

THALES CLAUSSEM VICENTE CORRÊA

**ABUNDANCE AND POPULATION DENSITY OF *Callithrix flaviceps* Thomas, 1903
(PRIMATES, CALLITRICHIDAE) IN THE PRIVATE NATURAL HERITAGE
RESERVE FAZENDA MACEDÔNIA, IPABA, MG AND SURROUNDINGS**

Dissertation submitted to the Animal Biology
Graduate Program of the Universidade Federal de
Viçosa in partial fulfillment of the requirements
for the degree of *Magister Scientiae*.

Adviser: Fabiano Rodrigues de Melo

**VIÇOSA - MINAS GERAIS
2023**

Ficha catalográfica elaborada pela Biblioteca Central da Universidade
Federal de Viçosa - Campus Viçosa

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C824a
2023

Corrêa, Thales Claussem Vicente, 1994-

Abundance and population density of *Callithrix flaviceps*
Thomas, 1903 (PRIMATES, CALLITRICHIDAE) in the Private
Natural Heritage Reserve Fazenda Macedônia, Ipaba, MG and
surroundings / Thales Claussem Vicente Corrêa. – Viçosa, MG,
2023.

1 dissertação eletrônica (17 f.): il. (algumas color.).

Texto em inglês.

Orientador: Fabiano Rodrigues de Melo.

Dissertação (mestrado) - Universidade Federal de Viçosa,
Departamento de Biologia Animal, 2023.

Referências bibliográficas: f. 15-17.

DOI: <https://doi.org/10.47328/ufvbbt.2023.360>

Modo de acesso: World Wide Web.

1. *Callithrix flaviceps* - Habitat (Ecologia) - Conservação.
2. Animais em extinção. 3. Primatas - Conservação - Ipaba
(MG). I. Melo, Fabiano Rodrigues de, 1973-. II. Universidade
Federal de Viçosa. Departamento de Biologia Animal. Programa
de Pós-Graduação em Biologia Animal. III. Título.

CDD 22. ed. 599.84

Bibliotecário(a) responsável: Bruna Silva CRB-6/2552

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APPROVED: March 20, 2023.

Assent:

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Data: 20/06/2023 12:08:50-0300
Verifique em <https://validar.it.gov.br>

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Documento assinado digitalmente
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Data: 20/06/2023 12:01:52-0300
Verifique em <https://validar.it.gov.br>

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Advisor

ACKNOWLEDGEMENTS

To God for life and grace.

To my parents for their care, love and education.

To my wife for her support, encouragement and love.

To the Federal University of Viçosa, for the opportunity to carry out the postgraduate course.

To Celulose Nipo-Brasileira – CENIBRA, for supporting and financing the project.

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

To my advisor for learning and inspiration.

To friends and colleagues who somehow contributed to the realization of this work: Igor Coelho, Gustavo Bretas, Eduarda Fialho, Esther Maciel, Beatriz Diniz, Sarisha Trindade, Mariana Soares, Adriana Milagres, Maria Paula, Kesleyane Pereira, Samuel Vieira, Roney Assis, Vanessa Guimarães, Gilberto Aires, João Batista, Adilson, Wemerson Marcelo e and João Hubner.

ABSTRACT

CORRÊA, Thales Claussem Vicente, M.Sc., Universidade Federal de Viçosa, March, 2023. **Abundance and population density of *Callithrix flaviceps* Thomas, 1903 (PRIMATES, CALLITRICHIDAE) in the Private Natural Heritage Reserve Fazenda Macedônia, Ipaba, MG and surroundings.** Adviser: Fabiano Rodrigues de Melo.

