossense, Brazil (Pérez-Granados and Schuchmann 2021), where greater vocal activity occurred in the dry season. These results suggest that the optimal period for bird surveys in the NAF, particularly for endangered species, is between the peak of the dry season and the onset of the rainy season. We recommend scheduling future surveys during this period to maximize species detection.

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Submitted: March 6, 2024
Accepted: February 26, 2025
Editorial responsibility: Claudia Hermes

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Competing Interests

The authors have declared that no competing interests exist.

Funding

This study was supported by the Instituto Chico Mendes de Conservação da Biodiversidade.

How to cite this article

Lima DM, Sousa AEBAS, Araujo HFP (2025) Temporal variation in the detection of endangered birds in the Northern Atlantic Forest. Zoologia 42: e24019. https://doi.org/10.1590/S1984-4689.v42.e24019

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