

**UNIVERSIDADE FEDERAL DE VIÇOSA**

**Ecology of southern muriquis (*Brachyteles arachnoides*) in the Área de  
Proteção Ambiental Barreiro Rico, São Paulo, Brazil**

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*Doctor Scientiae*

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**Ecology of southern muriquis (*Brachyteles arachnoides*) in the Área de  
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Thesis submitted to the Ecology Graduate Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Doctor Scientiae*.

Adviser: Fabiano Rodrigues de Melo

Co-adviser: Karen Barbara Strier

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## ABSTRACT

ROBBI, Beatriz, D.Sc., Universidade Federal de Viçosa, March, 2026. **Ecology of southern muriquis (*Brachyteles arachnoides*) in the Área de Proteção Ambiental Barreiro Rico, São Paulo, Brazil.** Adviser: Fabiano Rodrigues de Melo. Co-adviser: Karen Barbara Strier.

The Southern muriqui (*Brachyteles arachnoides*), the largest primate in America, is endemic to the Atlantic Forest in southeast Brazil. Its westernmost distribution is in the Área de Proteção Ambiental (APA) Barreiro Rico, in the interior of São Paulo state. This area has some forest fragments surrounded by pasture and sugarcane, eucalyptus and citrus plantations, but has a very rich biodiversity. The first register of muriquis in the APA Barreiro Rico dates from the 70's; since then, there has been some research in the 80's and again in the 00's, mainly studying the ecology and behaviour of muriquis and other primates. In 2022, a primate survey indicated a decline in the muriqui population size, raising concerns for local species conservation and the need for updated information. Our research is divided into three chapters. (1) In order to know the real size of the *B. arachnoides* population, we did a primate survey with thermal drones flying over eight forest fragments. In 127 flight hours covering 2,947 km, we recorded only 12 southern muriquis, in two groups across two fragments: one on private property and the other in the public protection area Estação Ecológica (ESEC) Barreiro Rico. (2) The second chapter aimed to compare some variables in two forest fragments, where there were registers of muriquis in the past (São Francisco do Tietê (SFT) Farm) and where they live now (ESEC Barreiro Rico). To test whether the number of food resource species and the number of larger trees were important variables in the species' occurrence, hypothesizing that they would be higher in the ESEC Barreiro Rico, where they occur nowadays. We implemented 10 plots (900 m<sup>2</sup> each) across those forest fragments. 943 trees with DBH > 5cm were measured, and samples were collected for further identification. The number of larger trees in both fragments is similar, the number of food resource trees is higher in the SFT Farm, but the proportion of the basal area of food resource trees is higher in the ESEC Barreiro Rico, indicating a possible preference for larger food patches. But, as the differences were small, we also raised the possibility that the legalized hunting of invasive species and, especially, forest fires play a major role in the population decline. The last part of this work (3) monitored the small group present in the ESEC Barreiro Rico to study their behaviour and diet, and to determine whether there is seasonal variation in their activities and food consumption throughout the year. We

monitored them between July 2023 and August 2024, recording their location, activity and height in the tree. We also monitored 642 trees in the plot at ESEC Barreiro Rico to study phenology and compare the availability of items with their consumption. We analysed 28 days with more than 10 scans from the adults in the group. They preferred taller trees, where they spent most of their time resting, followed by feeding, locomotion, and socializing. Only resting had a seasonal difference. There is no difference in their diet by item between the wet and dry seasons. Leaves and flowers were the most-consumed items, followed by seeds. And they had a strong preference for certain items, such as ripe fruit and flowers. All the information collected during this research is very helpful for understanding their behaviour and habitat use, and for improving decisions about local conservation efforts for the species.

Keywords: thermal drone; forest inventory; phenology; behavioural monitoring

## RESUMO

ROBBI, Beatriz, D.Sc., Universidade Federal de Viçosa, março de 2026. **Ecologia dos muriquis-do-sul (*Brachyteles arachnoides*) da Área de Proteção Ambiental Barreiro Rico, São Paulo, Brasil.** Orientador: Fabiano Rodrigues de Melo. Coorientador: Karen Barbara Strier.

O muriqui-do-sul (*Brachyteles arachnoides*), o maior primata das Américas, é endêmico da Mata Atlântica no sudeste do Brasil. Sua distribuição mais ocidental ocorre na Área de Proteção Ambiental (APA) Barreiro Rico, no interior do estado de São Paulo. Essa área possui alguns fragmentos florestais, circundados por pastagens e plantações de cana-de-açúcar, eucalipto e citros, e apresenta rica biodiversidade. O primeiro registro de muriquis na APA Barreiro Rico data da década de 1970; desde então, houve pesquisas nas décadas de 1980 e 2000, que estudaram principalmente a ecologia e o comportamento dos muriquis e de outros primatas. Em 2022, um levantamento de primatas indicou um declínio no tamanho da população de muriquis, o que gerou um alerta para a conservação da espécie na região e a necessidade de informações atualizadas. Nossa pesquisa está dividida em três capítulos. (1) Para determinar o tamanho real da população de *B. arachnoides*, realizamos um levantamento de primatas com drones térmicos sobrevoando oito fragmentos florestais. Em 127 horas de voo, cobrindo 2.947 km, registramos apenas 12 muriquis-do-sul, em dois grupos em dois fragmentos: um em propriedade privada e o outro na área de proteção pública Estação Ecológica (ESEC) Barreiro Rico. (2) O segundo capítulo teve como objetivo comparar algumas variáveis entre dois fragmentos florestais, um no qual havia registros de muriquis no passado (Fazenda São Francisco do Tietê (SFT)) e outro no qual eles vivem atualmente (ESEC Barreiro Rico). Para verificar se o número de espécies de recursos alimentares e de árvores com diâmetros maiores eram variáveis importantes na ocorrência da espécie, hipotetizamos que seria maior na ESEC Barreiro Rico, onde ocorrem atualmente. Implementamos 10 parcelas (900 m<sup>2</sup> cada) nesses fragmentos. Foram medidas 943 árvores com DAP > 5 cm e coletadas amostras para identificação posterior. O número de árvores maiores é semelhante em ambos os fragmentos; o número de árvores de recursos alimentares é maior na Fazenda SFT, mas a proporção da área basal dessas árvores é maior na ESEC Barreiro Rico, indicando uma possível preferência por áreas de alimentação maiores. Como as diferenças eram pequenas, levantamos também a possibilidade de que a caça legalizada de espécies invasoras e, especialmente, os incêndios florestais tenham um papel importante no declínio populacional.

A última parte deste trabalho (3) consistiu no monitoramento do pequeno grupo presente na ESEC Barreiro Rico, para estudar seu comportamento e sua dieta e determinar se há variação sazonal em suas atividades e no consumo alimentar ao longo do ano. Monitoramos o grupo entre julho de 2023 e agosto de 2024, registrando sua localização, atividade e altura na árvore. Monitoramos também 642 árvores na parcela da ESEC Barreiro Rico para estudar a fenologia e comparar a disponibilidade de itens com o consumo desses itens. Analisamos 28 dias com mais de 10 observações de adultos do grupo. Eles preferiram árvores mais altas, onde passaram a maior parte do tempo descansando, seguida de alimentação, locomoção e socialização. Apenas o descanso apresentou diferença sazonal. Não houve diferença na dieta por item entre as estações chuvosa e seca. Folhas e flores foram os itens mais consumidos, seguidos pelas sementes. E eles demonstraram forte preferência por certos itens, como frutos maduros e flores. Todas as informações coletadas durante esta pesquisa são muito úteis para compreender o comportamento e o uso do habitat desses animais e também para aprimorar as decisões relativas aos esforços de conservação local da espécie.