Callithrix flaviceps, commonly known as the Buffy-headed marmoset, is a primate species endemic to the Southeastern Atlantic Forest of Brazil. Its range is one of the smallest among platyrrhine species. Unfortunately, this species is critically endangered and considered one of the 25 most threatened primate species in the world. The population decline is largely attributed to habitat fragmentation, competition, hybridization with other invasive species, and susceptibility to yellow fever. The objective of this research was to estimate the abundance and population density of Buffy-headed marmosets in the RPPN Fazenda Macedônia, located along the Doce River in Ipaba, MG, and its surroundings. Population data were collected using the playback method in randomized sampling units and analyzed using the N-mixture model. The results indicate that the population of this species in the region of RPPN Fazenda Macedônia has an estimated average of 257.3 individuals (95% CI = 205.5-309 ind.) and an average population density of 11.4 individuals/km² (95% CI = 9.1-13.7 ind./km²). During the sampling, five hybrid marmosets were identified, highlighting the need for management strategies to prevent them from becoming a threat to the local population. This study provides a hopeful outlook for the conservation of the species by revealing the numbers of an important population of Buffy-headed marmosets living in a protected area and indicating that the RPPN Fazenda Macedônia has been a valuable area for the species' survival.

Keywords: *Callithrix flaviceps* - Habitat (Ecology) – Conservation. Endangered animals. Primates - Conservation - Ipaba (MG).

RESUMO

CORRÊA, Thales Claussem Vicente, M.Sc., Universidade Federal de Viçosa, março de 2023. **Abundância e densidade populacional de *Callithrix flaviceps* Thomas, 1903 (PRIMATES, CALLITRICHIDAE) na RPPN Fazenda Macedônia, Ipaba, MG e entorno.** Orientador: Fabiano Rodrigues de Melo.

Callithrix flaviceps, popularmente conhecido como sagui-da-serra, é uma espécie de primata endêmica da Mata Atlântica do sudeste do Brasil. Sua extensão de ocorrência é uma das menores entre os platirrinos. Infelizmente, essa espécie encontra-se criticamente em perigo de extinção, sendo considerada uma das 25 espécies de primatas mais ameaçadas do mundo. O declínio populacional deve-se, em grande parte, à fragmentação do habitat, à competição e hibridação com outras espécies invasoras, além de sofrer com a febre amarela. O objetivo desta pesquisa foi estimar a abundância e a densidade populacional do sagui-da-serra na RPPN Fazenda Macedônia, situada às margens do Rio Doce em Ipaba- MG, e em seu entorno. Os dados populacionais foram coletados por meio do método de playback em unidades amostrais aleatorizadas e analisados pelo modelo N-mixture. Os resultados indicam que a população da espécie na região da RPPN Fazenda Macedônia é composta pela média estatística de 257,3 indivíduos (IC 95% = 205,5-309 ind.) e apresenta uma densidade populacional média de 11,4 indivíduos/km² (IC 95% = 9,1-13,7 ind./km²). Na amostragem, foram identificados cinco indivíduos de saguis híbridos, se fazendo necessário um manejo para evitar que estes sejam ameaças para a população local. Este estudo traz um panorama de esperança para a conservação da espécie ao revelar números de uma importante população de saguis-da-serra vivendo em uma área protegida e indica que a RPPN Fazenda Macedônia tem sido uma valiosa área para a sobrevivência da espécie.

Palavras-chave: *Callithrix flaviceps* - Habitat (Ecologia) – Conservação. Animais em extinção. Primatas - Conservação - Ipaba (MG).

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ABUNDANCE AND POPULATION DENSITY OF *Callithrix flaviceps* Thomas, 1903 (PRIMATES, CALLITRICHIDAE) IN THE PRIVATE NATURAL HERITAGE RESERVE FAZENDA MACEDÔNIA, IPABA, MG AND SURROUNDINGS

1. INTRODUCTION

The Atlantic Forest is the second largest forest in South America and one of the most biodiverse biomes in the world, making it of great importance for the conservation of biological heritage. Its boundaries cover 17 states, which corresponds to approximately 15% of Brazil, however, these areas have been suppressed by the expansion of urban and rural areas to sustain the human population growth (MITTERMEIER *et al.*, 2004; RIBEIRO *et al.*, 2009; SOS MATA ATLÂNTICA, 2021). Today, we only have 12.4% of the original coverage of the Atlantic Forest remaining. The larger fragments of over 100 hectares, the main habitat for rare species, represent only 8.5% of the original forest (SOS MATA ATLÂNTICA, 2021).

