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Extreme weather events as agents of natural local extinction of bird populations in riparian forests

Extremos climáticos como agentes de extinção local natural de populações de aves em floresta ripária

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ABSTRACT

Natural history comprises important biological aspects in the establishment of public policies for biodiversity conservation. Climate change has expanded this challenge, making it necessary to evaluate and predict its negative impacts on biological systems. In this context, we evaluated the effect that floods have on the reproductive success of birds like the Amazonian motmot (*Momotus momota*), rufous-tailed jacamar (*Galbula ruficauda*), and swallow tanager (*Tersina viridis*) that nest on the banks of the Maria Lucinda stream in the municipality of Morrinhos, state of Goiás, Brazil. We identified, measured, and monitored 87 nests over five years. Predation represented the main cause of nest losses, with more significant rates for rufous-tailed jacamar (21%) and swallow tanager (21%). However, the record rain of October 2021 resulted in increased volume of the Maria Lucinda stream causing considerable losses of low-height nests, highlighting the vulnerability of this group of birds to climate change. The study emphasizes the need for stricter conservation policies of riparian forests — environments considered relevant in providing ecosystem services.

Keywords: Cerrado; flooding; breeding; conservation biology.

RESUMO

A história natural compreende aspectos biológicos importantes no estabelecimento de políticas públicas para conservação da biodiversidade. As mudanças climáticas ampliaram esse desafio, tornando-se necessário avaliar e prever seus impactos negativos aos sistemas biológicos. Neste contexto, nós avaliamos o efeito que as inundações têm no sucesso reprodutivo de aves como udu-de-coroa-azul (*Momotus momota*), ariramba-de-cauda-ruiva (*Galbula ruficauda*) e saí-andorinha (*Tersina viridis*) que nidificam nas margens do córrego Maria Lucinda na cidade de Morrinhos, estado de Goiás, Brasil. Identificamos, medimos e monitoramos 87 ninhos ao longo de cinco anos. A predação representou a principal causa das perdas de ninhos, com taxas mais significativas para rufous-tailed jacamar (21%) e swallow tanager (21%). Entretanto, a chuva recorde de outubro de 2021 resultou em aumento do volume do córrego Maria Lucinda, ocasionando perdas consideráveis de ninhos construídos à baixa altura, evidenciando a vulnerabilidade deste grupo de aves às mudanças climáticas. O estudo destaca a necessidade de políticas mais rígidas de conservação das florestas ripárias — ambientes considerados relevantes na prestação de serviços ecossistêmicos.

Palavras-chave: Cerrado; inundação; reprodução; biologia da conservação.

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Introduction

Paradoxically, tropical forests are regions known for both high diversity and substantial knowledge gaps in bird reproductive biology (Xiao et al., 2017). The lack of knowledge about the neotropical region tends to make it difficult to solve problems related to the conservation of threatened species (Marini and Garcia, 2005). Among the causes of population losses, offspring predation is the most important reproductive bottleneck that affects wild birds (Menezes and Marini, 2017). On the other hand, the synergy among forest reduction and fragmentation and climate extremes is considered new and urgent challenges from the perspective of sustainable development (Gomes et al., 2023), acting stochastically and abruptly on a large geographic scale and with a broad taxonomic range of wildlife (Ameca Y Juárez et al., 2012). Although stabilized, the net loss of forest cover on the planet was estimated at 402,000 km^2 between 1992 and 2018 (~15,000 km^2.year^{-1}), with the highest deforestation rates occurring in South America, especially in Brazil, Argentina, Paraguay, and Bolivia (Radwan et al., 2021). In fact, several studies have documented the effects of deforestation and climate change on the bird group in various regions of the planet, and high extinction rates are foreseen during this century (Northrup et al., 2019; Lees et al., 2022).

Regardless of the biome in which they are located, riparian forests (RF) are based on the banks of watercourses, being legally protected in several countries due to various ecosystem services provided to society, such as maintenance of the hydrological cycle, significant biodiversity shelter, forest connection, and protection of watercourses against erosion and siltation (Stutter et al., 2012; Nóbrega et al., 2020; Merritt, 2022). However, the effects predicted by climate change, such as the increase in volume and concentration of rainfall, tend to rise the frequency of floods and erosion of the banks of watercourses (Merritt, 2022). In the Cerrado biome of central Brazil, the breeding period of many bird species coincides with the beginning of the rainy season (Marini et al., 2012), making vulnerable the bird communities that use RFs as refuges, feeding, and reproduction sites (Anjos et al., 2007).