Palavras-chave: drone térmico; inventário florestal; fenologia; monitoramento comportamental

## Summary

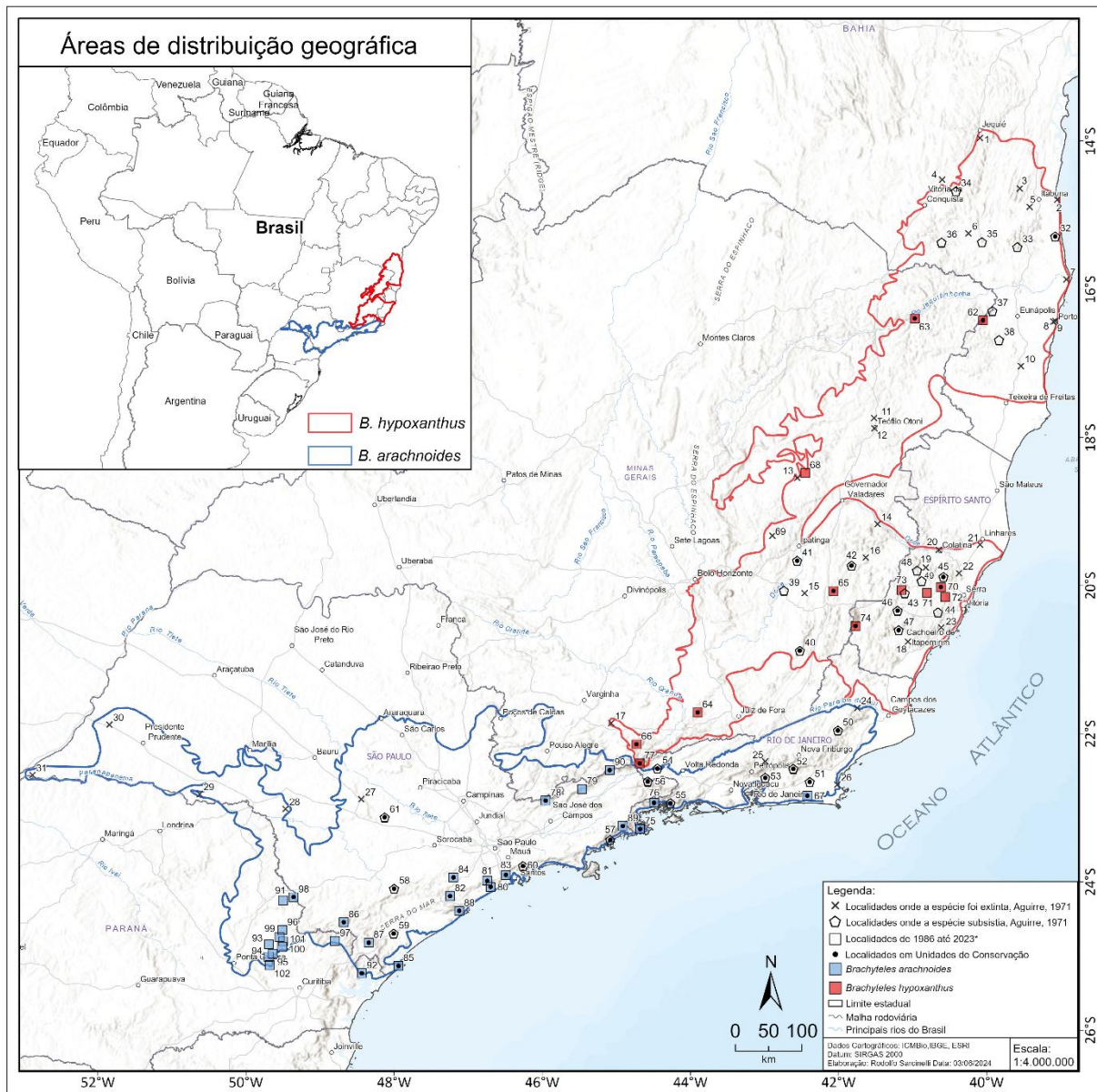
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## Introduction

The southern muriqui (*Brachyteles arachnoides*) is an endemic primate from the Atlantic Forest in southeast Brazil. It's one of the largest primates in the Americas, weighing up to 10 kg and measuring around 1.2m (Lemos de Sá; Glander, 1993), with herbivorous habits, feeding mainly on leaves, fruits and flowers, and it is an arboreal primate, preferring the dossel of taller trees (Milton, 1984; Martins, 2005c). The *B. arachnoides* lives in groups, with fluid composition varying throughout the day. The largest group ever registered comprised 48 individuals and lived in the Parque Estadual Carlos Botelho, another occurrence area where there is a long-term study with the largest population for this species (Talebi; Beltrão-Mendes; Lee, 2009; Coles; Lee; Talebi, 2012).

The southern muriqui is listed as 'Critically Endangered' by the International Union for Conservation of Nature (IUCN) and as 'Endangered' by the Brazilian government (Talebi et al., 2021; MMA, 2022). The species is also part of a governmental conservation program (Plano de Ação Nacional para a Conservação dos Primatas da Mata Atlântica e das Preguiças-de-Coleira and Programa de Manejo Populacional do Muriqui do Sul) that establishes conservation strategies to protect and restore habitats, reduce population declines and involve society in the species conservation (ICMBio, 2025a). Its occurrence is restricted to approximately 40 locations in the states of Rio de Janeiro, extreme south of Minas Gerais, São Paulo, and Paraná (Figure 1), and it is estimated that 1300 individuals are distributed across these locations (Melo; Jerusalinsky, 2024).

In São Paulo state, the westernmost occurrence of *B. arachnoides* is in the Área de Proteção Ambiental (APA) Barreiro Rico, a protected area. Surrounded by pasture and plantations of citrus, eucalyptus, and sugarcane, with a few forest fragments remaining and a high risk of forest fires, a rich biodiversity persists, including five species of primates, the *B. arachnoides*, *Alouatta guariba*, *Sapajus nigritus*, *Callicebus nigrifrons* and *Callithrix aurita* (Fundação Florestal, 2021; Mendes; Aguirre, 2024).



**Figure 1.** Map with the distribution of genus *Brachyteles*. In blue, the Southern muriqui (*B. arachnoides*) distribution and in red, the Northern muriqui (*B. hypoxanthus*) distribution. Occurrence in protected areas are marked with a ● and private properties marked with a □ (Melo; Jerusalinsky, 2024).

The muriquis from APA Barreiro Rico had been studied a few times since their first documentation (Aguirre, 1971). At the beginning of the 80's, Cecília Torres de Assumpção and Katherine Milton studied the ecology, covering topics such as distribution, population estimates, diet, and behaviour, then Rosa Lemos de Sá and Kenneth Glander studied capture techniques (Torres de Assumpção, 1983; Milton, 1984, 1985a, 1985b, 1986; Lemos de Sá; Glander, 1993). In the early 2000s, Milene Martins updated the population count, studied the density of primates in the region, and the ecology, while in the same decade, Maria Aparecida de Oliveira Azevedo-Lopes studied the behaviour of one of the existing groups in the region (Azevedo-Lopes, 2000; Martins, 2003, 2005a, 2005b, 2005c, 2008). Only in 2022 were the

studies back, with a primate survey commissioned by the Fundação Florestal do Estado de São Paulo and with our research starting in 2023 (Hileia, 2022; Robbi et al., 2025).