However, it still holds a large number of endemic fauna species, essential for maintaining the balance of its ecosystems, with approximately 298 mammal species, of which 90 are endemic (PAGLIA *et al.* 2012). The biome harbors 23 primate species, of which 17 are listed as threatened on the National List of Endangered Fauna Species (ICMBIO-MMA, 2019). Primates are a key component for maintaining neotropical biodiversity, contributing to various ecosystem services, mainly seed dispersal, and possessing great cultural and touristic importance for various communities. They also contribute their inestimable value to the development of biological sciences and their relationships with public health through the study of emerging diseases (ESTRADA *et al.*, 2017).

Defaunation is the process of decreasing the diversity and quantity of animals in an area. It can be caused by various factors, such as habitat fragmentation, illegal hunting, animal trafficking, excessive use of pesticides, and climate change. The consequences of defaunation include loss of biodiversity, ecological imbalance, decreased ability to control pests, and loss of ecosystem services (CORLETT, 2007; FA *et al.* 2002; JORGE *et al.* 2013; GENRICH, 2014).

The Buffy-headed marmoset, *Callithrix flaviceps*, is a small primate endemic to the Southeastern Atlantic Forest of Brazil. It occurs south of the Rio Doce in Espírito Santo to the border with Rio de Janeiro and extends inland, in the eastern part of Minas Gerais, in the Manhuaçu River basin (COIMBRA-FILHO *et al.*, 1981; MENDES & MELO, 2007; MELO *et al.* 2021), comprising one of the smallest occurrence ranges among all Neotropical primates, an area of approximately 30,000 km² (FERRARI & MENDES 1991).

In addition to the threat of environmental degradation due to the expansion of agriculture, livestock, eucalyptus plantations, mining, and urbanization (COIMBRA-FILHO 1990, FERRARI & MENDES 1991, MENDES & MELO 2007), *Callithrix flaviceps* also faces problems related to the introduction of allochthonous congeners in its native area, such as competition for resources with individuals of invasive *C. penicillata*, *C. jacchus*, and *C. geoffroyi*. The introduction of allochthonous species also brings another serious harm to native populations, which is the hybridization between taxa. As they are still very closely related

evolutionarily, their offspring are fertile, increasing the number of hybrid individuals in these populations and decreasing the proportion of individuals of the native species (VITAL *et al.*, 2020; MALUKIEWICZ *et al.* 2021).

The species also suffered significant losses during the yellow fever outbreak in 2016-2017, which was the main factor leading to an 80% reduction in the size of an important subpopulation in the RPPN Feliciano Miguel Abdala (POSSAMAI *et al.*, 2022), indicating likely population reductions in other areas. All these factors have led *Callithrix flaviceps* to a population decline of at least 80% over 18 years (three generations), placing the species in the ICMBio Red Book and classifying it as "Critically Endangered" (CR) on the IUCN Red List of Threatened Species (MELO *et al.*, 2021), as well as being listed as one of the 25 most endangered primates in the world (MELO *et al.*, 2022). It is estimated that the size of the remaining total population is around 4,440 individuals, with less than 2,500 mature individuals (HILÁRIO *et al.*, 2018).

The native forest preservation areas managed by the company Celulose Nipo-Brasileira - CENIBRA, including the Private Natural Heritage Reserve (PNHR) Fazenda Macedônia, located in the municipality of Ipaba and its surroundings, play an essential role in biodiversity conservation, housing 51 mammal species. Of these, 11 are endangered, including *C. flaviceps* (MASSARA, 2018; CENIBRA, 2021; CARMO, 2022).