Describing a species' natural history and identifying reproductive weaknesses, in the face of limitations imposed by climate change, is fundamental for establishing the degrees of species vulnerability and determining strategies against local extinctions (Zhang et al., 2021, 2023). Thus, the present study sought to evaluate the adaptive susceptibility of three species of birds: Amazonian motmot (*Momotus momota*; Linnaeus, 1766), rufous-tailed jacamar (*Galbula ruficauda*; Cuvier, 1816), and swallow tanager (*Tersina viridis*; Illiger, 1811) to the impact of extreme weather events, particularly floods during the breeding period in a RF.

Materials and methods

Study area

The location of this study is the Morrinhos Natural Park (MNP), 17°43'28.41" S / 49°07'31.11" W, a protected area of seasonal semideciduous forest of approximately 100 ha (Costa et al., 2019), located around the urban area of the municipality of Morrinhos, state of Goiás, Brazil (Figure 1A). Within the MNP, we established about 700 m of continuous banks of the Maria Lucinda (ML) stream to record and monitor the reproductive cycles of the three bird species. The ML stream originates within the MNP, with small width, depth, and water volume, making it possible to walk along its sediment bed even during the rainy season. The banks of the ML stream vary in height in relation to the water surface (0.5–4.0 m), being of medium clayey texture, without the presence of pebbles, and partially covered by herbaceous plants and tree roots (Figure 1B). The predominant vegetation in the region is the Cerrado in an advanced process of deforestation (Colman et al., 2024) and the climate is Aw type, hot from April to September and rainy from November to March (Pesquero et al., 2012).

Data collection and analysis

For five years (2018–2022), in the breeding months of the three species (August to November) (Silva et al., 2022), at intervals of sev-

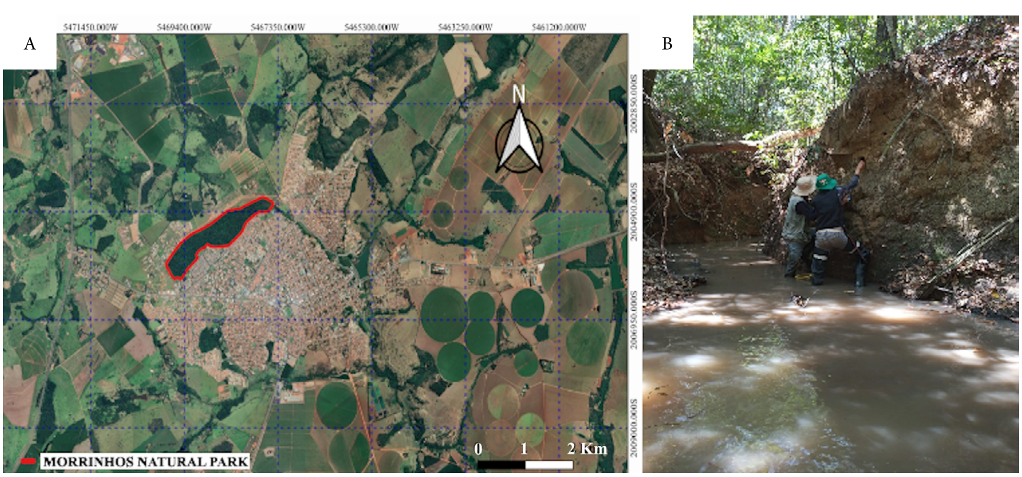

Figure 1 – (A) Morrinhos Natural Park in Morrinhos, Goiás, Brazil. (B) Banks of the Maria Lucinda stream.

en days, we traveled along the banks of the ML stream to map (GPS Garmin Etrex 20) and quantify the offspring of active nests using an optical probe from the egg stage until the end of the nestling stage. The optical probe was introduced into the nests during the absence of parents. At each reproductive period, we determined the survival percentage and causes of offspring and nest losses at the egg, nestling, and total stages (Silva et al., 2022). Predation is herein defined as the disappearance of an egg or nestling before the regular nest abandonment period (Pesquero et al., 2014, Nápoli et al., 2018; Veloso et al., 2018). Offspring losses due to predation, hatch failure, early abandonment by the parents, and flooding were factors used to estimate breeding success.