**Table 1.** All research with southern mureiqui in the APA Barreiro Rico found in academic databases. In the past, almost the entire study area was known as Barreiro Rico Farm, but today, the area is divided into different properties. The current names and their corresponding origins are as follows: Sarã is now São Francisco do Tietê Farm. Virareiro and Sede (and probably Água Funda as well) correspond to Bacury, Volta Redonda, and Barreiro Rico Farms together. Tabatingueira (and probably Cateto Branco as well) corresponds to the area now occupied by São Francisco do Tietê Farm and ESEC Barreiro Rico together. Monal (and probably Barreirinha as well) corresponds to Onça Queimada and Descalvado Farms. Only Água Sumida remains unchanged. Água Funda, Cateto Branco and Barreirinha are not confirmed because there was no map to check the location, but we can infer from the size of the forest fragment.

Title	Author	Year	Method	Sampling effort	Sampled areas	Observed /Estimated Population
O mono <i>Brachyteles arachnoides</i>	Aguirre	1971	Basic survey	-	Barreiro Rico Farm (2568 ha): Barreirinha (340 ha), Água Funda (1681 ha) and Cateto Branco (540 ha)	50-60
Ecological and behavioural information on <i>Brachyteles arachnoides</i>	Torres de Assumpção	1983	Opportunistic observations	1240h in total 21h of monitoring	Barreiro Rico Farm (1386 ha)	11-30
Habitat, Diet, and Activity Patterns of Free-Ranging Woolly Spider Monkeys ( <i>Brachyteles arachnoides</i> E. Geoffroy 1806)	Milton	1984	Census	11 months	Barreiro Rico Farm (3259 ha)	85-100 (Sarã: 45)
Population Estimate for <i>Brachyteles</i> at Fazenda Barreiro Rico, São Paulo State, Brazil	Milton and De Lucca	1984	Census	11 months	Barreiro Rico Farm: Sarã (422 ha), Virareiro (611 ha), Sede (325 ha), Tabatingueira (540 ha) and Monal (353 ha)	85-100 (Monal: 43; Virareiro :25; Sarã: 45)
Mating patterns of woolly spider monkeys, <i>Brachyteles arachnoides</i> : implications for female choice	Milton	1985a	Behavioural observations (scan samples)	6 months	Sarã (422 ha)	5 females + 2 infants
Urine Washing Behavior in the Woolly Sider Monkey ( <i>Brachyteles arachnoides</i> )	Milton	1985b	Behavioural observations (scan samples)	31 days	Sarã (422 ha)	7 females + 7 males
Ecological Background and Conservation Priorities for Woolly Spider Monkeys	Milton	1986	Behavioural observations (scan samples)	11 months	Barreiro Rico Farm: Sarã (422 ha), Virareiro (611 ha), Sede (325 ha), Tabatingueira (540 ha) and Monal (353 ha)	Monal (12-14), Virareiro (23-28), Sarã (43-45)

Capture Techniques and Morphometrics for the Woolly Spider Monkey, or Muriqui ( <i>Brachyteles arachnoides</i> , E. Geoffroy 1806)	Lemos de Sá and Glander	1993	Capture techniques	-	Barreiro Rico Farm (1000 ha)	-
Ecologia e Comportamento do Mono-Carvoeiro do Sul ( <i>Brachyteles arachnoides</i> ), na Fazenda São Francisco do Tietê (SP): Contribuindo para a Conservação do Gênero	Azevedo-Lopes	2000	Behavioural observations (scan samples)	7 months	São Francisco Tietê Farm (500 ha)	16
Forest fragments in Barreiro Rico, Southern Brazil: the need for conservation action	Martins	2003	-	-	Barreiro Rico Farm (2325 ha)	-
Density of Primates in Four Semi-deciduous Forest Fragments of São Paulo, Brazil	Martins	2005a	One and Two-way line-transect surveys + pooled analysis + Distance	10 months	Barreiro Rico Farm: Água Sumida (240 ha), Virareiro/Tabatingueira (1450 ha), Sarã (501 ha) and Monal (374 ha)	601
Comparative Seed Dispersal Effectiveness of Sympatric <i>Alouatta guariba</i> and <i>Brachyteles arachnoides</i> in South-eastern Brazil	Martins	2005b	Collection of dung and observations of feeding behaviour	12 months	Barreiro Rico Farm (1450 ha)	-
The Southern Muriqui, <i>Brachyteles arachnoides</i> : Ecology of a population in a semideciduous forest fragment	Martins	2005c	Behavioural observations (scan samples)	12 months	Barreiro Rico Farm (1450 ha)	25-30
Fruit diet of <i>Alouatta guariba</i> and <i>Brachyteles arachnoides</i> in South-eastern Brazil: comparison of fruit type, colour, and seed size	Martins	2008	Behavioural observations (scan samples)	12 months	Barreiro Rico Farm (1450 ha)	25-30
Levantamento de dados Populacionais para Ações de Conservação dos Primatas da APA Barreiro Rico e da Estação Ecológica Barreiro Rico	Hileia	2022	Line-transect surveys + Distance + Playback	3 months (335.36 km)	Área de Proteção Ambiental Barreiro Rico: Água Sumida Farm, São Francisco Tietê Farm, Bacury Farm, Estação Ecológica Barreiro Rico, Onça Queimada Farm and Volta Redonda Farm	45

Nowadays, we have the advantage of using new technologies in research involving wildlife, such as the use of drones equipped with thermal cameras to survey or monitor populations, and it's an increasing method of research for several species and habitats (Spaan et al., 2019; Brunton; Leon; Burnett, 2020; Santos et al., 2023). Some species of primates, such as the southern muriqui, are very good candidates for search with this technology, as they are large, arboreal primates that primarily use the dossel (Melo, 2021; Gazagne et al., 2024).

Our research aim is to study the ecology of the southern muriqui in the APA Barreiro Rico, collecting information on the distribution, population size, behaviour, diet and use of space. This information will allow for a better understanding of how and where they are surviving, if the area can still sustain the muriqui population, and support conservation efforts for the local population, since the last studies were 20 years ago, and a major decline in the *B. arachnoides* population size was reported in 2022.

This thesis is divided into three chapters: (1) we conducted a survey of primates with a thermal drone in more forest fragments than the previous census, on private properties and in the public protected area, Estação Ecológica (ESEC) Barreiro Rico, to assess the current state of this population, including distribution and population size in those forest fragments. (2) the structure of two forest fragments, with and without muriquis living there now, to understand whether the availability of food resources and larger trees can influence the presence of southern muriquis. (3) And to conclude the research, we conducted a behavioural monitoring of the group in the ESEC Barreiro Rico, taking notes and collecting data on behaviour, diet, and home range to better understand how they use the forest.

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# 1. Use of thermal drone to survey *Brachyteles arachnoides* at Área de Proteção Ambiental Barreiro Rico, São Paulo, Brazil

## 1.1 The last remaining Southern Muriquis (*Brachyteles arachnoides*) from the interior of São Paulo state, Brazil

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The southern miqui *Brachyteles arachnoides*, one of the largest primates in the Americas, is categorized as Critically Endangered on the IUCN Red List. It is endemic to the Brazilian Atlantic Forest, where it is restricted to the states of Paraná, São Paulo, Rio de Janeiro and the extreme south of Minas Gerais. The most north-western population in São Paulo state occurs in the Barreiro Rico Environmental Protection Area, a 30,142-ha area including the Barreiro Rico Ecological Station and seven other fragments with a total of 3,818 ha of forest. Intensive agricultural activities (sugar cane, eucalyptus, citrus) and pasture have significantly altered the landscape between the Tietê and Piracicaba Rivers, causing forest fragmentation. Yet despite these environmental changes, the Protection Area has a rich biodiversity and is home to five sympatric primates: the buffy tufted-ear marmoset *Callithrix aurita*, the brown-howler monkey *Alouatta guariba*, the black-fronted titi monkey *Callicebus nigrifrons*, the black-horned capuchin *Sapajus nigritus* and the southern miqui *Brachyteles arachnoides*.