Monitoring and population estimates of wildlife species are fundamental to building a good understanding of their ecology, demographic issues, and conservation. This process is also essential to guide the decision-making process, in order to carry out good management and, consequently, good biodiversity conservation (GUILLERA-ARROITA *et al.*, 2010; COELHO *et al.*, 2020). Therefore, this study aims to identify and evaluate the population abundance and density of the species *Callithrix flaviceps* in the region of RPPN Fazenda Macedônia in Ipaba, Minas Gerais, in order to generate a better understanding of the current conservation status of the species.

2. METHODS

2.1. STUDY AREA

The studied area is located on the right bank of the Doce River, within the boundaries of the municipalities of Bugre and Ipaba in the eastern region of Minas Gerais, Brazil (Figure 1). The total size of the area is approximately 4,350 hectares and is owned by the company Celulose Nipo-Brasileira - CENIBRA. Within this area lies the Fazenda Macedônia Private Natural Heritage Reserve, an important remnant of the Atlantic Forest in the state, covering 560 hectares and recognized by IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) through Ordinance No. 111, dated October 14, 1994 (AMARAL *et al.*, 2009).

These areas are characterized by mosaics where eucalyptus plantations and secondary native forests of the Semideciduous Forest type, belonging to the Atlantic Forest domain, predominate in the middle Doce River region (OLIVEIRA-FILHO & FONTES 2000; OLIVEIRA-FILHO

et al. 2006; FRANÇA & STEHMANN, 2013). Of the total area, 52% (2,259 ha) is covered with native forest and 38% (1,660 ha) with eucalyptus plantations (CENIBRA, 2021).

The Fazenda Macedônia is considered a High Conservation Value Area - HCV, a terminology used by the Forest Stewardship Council® - FSC to designate areas considered notably significant or of extreme biological, ecological, social, or cultural importance (FSC, 2016). In the specific case of Fazenda Macedônia, the main attribute that confers it as an HCV is the presence of a significant amount of endangered Brazilian fauna species (CENIBRA, 2021).

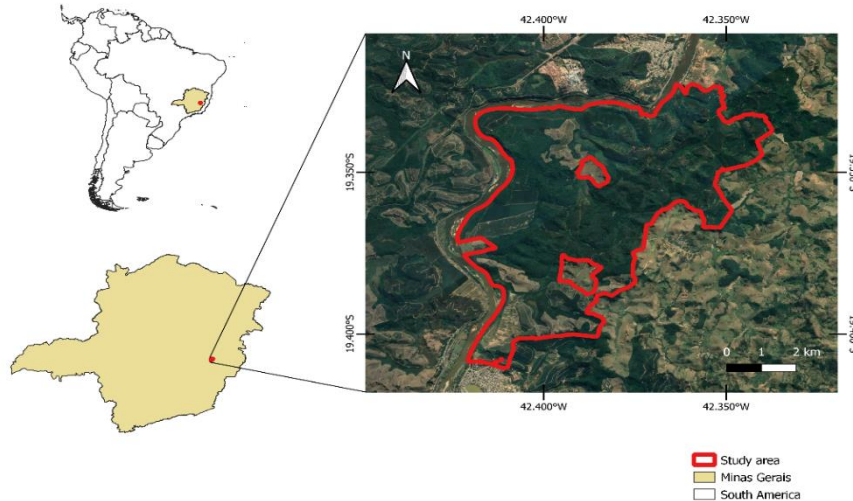


Figure 1 - Location of the region of Fazenda Macedônia, on the right bank of the Doce River, in the eastern region of Minas Gerais.

The predominant climate in this region, according to the Köppen classification, is Aw, which refers to a humid tropical climate with a dry winter and a rainy summer (ALVARES *et al.*, 2013). Over the past 18 years, the average annual temperature has been 23.3 °C, with an average maximum temperature of 30.3 °C and an average minimum temperature of 18.5 °C. The average annual precipitation since 2005 has been 1,230 mm. The average relative humidity during this period has been 76.6%. These data were collected at the Fábrica meteorological station, owned by CENIBRA S.A in Belo Oriente, MG.