Using a pocket tape, we determined the height of the nests from the water surface of the ML stream before the start of the rainy season (September). We compared the means and proportions of nest height classes (units of 100 cm arbitrarily defined) between species using analysis of variance (after the D'Agostino-Pearson normality test) and the G test, respectively. Rainfall data from the study period were obtained from the National Water and Sanitation Agency (*Agência Nacional de Águas e Saneamento Básico* [ANA], 2023) through the meteorological station 1749003 in Morrinhos and described in temporal series in order to associate with the reproductive success of birds. Descriptive and inferential analyses were carried out using BioEstat 5.3 (Ayres et al., 2007).

Results

We identified, measured, and monitored a total of 87 nests, including 28 rufous-tailed jacamar, 30 Amazonian motmot, and 29 swallow tanager nests across five breeding seasons in the MNP. Except for Amazonian motmot (7%), predation rates accounted for the largest nest losses of rufous-tailed jacamar (21%) and swallow tanager (21%) over the five years (Table 1).

Table 1 – Causes of Galbula ruficauda, Momotus momota, and Tersina viridis offspring losses in the riparian forest of Morrinhos, Goiás, Brazil, over five reproductive periods (2018–2022).

Parameters	2018	2019	2020	2021	2022	Total
Galbula ruficauda						
Hatch failure	0/11	2/14 (14)	0/18	1/18 (5)	0/21	3/82 (4)
Predation[1]	0/11	2/14 (14)	6/18 (33)	2/18 (11)	6/21 (29)	16/82 (19)
Predation[2]	0/4	1/5 (20)	2/6 (33)	1/6 (17)	2/7 (29)	6/28 (21)
Abandonment[1]	0/11	2/14 (14)	0/18	2/18 (11)	2/21 (9)	6/82 (7)
Abandonment[2]	0/4	1/5 (20)	0/6	1/6 (17)	1/7 (14)	3/28 (11)
Rain[1]*	0/11	0/14	0/18	9/18 (50)	0/21	9/82 (11)
Rain[2]*	0/4	0/5	0/6	3/6 (50)	0/7	3/28 (11)
Success[1]	11/11 (100)	9/14 (64)	12/18 (67)	4/18 (22)	13/21 (62)	49/82 (60)
Success[2]	4/4 (100)	3/5 (60)	4/6 (67)	1/6 (17)	4/7 (57)	16/28 (57)
Momotus momota						
Hatch failure	6/16 (37)	0/18	2/18 (11)	2/19 (10)	0/19	10/90 (11)
Predation[1]	0/16	0/18	2/18 (11)	2/19 (10)	0/19	4/90 (4)
Predation[2]	0/6	0/6	1/6 (17)	1/6 (17)	0/6	2/30 (7)
Abandonment[1]	0/16	0/18	0/18	0/19	0/19	0/90
Abandonment[2]	0/6	0/6	0/6	0/6	0/6	0/30
Rain[1]*	0/16	0/18	0/18	10/19 (53)	0/19	10/90 (11)
Rain[2]*	0/6	0/6	0/6	3/6 (50)	0/6	3/30 (10)
Success[1]	10/16 (62)	18/18 (100)	14/18 (78)	5/19 (26)	19/19 (100)	66/90 (73)
Success[2]	5/6 (83)	6/6 (100)	5/6 (83)	2/6 (33)	6/6 (100)	24/30 (80)
Tersina viridis						
Hatch failure	0/11	1/15 (7)	0/14	0/16	0/18	1/74 (1)
Predation[1]	3/11 (27)	3/15 (20)	0/14	6/16 (37)	5/18 (28)	17/74 (23)
Predation[2]	1/5 (20)	1/5 (20)	0/6	2/6 (33)	2/7 (29)	6/29 (21)
Abandonment[1]	0/11	0/15	0/14	0/16	3/18 (17)	3/74 (4)
Abandonment[2]	0/5	0/5	0/6	0/6	1/7 (14)	1/29 (3)
Rain[1]*	0/11	0/15	0/14	2/16 (12)	0/18	2/74 (3)
Rain[2]*	0/5	0/5	0/6	1/6 (17)	0/7	1/29 (3)
Success[1]	8/11 (73)	11/15 (73)	14/14 (100)	8/16 (50)	10/18 (55)	51/74 (69)
Success[2]	4/5 (80)	4/5 (80)	6/6 (100)	3/6 (50)	4/7 (57)	21/29 (72)

Numbers in parentheses indicate percentages. [1]Individuals; [2]nests; *losses due to rain are subdivided into flooding and landslide.