The miqui population at Barreiro Rico is considered a top priority for the species because of its extreme geographical location and isolation (Strier et al., 2017, PLOS One, 12, e0188922). The population was first estimated at 50–60 individuals by Aguirre (1971, Academia Brasileira de Letras) and subsequent estimates recorded population growth during the 1970s to the early 2000s (Milton, 1984, International Journal of Primatology, 5, 491–514; Martins, 2005, Biodiversity and Conservation, 14, 2321–2329). However, in 2012 and 2018, two large fires destroyed parts of three forest fragments and one entire fragment, reducing the size and quality of the forest. In a 2022 census commissioned by the Fundação Florestal (carried out by environmental consulting company Hileia Consultoria Ambiental) only 45 miquis

were estimated to remain, in an area of 2,250 ha. These results must be interpreted with caution because of the low rate of sightings.

With funding from the Fundação do Amparo à Pesquisa do Estado de Minas Gerais and Re:wild, and logistical support from the Fundação Florestal do Estado de São Paulo, we used a drone equipped with an infrared and a colour camera to search for southern muriquis in the Barreiro Rico Environmental Protection Area during January–August 2024. In 127 flight hours covering 2,947 km we recorded only 12 southern muriquis, in two groups in two fragments: the Barreiro Rico Ecological Station, a federal conservation unit of 293 ha, and a private property of 926 ha. We noted other primate species including the black-horned capuchin *Sapajus nigritus* and brown howler monkey *Alouatta guariba* in other fragments, suggesting that our failure to locate muriquis in these areas was not because of poor visibility or flight conditions. Our results highlight the precarious status of this unique *Brachyteles arachnoides* population and emphasize the urgent need for conservation and management actions to rescue it.

## 1.2 Thermal drone as an effective tool to survey primates in the Atlantic Forest in the interior of Brazil

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### Abstract

The use of drones equipped with infrared, or thermal, sensors to search for animals in different biomes has increased in recent years. Large primates that use the tree canopy, such as the southern muriqui (*Brachyteles arachnoides*), are relatively easy to detect, and therefore are good targets for drones. Endemic to the Atlantic Forest of southeastern Brazil and considered Critically Endangered, the southern muriqui is present in approximately 40 locations in the states of São Paulo, Minas Gerais, Rio de Janeiro, and Paraná. The most inland population of southern muriquis occurs in the Area de Proteção Ambiental (APA) Barreiro Rico, an Environmental Protection Area that is highly fragmented by human influence and has suffered from recurrent fires. Since the early 1980s, the size of the population has declined, making a more detailed assessment necessary to understand its current status. Between January and August 2024, a drone with thermal camera was flown over eight forest fragments separated by roads, pastures and plantations to search for muriquis. Several species of mammals were recorded, and all fragments included at least one primate species (e.g., black-horned capuchin monkey (*Sapajus nigritus*), brown howler monkey (*Alouatta guariba*), or southern muriqui). Only two groups of southern muriquis, with a total of 12 individuals, were sighted in two of the fragments, confirming the need for management actions for this population. These results also reinforce the value of drones equipped with thermal cameras for surveying endangered primates.

### Resumo

O uso de drones equipados com sensores infravermelhos, ou térmicos, para procurar por animais em diferentes biomas tem aumentado nos últimos anos. Grandes primatas que utilizam a copa das árvores, como o miquiqui-do-sul (*Brachyteles arachnoides*) são relativamente fáceis de detectar, portanto são bons alvos para a busca com drones. Endêmico da Mata Atlântica do sudeste do Brasil e considerado criticamente em perigo, o miquiqui-do-sul está presente em aproximadamente 40 localidades nos estados de São Paulo, Minas Gerais, Rio de Janeiro e Paraná. A população mais interiorana de miquiqui-do-sul está localizada na Área de Proteção Ambiental Barreiro Rico (APA Barreiro Rico), uma área altamente fragmentada pela influência humana e que tem sofrido com incêndios recorrentes. Desde a década de 1980, o tamanho da população diminuiu, o que torna necessário uma avaliação mais detalhada para entender seu estado atual. Entre janeiro e agosto de 2024, um drone com câmera térmica sobrevoou oito fragmentos florestais separados por estradas, pastagens e plantações para procurar por miquiquis. Várias espécies de mamíferos foram registradas e todos os fragmentos incluíam pelo menos uma espécie de primata, por exemplo, macaco-prego (*Sapajus nigritus*), bugio-ruivo (*Alouatta guariba*) ou miquiqui-do-sul. Apenas dois grupos de miquiquis-do-sul, com um total de 12 indivíduos, foram avistados em dois dos fragmentos, confirmando a necessidade de ações de manejo para esta população. Esses resultados também reforçam a importância de drones equipados com câmera térmica no levantamento de primatas ameaçados.

## **Keywords**

APA Barreiro Rico, *Brachyteles arachnoides*, Forest Fragmentation, Infrared Camera, Local Extinction, Primate Survey, Southern Miquiqui, Unoccupied Aerial Vehicle.

## **Introduction**

Censusing nonhuman primate (hereafter, primate) populations is important to assess density, changes in numbers over time, and habitat variation for the species (Plumptre & Cox, 2006). This information can be used along with the understanding of ecology, behaviour and habitat needs to improve conservation strategies (Strier et al., 2017). The most common technique for conducting primate surveys is the line transect, where the researcher walks along defined trails, and measures the distance between the animal detected and the trail (Buckland et al., 2010). Increasingly, the use of unmanned aerial vehicles (drones) equipped with colour

and infrared (thermal) cameras have proven effective for surveying and monitoring fauna (Burke et al., 2019; Beaver et al., 2020; Brunton et al., 2020; Corcoran et al., 2021; Santos et al., 2023). When flying over a forest, animals stand out as heat sources in the canopy and can therefore be detected by the infrared camera. The greater distances that can be reached by a drone permit drone surveys to be carried out in a shorter period of time, making drone surveys an efficient method for finding large, arboreal animals, such as muriquis, *Brachyteles* spp. (Spaan et al., 2019; Zhang et al., 2020; Melo, 2021; Gazagne et al., 2024).

The genus *Brachyteles* is the largest primate in the Americas and endemic to the Brazilian Atlantic Forest (Talebi et al., 2021). The southern muriqui (*B. arachnoides*) is classified nationally as “Endangered” (MMA, 2022) and as “Critically Endangered” by the International Union for Conservation of Nature (Talebi et al., 2021). The main threat is habitat loss, which restricts its distribution to very few viable areas (Talebi et al., 2021). The western limit of its distribution is the Área de Proteção Ambiental Barreiro Rico (APA Barreiro Rico), an Environmental Protection Area located in the central region of the state of São Paulo, Brazil, where the Piracicaba and Tietê rivers meet.

The APA Barreiro Rico is an area of the Atlantic Forest with great ecological importance, as it is home to a rich biodiversity and is the only protected area in the interior of the state with five sympatric species of primates: the buffy-tufted-ear marmoset (*Callithrix aurita*), the black-fronted titi monkeys (*Callicebus nigrifrons*), the black-horned capuchin (*Sapajus nigritus*), the brown howler monkey (*Alouatta guariba*) and the southern muriqui (*Brachyteles arachnoides*) (Martins, 2005). It is considered a priority for the conservation of the southern muriqui, due to its geographic location and its isolation from other populations (Strier et al., 2017). Moreover, the southern muriqui population in the APA Barreiro Rico appears to have greatly declined since the early 1980s, from some 78-87 individuals in three fragments (Milton & de Lucca, 1984; Milton, 1986) to only 12 individuals in two fragments in 2024 (Robbi et al., 2025), raising the question of whether additional animals in these or other fragments might be present but unaccounted for in terrestrial surveys.