2.2. SAMPLING

Data collection was conducted from January to November 2022 in week-long campaigns each month. The study area was divided into non-overlapping hexagons of equal size to be used as sampling units (Figure 2). The dimensions of the hexagons were defined based on an inner circle with a radius of 663 meters, as this is the size of the largest home range recorded for *C. flaviceps* (HILÁRIO & FERRARI, 2010). Randomly, 40% of the existing hexagons were selected for data collection, resulting in a total of 15 polygons. Within these polygons, two to three playback points were defined only in areas of native forest, depending on the amount of native forest present in each hexagon, aiming for a more independent and spatially homogeneous distribution (SMITH, ANDERSON & PAWLEY, 2017). Additionally, a minimum distance of 400 meters was maintained between the points. This distance was defined as twice 200 meters, which is the maximum distance at which the playback sound could be

heard by the team in previously conducted tests, to avoid overlap of the sampled area and prevent double counting of individuals.

The collect was always conducted between 7-11 AM and 1-5 PM, and each playback point lasted 27 minutes, consisting of three cycles of seven minutes of vocalization playback followed by two minutes of silence. For this purpose, a "Megaphone KD150" model speaker with an attached tweeter was used to better accommodate the high-frequency vocalizations of *C. flaviceps* and provide a louder sound reproduction. During the census, individuals sighted were identified based on the phenotype of *C. flaviceps*, classifying them as either "pure" individuals or intermediates with other *Callithrix* species such as *C. penicillata* and *C. geoffroyi*, which were considered hybrids (Silva, 2018). Data such as the number of individuals sighted, age/development stage, date, time, coordinates of the record, and the elapsed time of playback until the group was visualized were recorded.

A total of 75 sampling occasions were conducted, with 5 repetitions of the 15 randomly selected hexagons. All points contained within each hexagon were executed in the shortest possible time. One immediately after the other, to prevent the movement dynamics of the groups from influencing data collection.

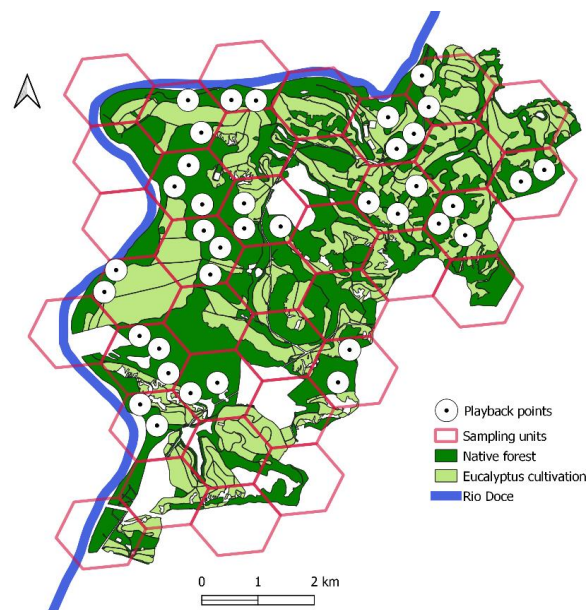


Figure 2 - Playback points in the 15 randomly selected hexagons and the two main components of land use in Fazenda Macedônia: native forests and eucalyptus cultivation

2.3. DATA ANALYSIS

The N-mixture model is a statistical method used to estimate the abundance of a population of individuals from random samples. It is based on probabilistic mixture models, which allow representing the distribution of individuals in a population as a combination of subpopulations. The model is especially useful in situations where the detection of individuals is imperfect. This is common in wildlife studies, where animals may be difficult to detect due to their discretion or ability to camouflage (ROYLE, 2004; KEEVER *et al.*, 2017).