In fact, the largest losses of Amazonian motmot offspring were due to failed egg development (11%) (Table 1).

In October 2021, the precipitation recorded in Morrinhos (GO) was the highest in 40 years, accumulating 260.8 mm at the end of the month (Figures 2A and 2B). On October 14, 2021, it rained 54.2 mm (21% of all October's rain), with 37 mm recorded in an interval of just 30 minutes (4:30–5:00 pm) (Figure 2C). The drainage of rainwater from the urban area into the MNP largely contributed to the instantaneous increase in the volume of water in the ML stream (Figure 1A). Two days after the storm on October 14, 2021, we found that the rain resulted in flooding and landslides in the ML stream, affecting three rufous-tailed jacamar nests (50%), three Amazonian motmot nests (50%), and one swallow tanager nest (17%), killing nine, ten, and two nestlings of the species, respectively (Table 1).

Of the six rufous-tailed jacamar nests recorded in 2021, three located at 150, 190, and 200 cm above the water surface were affected by flooding and/or landslides; two others located 130 and 180 cm high were abandoned or destroyed before the flood; and only one nest positioned at 250 cm from the water surface resulted in the success of four nestlings (Table 2). In the case of the Amazonian motmot, the three nests affected by flooding and/or landslides were situated at 140, 150, and 170 cm high from the water surface; another nest settled 300 cm high was predated; while two others located 240 and 380 cm high above the water surface, despite being active on the date of the flood, were not affected (Table 2). Although all six swallow tanager nests were vulnerable to the 2021 flood, only the one at 160 cm above the water surface was impacted by the October 14, 2021 flood. Two nests at 100 and 160 cm height completed the cycles in the first week of October; two other nests at 90 and 130 cm high were predated at the end of September; and another located 200 cm high in relation to the water surface started laying eggs in the last week of October (Table 2).

From 60 cm above the water level, the birds nested almost across the entire height gradient of the ML stream banks but Amazonian motmot nests were located approximately 60 cm higher than swallow tanager nests ($F_{2, 102}$=4.55, p-value [p]<0.02) (Figure 3A). The distribution of nest heights was related to bird species (G=16.5, degrees of freedom [df]=6, p<0.02) (Figure 3B). The number of swallow tanager nests in the first range of 200 cm above the water surface was proportionally greater than that of Amazonian motmot (G_{Yates}=7.1, df=1, p<0.01). In fact, the majority of swallow tanager (77%) and rufous-tailed jacamar (70%) nests were found below 200 cm in height, while Amazonian motmot built less than 45% of its nests in that same range height (Figure 3B).