Demographic monitoring of small populations of muriquis at regular intervals has been identified as a priority by the Brazilian National Action Plan for the genus (Jerusalinsky et al., 2011; Strier et al., 2017). Given the need to assess the current situation of the muriquis in the APA Barreiro Rico and plan a management program to preserve this population, we used thermal drone overflights in the forest fragments. The large body size and vertical strata use of this species are two factors that make muriquis relatively easy to locate by thermal drones

(Corcoran et al., 2021; Gazagne et al., 2024). The specific aim of this study was to identify and count individuals to confirm the size of the population and the number of different groups of muriquis in the APA Barreiro Rico. Because the muriquis are the largest of the sympatric primates, we considered the detection of other, smaller primate species in these forest fragments to indicate that the failure to detect muriquis was an accurate reflection of their absence in those fragments.

### **Study area**

The study area is the Área de Proteção Ambiental (APA) Barreiro Rico (Figure 1), located in the interior of the state of São Paulo, encompassing the cities of Anhembi, Botucatu, Piracicaba, and São Pedro (22°41'S, 48°06'W). The APA Barreiro Rico has an area of 30,142.63 hectares, consisting of public and private lands. There are large areas of pasture (28.3%), sugarcane (17.2%) and citrus (11.3%) plantations, and some areas with Eucalyptus plantations (5.9%), which are very close to 18.8% of the APA comprised of native forest vegetation and the predominant biome is the Atlantic Forest, with Semideciduous Seasonal Forest and Cerrado enclave (Fundação Florestal, 2021).

The altitude varies from 450 to 586 meters, and the terrain is generally flat (Torres de Assumpção, 1983; Martins, 2005). According to the Koeppen system, the climate of the region is CwA, hot and humid (Torres de Assumpção, 1983), with an average annual precipitation of 1,203 mm, with rains concentrated from October to March (Fundação Florestal, 2021). The average temperature is 21.3 degrees, with May to August being the coldest months of the year, and September to April being the hottest months (Fundação Florestal, 2021).

The fragments were selected based on previous work in the region, including past records of primates and personal communication with the local community. Eight fragments were chosen for overflight (Table 1; Figure 1), with Bacury Farm, São Francisco do Tietê Farm, and Estação Ecológica (ESEC) Barreiro Rico having a historical presence of southern muriquis (see legend to Figure 1) (Milton, 1984; Martins, 2005; Hileia, 2022). These three fragments were severely affected by a fire in 2018 (Fundação Florestal, 2021), but all of the fragments are separated by agricultural lands or unpaved roads and have edges with some degree of degradation, characterized by the high presence of lianas and lower trees caused by the edge effect of past forest fires.

The Bacury Farm has the largest continuous forest fragment in the region (926.7 ha), followed by the São Francisco do Tietê Farm, which has two fragments (810.2 ha), one of which

is continuous with the ESEC Barreiro Rico. The ESEC Barreiro Rico (293.4 ha) is the only public protected area in the APA Barreiro Rico. The Descalvado Farm is composed mainly of narrow strips of vegetation (252.1 ha) with some degree of degradation and is separated from Descalvado Farm + Onça Queimada Farm (310.6 ha) by a dirt road wide enough for the treetops not to meet. The Água Sumida Farm (257.7 ha), Primavera Farm (405.5 ha) and Boa Vista Farm (562.5 ha) are separated from the other fragments by a paved state highway (SP-191) with heavy truck traffic.

## **Methods**

### **Unmanned Aerial Vehicle and Ground testing of drone sightings**

The drone used for the flights was the Mavic 2 Enterprise Advanced model manufactured by Shenzhen DJI Sciences and Technologies Ltd. It has an infrared thermal camera with a resolution of 640 x 512 pixels, and a colour camera with a maximum resolution of 3840 x 2160 pixels and a 4x zoom (at a lower resolution of 1920 x 1080), which records images simultaneously. It is equipped with 4 batteries that last approximately 20 minutes. The colour scale used was grey, with white being the warmest tone.

The overflights were conducted manually to allow accurate identification of the species (Trinh-Dinh et al., 2024). They took place between January and August 2024, in the morning, between 06h00 and 09h30, and in the late afternoon, between 16h30 and 19h00. During these periods, the forest temperature is lower, and it is easier to see warm bodies as they stand out from the rest of the environment (Trinh-Dinh et al., 2024). When the weather conditions were not favourable (e. g. rain or high winds), we waited for conditions to improve or else we cancelled flights during that period of the day.

When an animal was sighted, we flew close enough to identify the species without disturbing it. If any southern muriqui was detected, we recorded the coordinate and tried to locate the animal from the ground to confirm its sex and age, and the composition of other group members, if present, following criteria described in Strier et al. (2017). Recordings of all flights were later analysed with the VLC Media Player 3.0.21 to confirm the time, geographic coordinates and the species recorded. All the files generated by the drone during flights were converted to KML files in the website [app.airdata.com](http://app.airdata.com) and used in the program QGIS Desktop 3.30.3 to create the maps and to calculate the area overflow, by creating a polygon from the flight lines.

In the ESEC Barreiro Rico, one group of 4-5 muriquis was the subject of behavioural observations from June 2023 to August 2024, providing an opportunity to document changes in the group composition a longer period of time. Observations of this group also permitted us to evaluate the accuracy of sightings made using drone flights compared to the known group size and composition based on behavioural follows.

### **Analyses**

The percentage of forest sampled was calculated by dividing the area overflown by the total area of each forest fragment. Sampling effort was calculated by dividing the number of flights and the total time of flight in minutes by the number of encounters for each primate species, resulting in the flight sampling effort and minute sampling effort, respectively.

Because variation in the number of flights and minutes flown in the different fragments could bias our encounter probabilities, square-root transformations were used, following the rationale of Osborne (2002) to control for variation in sampling. Then, based on Trinh-Dinh et al. (2024), we used the treated data to calculate the probability of encountering (E) a primate species in the area where it was encountered by dividing the total number of encounters by the total minutes flown (F) and by the number of flights in that area only for comparison purposes, with the probability of missing those primates (false-negative) calculated as  $(1-E)F$ , after the average flight time. We calculated the same rates for every primate species in all fragments.

### **Results**

We totalled 126.83 hours of flight time during 453 flights, with 2,947 kilometres travelled over an area of 3,221.7 hectares, corresponding to 83% of the total area of the eight sampled forest fragments (Table 1; Figure 4). Primates were detected in all eight fragments, though the number of species detected ranged from one to three. Muriquis were only detected in two of the fragments, Bacury Farm and ESEC Barreiro Rico, where both capuchin monkeys and howler monkeys were detected. The closest distance recorded between the two muriqui groups was 703 meters.

A total of seven muriquis, including one infant estimated to be between one and two years old, was counted across the 81 flights over Bacury Farm (Figure 2a). We were unable to collect further information about the composition of this group because we did not have access to enter the property on the ground. The number of muriquis detected in the flights over ESEC Barreiro Rico increased from four, including one adult male, two adult females, and one infant male, to five, owing to the birth of a second infant in July 2024, which was later determined to be a

female (Figure 2b). These numbers corresponded with our systematic behavioural and demographic observations of this group over the year.

The average sampling effort to detect the muriquis required 7.81 flights or 131.16 minutes. This was higher than that required for the capuchin monkeys (5.81 flights, 97.53 minutes), but lower than the sampling effort required to detect howler monkeys (20.59 flights, 345.77 minutes).