To estimate the abundance (λ) of the total study area, environmental covariates were tested to identify the factors that are related to individual abundance in the sample units (Table 1). Among the covariates tested are the percentage of eucalyptus cultivation (% Eucalipto), percentage of native forest (% Mata), average height of native forest (AltMata), relative percentage of roads (% Estrada), percentage of pasture (% Pasto), and percentage of perennial water bodies (% Agua).

We evaluated model adequacy using a parametric bootstrap of the chi-squared test, using the "Nmix.gof.test" function in the R software package "nmixgof" 1.0.2 (KNAPE *et al.*, 2018) with 1,000 simulations. We estimated the count of *C. flaviceps* at each sampling location and predicted abundance in each non-overlapping hexagon that covers the entire study area ($n = 37$) using the "predict" function in "unmarked" (FISKE & CHANDLER, 2011).

The Binomial model had the best fit, with adequate GoF values, but generated completely unrealistic estimates. This is a relatively common problem, also known as the "good fit, bad prediction" dilemma (KÉRY & ROYLE, 2016; ZULIAN *et al.*, 2020). Therefore, we decided to adopt the Poisson model, which despite exhibiting overdispersion with a C-hat of 2.85, was the only model that delivered realistic lambda estimates. To do this, we chose to correct the estimates considering the value of C-hat, according to the "OD correction" described in chapter 6.9.4 of KÉRY & ROYLE's book (2016).

After estimating the number of individuals in the total study area, population density was calculated based on the ratio of the number of individuals over the area of native forest in square kilometers.

3. RESULTS

We found 31 groups of mountain marmosets (Figure 3) in the 75 sampling occasions, with group size varying from 1-7 individuals (mean of 3.8 ind./group, $SD \pm 1.6$). Only three groups had hybrid marmosets (*Callitrix* sp.), totaling five individuals. From the sampled hexagons, 0-2 groups were detected, but only two hexagons recorded more than one group of marmosets on the same sampling occasion. The average response time of groups to playback calls was 9 minutes, and the maximum response time was 17 minutes.

Models with the covariates of "% Eucalipto" within a radius of 1000 m, "% Mata" within a radius of 100 m, "% Estrada" within a radius of 500 m, and "% Agua" within a radius of 1000 m had the lowest AICc, in that order. These models, with parameters better than the null model, were good predictors of abundance. However, due to the low sample size (15 hexagons), the most significant model with only "% Eucalipto" within a radius of 1000 m was selected to avoid reducing the model's adequacy to the collected data. The models of "AltMata" and "% Pasto" were not good predictors of abundance at any of the spatial scales tested.

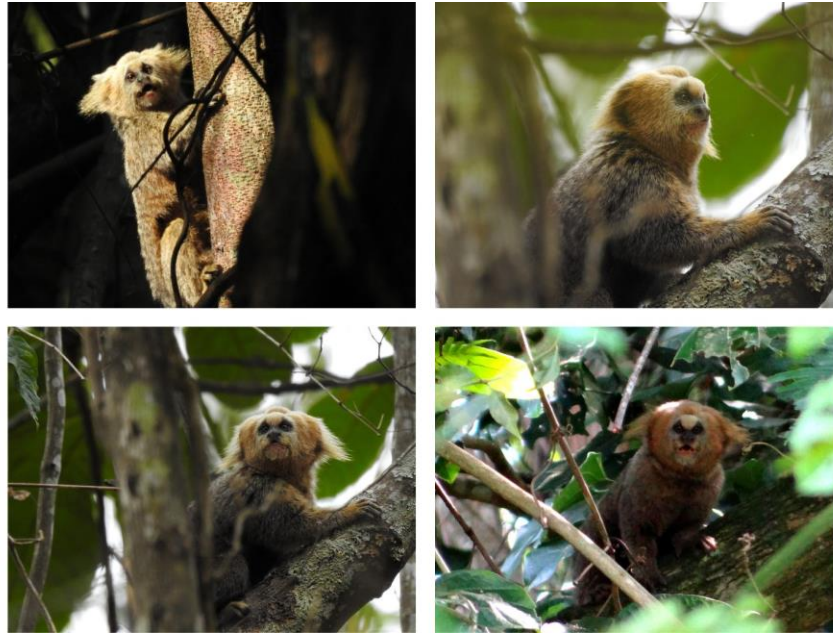


Figure 3. Images of *Callithrix flaviceps* individuals recorded on PNHR Fazenda Macedônia.