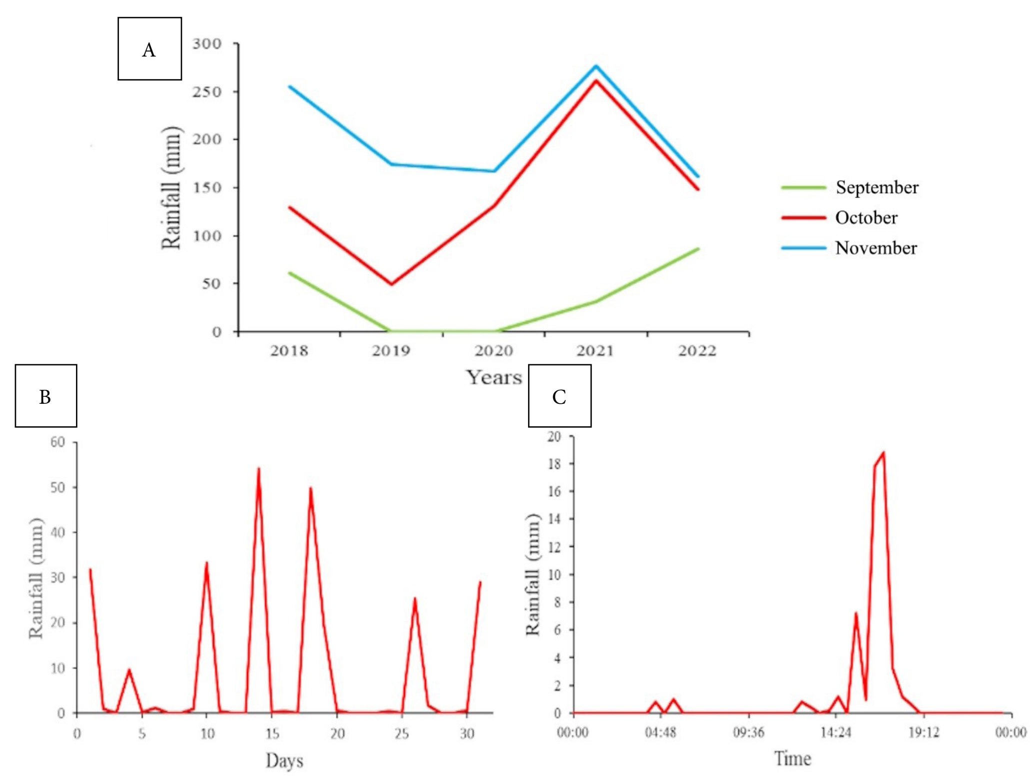

Figure 2 – Rainfall regime for Morrinhos, Goiás, Brazil. (A) September, October and November, 2018 to 2022; (B) days of October, 2021; (C) time of October 14, 2021.
Source: ANA (2023).

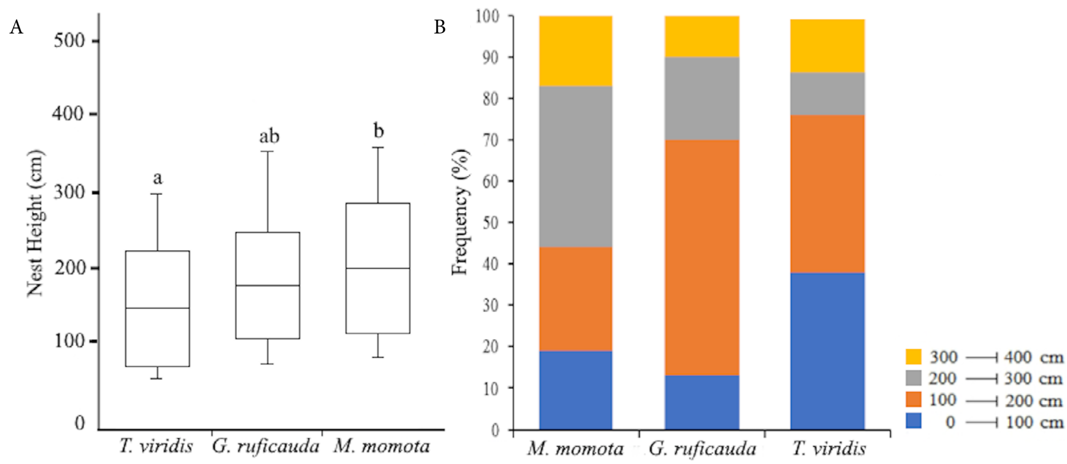

Figure 3 – (A) Height of the nests of Galbula ruficauda (n=30), Momotus momota (n=36), and Tersina viridis (n=39) above the surface of the Maria Lucinda stream in Morrinhos, Goiás, Brazil. B: Frequencies of nest heights of Galbula ruficauda, Momotus momota, and Tersina viridis in relation to the surface of the Maria Lucinda stream in Morrinhos, Goiás, Brazil.

Line: average; box: standard deviation; whiskers: maximum and minimum. Averages followed by the same letter do not differ from each other (Tukey p<0.05).

Table 2 – Height of active nests of Galbula ruficauda, Momotus momota, and Tersina viridis in relation to the surface of the Maria Lucinda stream during the 2021 reproductive period in Morrinhos, Goiás, Brazil.

Nest	Height (cm) of nests in relation to the stream level		
	Galbula ruficauda	*Momotus momota*	*Tersina viridis*
1	130[2]	140[1]	90[2]
2	150[1]	150[1]	100[4]
3	180[3]	170[1]	130[2]
4	190[1]	240[4]	160[1]
5	200[1]	300[2]	160[4]
6	250[4]	380[4]	200[4]

[1]Nest affected by flood; [2]redated nest; [3]abandoned nest; [4]successful nest.