Differences in probability of encountering muriquis could only be compared between the two fragments where they were encountered. The probability of encountering the muriquis per minute of flight in ESEC Barreiro Rico was 14%, almost three times higher than in the Bacury Farm was 5% (Figure 3; Supplementary Table 1). The probability of missing the southern muriqui (false-negative) after flying 28.8 minutes (the average flight time in the fragments) is zero for the ESEC Barreiro Rico. The probability of encounter and the false negative of other primate species sighted at different forests from APA Barreiro Rico is shown in Figure 3 and Supplementary Table 1 and all primate register is shown in Supplementary Table 2.

Other species of vertebrates were occasionally recorded with the drone: coati (*Nasua nasua*), tayra (*Eira barbara*), collared peccary (*Pecari tajacu*), deer (*Mazama sp.* or *Subulo gouazoubira*), toco toucan (*Ramphastus toco*), jay (*Cyanocorax chrysops*) and king vulture (*Sarcoramphus papa*) (Supplementary Figure 1).

## Discussion

The survey of large arboreal primates using a drone with thermal camera in the APA Barreiro Rico proved to be effective. In addition to other mammals and birds, at least one primate species was recorded in all eight fragments and visible infants were sighted in the two groups of southern muriquis. The two fragments where muriquis were recorded, ESEC Barreiro Rico and Bacury Farm, are separated by a dirt road of about 15 meters but the canopies of trees on the edge of these fragments do not connect. Despite the ability of the closely related northern muriqui (*Brachyteles hypoxanthus*) to cross gaps in the canopy by using the ground (Valle et al., 1984; Dib et al., 1997), we did not record any such behaviour or any encounters between these two southern muriqui groups during the monitoring of the ESEC Barreiro Rico group during the 14-month monitoring period between 2023 and 2024.

Having more than one muriqui group in the same population is very important to this genus because when females reach sexual maturity, around 5 years of age, they typically disperse from their natal groups into another group to reproduce with unrelated males, thereby avoiding

inbreeding and maintaining genetic diversity (Strier, 1996, 2000; Strier et al., 2006). In addition, small, isolated populations are susceptible to catastrophic events, such as diseases and fires (Strier, 2000; Chapman and Peres, 2021; Forero-Sánchez et al., 2025). For example, during a severe outbreak of yellow fever that occurred in 2016 and 2017, the populations of northern muriquis in the Private Natural Heritage Reserve (RPPN)–Feliciano Miguel Abdala and RPPN Mata do Sossego in Minas Gerais suffered heavy losses, decreasing by 10% and 26% of their populations, respectively (Strier et al., 2019). In the region of the APA Barreiro Rico, recurrent fires, including one in 2018, are known to have seriously altered the habitat, including areas previously used by muriquis (Fundação Florestal, 2021).

We detected both brown howler monkeys and black-horned capuchin monkeys in both of the forest fragments with muriqui groups, as well as in two fragments in which no muriquis were detected. We do not believe this reflects a false negative, because based on the lower sampling effort, it was easier to detect muriquis than brown howler monkeys. Thus, if muriquis were present in other fragments where howler monkeys were sighted, such as Água Sumida, Boa Vista, Descalvado + Onça Queimada and Primavera Farm, we should have detected them in our flights. Indeed, our sampling effort for southern muriquis (131.16 minutes) was between the 32.0 and 186.75 minutes Guimarães (2023) reported in two different Atlantic Forest locations.

Other work surveying Geoffroy's spider monkeys (*Ateles geoffroyi*) in Yucatan Peninsula, Mexico, calculated the proportion of detections, equivalent to the probability of encounter (E) calculated here and their results are lower ( $n = 0.053$ ) (Spaan et al., 2022) compared to ours for the muriqui ( $n = 0.35$ ) and almost 10 times lower if compared with our probability of encounter any primate ( $n = 0.59$ ). This may be due to the type of drone used with no infrared camera, which makes it more difficult to locate primates in the forest canopy (Corcoran et al., 2021). Using a drone equipped with colour and infrared cameras is more efficient in terms of field time and personnel (Trinh-Dinh et al., 2024).

Since the use of thermal cameras with drones is relatively new (Pinel-Ramos et al., 2024), there are few data for comparisons of the detection efficiency. Data on the number of records, the probability of encounter (E) and minimum flight time to find the species (Supplementary Table 1) can enable comparisons with other studies. It is important that comparisons consider habitat and behavioural differences that may affect detection efficiency. For example, the absence in registers of *Callithrix aurita* and *Callicebus nigrifrons* may be explained by the preferences of these species to use lower and medium strata, respectively, making it difficult to detect them with the drone (Trevelin et al., 2007; Guedes & Souza-Alves, 2024). Indeed, the

most recent register of these species were the vocalizations heard in 2024 at the ESEC Barreiro Rico, indicating their presence in this fragment despite our inability to find them with the drones.

It is estimated that, in nature, 1,300 individuals of southern miqui are distributed across 40 locations (Melo & Jerusalinsky, 2024). The total miqui population of 12 individuals at the APA Barreiro Rico represents a very small fraction of the species, even with two groups. A canopy crossing bridge was installed in September 2024 to facilitate the movement of fauna between the two fragments with miquis, and until July 2025, no species has used the bridge to cross between fragments (J. M. Elias, personal communication, July 2025), we hope they will begin to use it. Even so, the situation of the southern miquis in the APA Barreiro Rico could be considered critical without active management efforts to safeguard it.

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**Conflicts of interest** None.

**Ethical standards** The Solicitação de Acesso de Aeronaves Remotamente Pilotadas (SARPAS) authorization from the Brazilian government for all flights carried out was obtained from the Departamento de Controle de Espaço Aéreo (DECEA) (protocol numbers EEA02A53, EEA02A53, B80ABE70, DDCBA08F, A1ABF1A8, 77FB90AB, 0E86255E, 977B7A64, 789E5E36, 40E249E1, 03F6B311, FE4D5053, 9B3B3185, 484E66DC, 012B6B40,

EB7A0374, 0591E9AC, AD1D93CF and E2177F96). The research was approved by the Comitê de Ética no Uso de Animais (CEUA) of Universidade Federal de Viçosa (register number 12/2023), according to the rules issued by Conselho Nacional de Controle de Experimentação Animal (Concea). The Instituto de Pesquisas Ambientais (IPA) authorization from the Fundação para Conservação e Produção Florestal do Estado de São was obtained (protocol number 0001004/2023).

**Data availability** The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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TABLE 1 Information on the locations of each property, total area of the forest fragment, area flown over, distance traveled, flight hours, number of flights, number of days and primate species found in each fragment: A=*Alouatta guariba*, B=*Brachyteles arachnoides* and S=*Sapajus nigritus*. The data presented in this table are not treated. Forest fragments are listed in alphabetical order, except for the ESEC Barreiro Rico, which is the only fully public protected area in the APA, the others are private properties.