The number of playback points (Npbs) was not the same in all sampled hexagons, so a model that considers "% Eucalipto " in 1000 m combined with "Npbs" as a fixed variable of abundance was also tested, to "force" the model to consider that the more playback points (larger area sampled in a site), the greater the number of potentially sampled individuals in that site. However, this model had a higher AICc than the model with only "% Eucalipto " in 1000 m, showing to be less significant.

The estimated average abundance from the N-mixture model for the entire study area (37 hexagons) is 257.3 individuals (95% CI = 205.5-309 individuals). The estimated density from the N-mixture model for the entire native forest area is 11.4 individuals/km² (95% CI = 9.1-13.7 ind./km²).

Model	AICc	Δ AICc	ModelLik	AICcWt	LL
mEucalipto	291,70	0	1	9,95E-01	-141,76
mMata	302,20	10,51	5,23E-03	5,20E-03	-147,01
mEstrada	312,06	20,36	3,78E-05	3,76E-05	-151,94
mAgua	313,49	21,80	1,85E-05	1,84E-05	-152,65
mnull	314,37	22,68	1,19E-05	1,18E-05	-154,69
mAltMata	314,62	22,93	1,05E-05	1,04E-05	-153,22
mPasto	317,35	25,65	2,69E-06	2,67E-06	-154,58

Table 1: Comparison to define the best models.

Abbreviations: mEucalipto, model with eucalyptus cultivation; mMata, model with native forest; mEstrada, model with roads; mAgua, model with perennial water bodies; mnull, null model; mAltMata, model with average height of native forest; mPasto, model with pasture; AICc, Akaike information criterion corrected for small sample sizes; Δ AICc, the difference between the AICc of each model and the AICc of the most parsimonious model; ModelLik, likelihood function; AICcWt, AICc weight; LL, log-likelihood function of the models.

4. DISCUSSION

Some studies have assessed the population densities of *Callithrix flaviceps* in different conservation units within the species' range, such as the Augusto Ruschi Biological Reserve located in Espírito Santo, where Pinto *et al.* (1993) and Hilário (2009) reported average densities of 7.1 individuals/km² and 15.4 individuals/km², respectively. On the other hand, the Feliciano Miguel Abdala Private Natural Heritage Reserve in Minas Gerais exhibited observed densities of 40 individuals/km² (Ferrari, 1988) and 13 individuals/km² (Almeida-Silva *et al.*, 2005). However, a population in the Caratinga region experienced a significant decline in abundance due to the yellow fever outbreak in 2016-2017, with an 80% loss in size, reducing the population from 85 individuals to 15-17 individuals after the outbreak (POSSAMAI *et al.*, 2022). This suggests that other subpopulations of the species may have also suffered losses from the zoonosis in other locations, placing their conservation in an even more concerning situation.

In comparison to other locations, PNHR Fazenda Macedônia exhibited a population density within the expected range with 11.4 individuals/km². However, in the post-yellow fever outbreak context that occurred in the Southeast of Brazil in previous years, the population density of the species in the PNHR Fazenda Macedônia region is potentially one of the highest in Brazil currently.

Carmo (2022) estimated the occupancy probability of the species in the Fazenda Macedônia Private Natural Heritage Reserve and fragments in its surroundings (the same study area), and identified a mean occupancy probability of *C. flaviceps* of $\psi = 0.55$ throughout the study area. This result suggests that the species has a good chance of occupying a large part of Fazenda Macedônia, corroborating with the present study in attesting to the quality of the area for the conservation of the species.