Discussion

Bird offspring deaths because of excessive rain were documented with *Momotus mexicanus* in Mexico in 2003 due to the El Niño effect, flooding (32.4%) and collapsing nests (14.3%) (Charre et al., 2017), but our observations represent the first record of the effect of floods on avian populations in the Cerrado-Brazilian savanna. Despite being occasional, the large losses of nests that occurred in 2021 due to flooding and landslides on the banks of the ML stream represent the severity of extreme weather events on the population growth of birds that inhabit RF (Ameca Y Juárez et al., 2012). Global warming is expected to further intensify the water cycle, increasing the frequency of floods (IPCC, 2022). In October, which is a period of high reproductive activity for the bird species studied here (Pesquero et al., 2014; Nápoli et al., 2018; Veloso et al., 2018), the rainfall was record high and only surpassed by the one that occurred in 1982, although two other smaller rainfall peaks were recorded in 2006 and 2011 (ANA, 2023). In fact, extreme rain events have been occurring increasingly in the municipality of Morrinhos lately (Oliveira et al., 2023).

Borges et al. (2019) point out that the onset of bird breeding period is directly related to the onset of the rainy season in the Brazilian Cerrado region and speculate on the effects of rainfall changes on the balance between demand and supply of food and consequently on bird reproductive success. In fact, several bird species that inhabit the Cerrado biome reproduce during the rainy season (Marini et al., 2012). That synchronism of breeding and rainy seasons makes floods a serious selective factor for burrow nesting birds when choosing the height at which they can establish their nests along RF riverbanks. Among the three species analyzed, the Amazonian motmot showed greater plasticity in the occupation of the banks of the ML stream and, therefore, a higher capacity to adapt to floods. However, the preferential nesting below 200 cm in relation to the water surface indicates that floods were not a frequent phenomenon in the past to the point of representing an important component of natural selection on this group of birds and, therefore, did not impose a strong limitation to reproduction and population growth. Thus, monitoring reproductive dynamics over time results in a better perception of the vulnerability of this group of birds to climate change and more effective fauna conservation plans (Hale et al., 2019).

Predation is another selective force that could move nests to higher positions on the riverbanks as has been documented for tree cavity-nesting birds (Joy, 2000), but in riverine environments, there appears to be no relationship between predation rates and the height of burrow nests (Silva et al., 2022). Although it is the primary cause of offspring losses, the predation on burrow nesting birds observed here has less selective pressure compared to open nests (Liu et al., 2021). The low predation rate of the Amazonian motmot corroborates the results of Silva et al. (2022), who attribute the high reproductive success to the long access tunnel to the nest and the large size of the species, making the action of predators difficult. On the other hand, developmental failures of the Amazonian motmot eggs, which can be attributed to genetic and environmental factors that cause infertility or premature embryo death (Assersohn et al., 2021), require further investigation.

The ecological relevance (Anjos et al., 2007; Lees and Peres, 2008) and ecosystem services of the RF (Nóbrega et al., 2020) are key characteristics to be considered by Brazil and other countries in the elaboration of legal norms for environmental protection (Metzger, 2010) and in contingency plans on climate change (Pacifici et al., 2015; Ameca et al., 2016). The minimum limits of RF perceived by species may vary, but studies carried out with different taxonomic groups (vascular plants, mammals, birds, fish, aquatic invertebrates) indicate dependence between 40–200 m of distance on both sides of watercourses (Lees and Peres, 2008; Mitchell et al., 2018; Dala-Corte et al., 2020). Inadvertently, in Brazil, the limits of the riparian zone are not covered by the Forest Code (Metzger, 2010).

Conclusion

Flooding, a phenomenon whose frequency is expected to increase throughout this century due to climate change, represents a serious threat to populations of the study bird species, particularly swallow tanager and rufous-tailed jacamar. A combination of factors, such as the synchronization between reproductive seasonality and rainy season, the use of watercourse margins as a reproduction habitat, and the nesting preferably at a low height enhance the vulnerability of these and various other species that inhabit RF to the floods. Our results reinforce the RF as highly sensitive environment in relation to the degrees of vulnerability for the design of effective conservation measures in the face of climate change within the Cerrado region.

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Authors' contributions

PESQUERO, M.A.: conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, supervision, writing – original draft, writing – review & editing. CARVALHO, C.B.: project administration, writing – review & editing. FREITAS, D.A.C.: funding, acquisition, investigation, writing – review & editing. FARIA, L.M.: funding, acquisition, investigation, writing – review & editing. ARRUDA, F.V.: formal analysis, writing – review & editing.

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