Property	Coordinates	Forest size (ha)	Forest area flown over (%)	Distance traveled (km)	Flight hours	Number of flights	Number of days	Primate species
<b>Água Sumida</b>	22°38'00"S 48°17'27"W	257.7	209.1 (81)	180	9.16	27	4	A; S
<b>Bacury</b>	22°38'11"S 48°14'41"W	926.7	830.8 (89)	579	23.42	81	10	A; B; S
<b>Boa Vista</b>	22°39'11"S 48°14'35"W	562.5	473.2 (84)	304	9.47	31	5	A
<b>Descalvado + Onça Queimada</b>	22°40'20"S 48°11'49"W	310.6	295.5 (95)	143	5.68	18	3	A; S
<b>Descalvado</b>	22°40'34"S 48°08'33"W	252.1	158.2 (62)	130	4.69	15	5	S
<b>Primavera</b>	22°39'52"S 48°08'49"W	405.5	358.4 (85)	324	10.48	34	6	A
<b>São Francisco do Tietê</b>	22°41'49"S	419.9	264.6 (63)	123	8.53	26	5	S
	48°05'04"W	390.3	361.4 (92)	321	9.61	31	4	S
<b>ESEC Barreiro Rico</b>	22°43'51"S 48°05'51"W	293.4	270.5 (92)	843	45.80	190	61	A; B; S
<i>Total</i>		3,818.7	3,221.7 (83)	2,947	126.84	453	103	3

FIG. 1. Location of the forest fragments within the APA Barreiro Rico and its geographic position in the state of São Paulo, Brazil. The following maps highlight the areas flown over in each fragment: Água Sumida Farm (1), Bacury Farm (previously known as Barreiro Rico Farm; (Torres de Assumpção, 1983), or Virareiro; (Milton, 1986)) (2), Boa vista Farm (3), Descalvado and Onça Queimada Farms (4 and 5), Primavera Farm (6), São Francisco do Tietê Farm (previously known as Sarã (Martins, 2005; Milton, 1984)) (7) and Estação Ecológica Barreiro Rico (previously known as Tabatingueira (Milton, 1984)) (8).

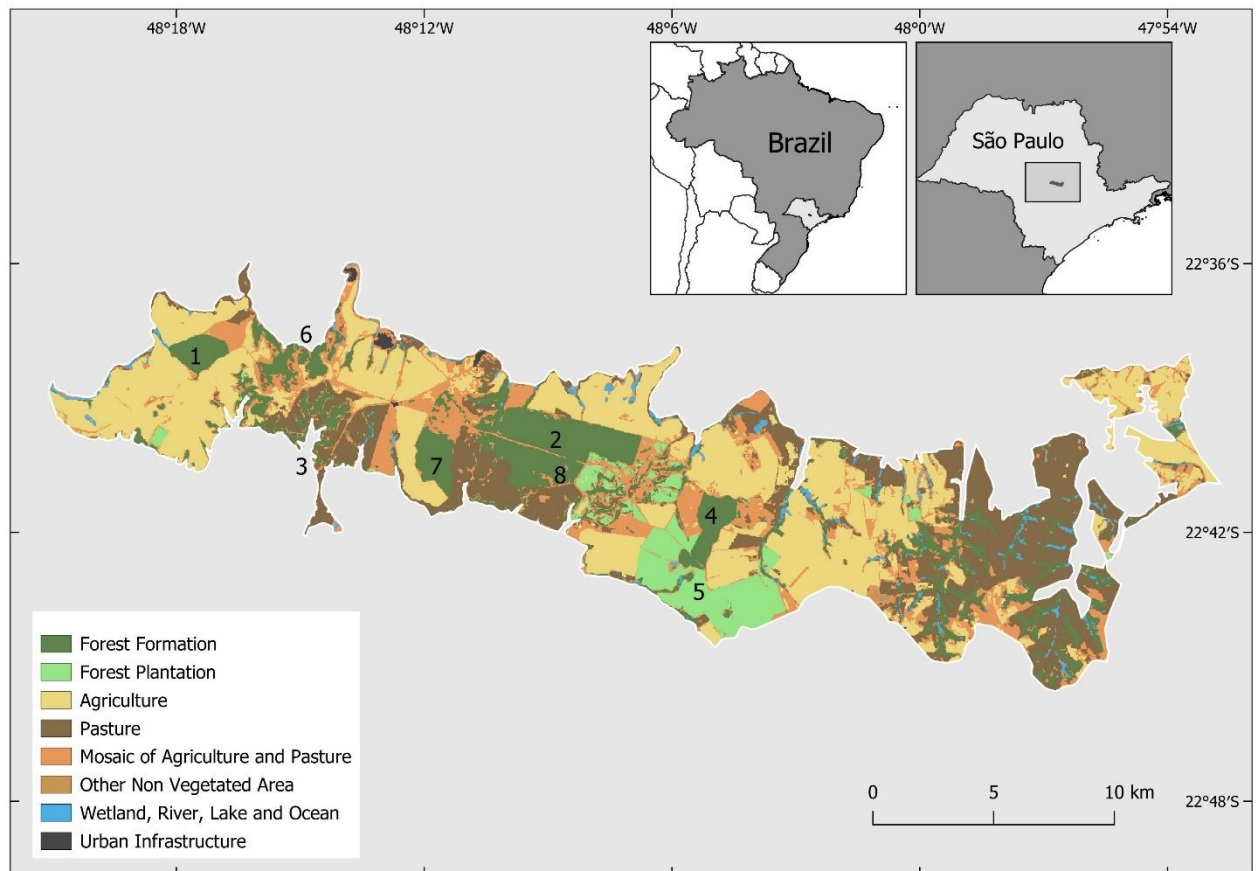


FIG 2 Part of the murre groups found at Bacury Farm (a) and ESEC Barreiro Rico (b).



## 2. Can the availability of food resource species and the presence of larger trees influence the occurrence of the southern miqui?

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### Abstract

Many variables can influence the occurrence of species in different habitats. For arboreal primates, such as the southern miqui (*Brachyteles arachnoides*) in the Atlantic Forest of Brazil, these variables can be related to resource availability, the presence of predators or competitors, and habitat size, among others. This work aims to test whether the availability of trees with higher diameters and the availability of food resources are important variables in their occurrence by comparing two forest fragments of the Área de Proteção Ambiental (APA) Barreiro Rico in the interior of São Paulo: Estação Ecológica (ESEC) Barreiro Rico, with southern miquis now, and São Francisco do Tietê (SFT) Farm, with the occurrence of the species in the past. This study took place between August 2023 and July 2024. In the two forest fragments, we demarcated 10 plots, measured, and collected samples from 943 trees for further identification. We conducted non-systematic research across three academic databases to identify any dietary records for the miqui in the APA Barreiro Rico. An analysis of tree diversity, evenness, similarity, horizontal and parametric structure, and food resources was conducted, and the results were finally compared between the forest fragments. Our results indicate that the diameter distribution between forest fragments is similar, making it difficult to affirm that this is an important variable for them. The diversity and evenness calculated indicate higher diversity and evenness across species in the ESEC Barreiro Rico. The proportion of trees serving as food resources was higher in the SFT Farm. But the basal area indicates greater availability of larger food-resource trees in ESEC Barreiro Rico, suggesting a possible preference for larger food patches. Given that the differences in these variables between the fragments were small, we cannot affirm that only these variables influenced their occurrence; also, we cannot rule out that legalized hunting and, especially, large forest fires in the region may have played a significant role in the decline of miqui populations.

### Key words

Occurrence; Forest structure; Larger trees; Food resource trees; *Brachyteles arachnoides*.

## Introduction

Species prefer certain habitats based on their biotic and abiotic characteristics. Abiotic characteristics include temperature, humidity, soil type, and others, and biotic characteristics include the presence of predators, the species in the diet, and the presence of conspecifics (Hamilton, 2010; Montgomery; Roloff, 2017). Understanding how environmental variables influence a species' habitat preference by comparing habitat characteristics with the species' behavior helps to understand the species' need to be present in a specific location (Montgomery; Roloff, 2017). Knowing a species' requirements for survival and thriving in an area can help preserve biodiversity. Recognizing the characteristics of the location can help to understand how a specific population is increasing or decreasing in size, and even improve conservation actions to save populations and species from extinction (Martins, 2003; Mendes et al., 2005; Silva-Junior et al., 2010; Mascaró Castro, 2021).