The presence of hybrid marmoset groups in a preserved forest can be concerning as it leads to competition with the native species and loss of genetic heritage. Furthermore, the presence of these hybrids can negatively affect social and reproductive interactions among individuals of different species, compromising the survival of these populations (MALUKIEWICZ *et al.*, 2014; MALUKIEWICZ *et al.*, 2021). Therefore, identifying and managing these groups are important measures for biodiversity conservation (VITAL *et al.*, 2020). Although the number of individuals with hybrid phenotypes present in the sampled area is low compared to individuals with the phenotype of the native species, it is recommended to implement population management measures to control the invasive population. Among these measures, sterilization of hybrid individuals stands out, which can be adopted as a strategy to prevent the proliferation of these groups. Maciel (2023) carried out a capture and sterilization campaign of a group of 8 hybrid individuals in the same area evaluated in this study and suggests that other sterilization campaigns be carried out with the remaining unsterilized individuals in Fazenda Macedônia. Early implementation of population management is crucial to minimize negative effects, as an increase in the number of invasive individuals can make the problem more complex and difficult to solve.

During data collect, it was observed that no pure or mixed group was recorded after 17 minutes of stimulation using the playback technique, indicating that this is the time limit for calling at

each sampling point to maximize sampling efficiency in future studies. This observation is relevant since optimizing data collection time is crucial to increase sampling effort and, consequently, the reliability of results.

In this particular study, a negative relationship was identified between the percentage of eucalyptus forests and the abundance of the Buffy-headed marmoset, which proved to be a suitable prediction model for Fazenda Macedônia. This result can be explained by two plausible factors: Firstly, it is known that, when compared to native forest areas, eucalyptus forests are considered a less suitable habitat for sustaining populations of medium and large mammals due to relatively lower resource availability (CALVIÑO-CANCELA *et al.*, 2012). The second factor is that eucalyptus areas represent almost the entirety of the matrix in Fazenda Macedônia, occupying about 80% of the space between native forest fragments and, therefore, having more significant values than other types of matrices tested as parameters for abundance estimation.

However, recent studies have highlighted the potential of eucalyptus plantations to act as an important ally in biodiversity conservation. In landscapes where forests are the natural land cover, eucalyptus areas can serve as ecological corridors, connecting forest fragments and facilitating gene flow between subpopulations, in addition to providing complementary forest habitat and reducing edge effects on native forest fragments. This is largely due to the fact that planted forests are a low-contrast matrix when compared to matrices composed of other forms of agricultural cultivation (BROCKERHOFF *et al.*, 2008).

The study by Bonilla-Sánchez *et al.* (2012) found that a population of *Alouatta pigra* frequented areas of eucalyptus plantation and fed on resources available in the understory throughout the year, without negatively affecting population growth. Therefore, if forest management is done with environmental responsibility, eucalyptus planting can contribute to maintaining population dynamics and increasing biological diversity in fragmented forests. According to LINDENMAYER & HOBBS (2004) and FRANKLIN & LINDENMEYER (2009), improving matrix quality can generate greater conservation benefits than manipulating the size and configuration of remaining fragments, which are affected by habitat destruction (PRUGH *et al.* 2008).

5. CONCLUSION

This study provides the first data on the abundance and population density of the Buffy-headed marmoset in the Fazenda Macedônia Private Natural Heritage Reserve, bringing hope for the conservation of the species by revealing the existence of an important population inhabiting a protected area. Despite the significant population losses the species has experienced over the past decades, the population density value found in the Fazenda Macedônia is comparable to historical values in other important areas where the species occurs. This fact highlights the importance of this area for the conservation of the black-fronted titi monkey.

The results will also enable future Population Viability Analysis (PVA), another important tool to understand population dynamics and develop strategies to maintain its viability and growth.

Ultimately, the obtained results contribute to the development of effective strategies to reduce the population decline, in line with the National Action Plan for the conservation of primates in the Atlantic Forest and the Maned Three-Toed Sloth, aiming for the long-term survival and conservation of the species.

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