When considering primates, such as the southern muriqui (*Brachyteles arachnoides*), the plant species present in the forest can influence their existence in many ways. Taller and bigger trees can be used as a dormitory or for locomotion, some species can be eaten and some not, the leaves, flowers or fruits make part of the diet, even lianas can serve as an excellent food source (Milton, 1984; Strier, 2000; Martins, 2009; Mascaró Castro, 2021).

The southern muriqui (*Brachyteles arachnoides*) is endemic to the Atlantic Forest in southeastern Brazil; it's a threatened species, classified as 'Critically Endangered' mainly due to habitat loss and hunting (Talebi et al., 2021). It is the largest primate in South America, weighing around 10 kilograms. It's arboreal, preferring taller trees to feed and rest, and herbivores, feeding mainly on leaves, fruits, flowers and seeds (Milton, 1984; Lemos de Sá; Glander, 1993; Martins, 2008). The westernmost limits of its distribution are in the Área de Proteção Ambiental Barreiro Rico (APA Barreiro Rico), an environmental protection area in the interior of the state of São Paulo, that holds a single population in an unique occurrence area of this species, that has historical occurrence in some fragments since the 1970s (Aguirre, 1971; Torres de Assumpção, 1983; Milton, 1986; Martins, 2005a) but has disappeared from some of them (Robbi et al., 2025).

The APA Barreiro Rico is a very important area in the interior of São Paulo state from the point of view of wildlife conservation, due to its Semidecidual Seasonal Forest, which holds a rich biodiversity. This region also has strong agricultural activity; the forest fragments are surrounded by pasture, sugar cane, citrus and eucalyptus plantations, giving it a fragmented

character. Furthermore, the regions also suffer from fires with a great capacity for destruction of the forest fragments, as observed in the last two fires that occurred in the region, in 2012 and 2018, that even today, traces of emergent trees that were burned stand out in the remaining forest (Milton; De Lucca, 1984; Fundação Florestal, 2021). In this scenario, the study aimed to understand if the forest structure and food resource availability may influence the occurrence of southern muriquis in two fragments in the APA Barreiro Rico, by comparing the forest structure of two forest fragments, one with southern muriqui (ESEC Barreiro Rico) and the other with it in the past, 20 years ago (SFT Farm). We hypothesized that there would be more food resources and a higher density of bigger trees where they occur nowadays than occurred in the past.

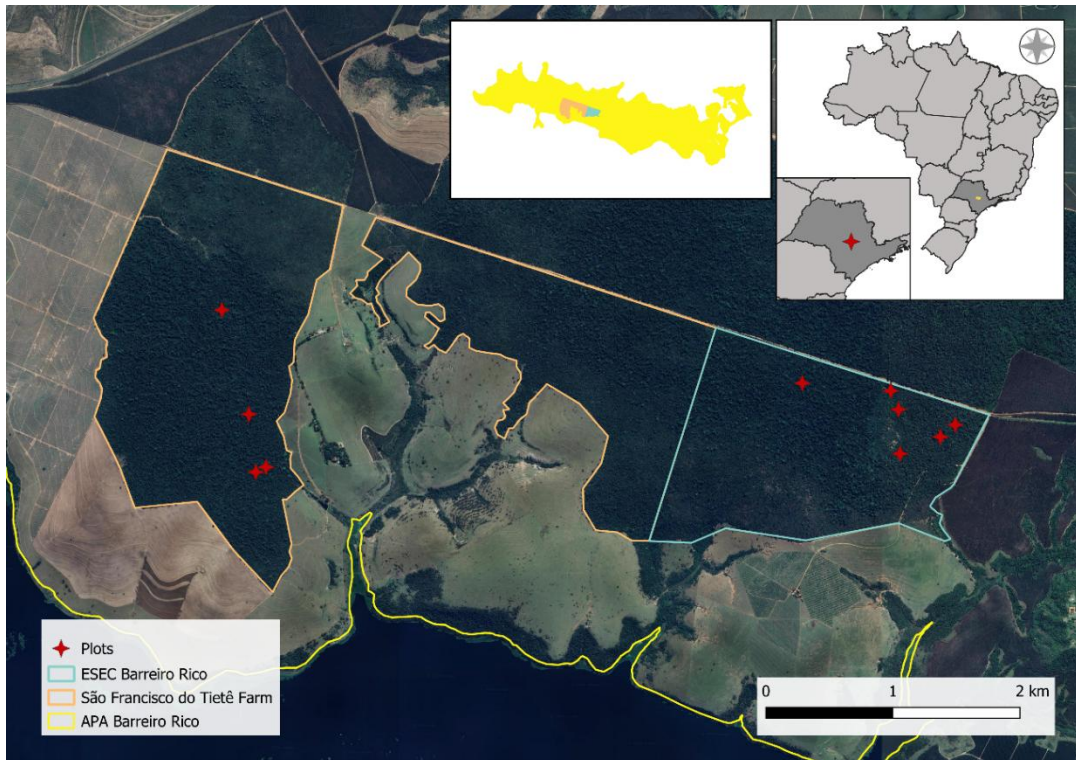
## **Methods**

### **Study area**

The two forest fragments studied are located in the Área de Proteção Ambiental Barreiro Rico (22°41'S, 48°06'W), which encompasses the cities of Anhembi, Botucatu, Piracicaba, and São Pedro in the interior of the state of São Paulo, Brazil. The first forest fragment is the Estação Ecológica Barreiro Rico (ESEC Barreiro Rico), a protected public area of 292.8 ha. The second is in the São Francisco do Tietê Farm (SFT Farm), a private property with a fragment of 419.9 ha (Figure 1). The predominant biome in the region is the Atlantic Forest, with Semideciduous Seasonal Forest (Fundação Florestal, 2021).

The FST Farm had southern muriqui groups during the 1980s and 2000s, when behavioural studies took place, reporting groups of at least 16 individuals and an estimated 45 individuals for this fragment (Milton, 1984; Azevedo-Lopes, 2000). However, now, there is no evidence of its register (Robbi et al., 2025). The ESEC Barreiro Rico, today, has a small group of southern muriqui with five individuals (Robbi et al., 2025), but no records in the past; however, the adjacent forest fragment (Bacury Farm, former Barreiro Rico Farm) had its first record in 1971 (Aguirre, 1971).

Since the 1980s, the size of these forest fragments in this region has not drastically changed (Projeto MapBiomias, 2020). Still, the quality of the environment may have decreased due to recurrent forest fires and illegal logging, a common practice that occurred in this area until its prohibition in 1998 (MMA, 1998; Martins, 2005c; Fundação Florestal, 2021). Over the years, the SFT Farm may be more susceptible to forest fires due to its location, near a paved road where several fires have started, and because its surroundings were sugar-cane plantations, which commonly use pre-harvest fires.



**Figure 1.** Location of the 10 plots distributed in the ESEC Barreiro Rico and São Francisco do Tietê Farm, in the APA Barreiro Rico.

## Inventory

Following a protocol created to assess the multifunctionality of the forest (Projeto NewFor, 2021), during 12 days in August 2023, we demarcated 10 plots distributed in both forest fragments, each measuring 900 m<sup>2</sup> (preferring 30 x 30 m, when it was not possible the measure was 20 x 45 m), with a string in an appropriate area (e.g., absence of tangle of liana, no significant tree fall), along pre-existing trails in these forest fragments. It was difficult to find a more appropriate area, as required by the protocol used, to install another plot in the SFT Farm; for this reason, we installed six in the ESEC Barreiro Rico and four in the SFT Farm.

These plots were at least 30 m from the forest edge and 60 m apart. All trees within these plots with diameters > 5 cm at breast height (DBH) were marked with nails (SFT Farm) for a permanent register and nylon threads (ESEC Barreiro Rico), as required by the

conservation unit management, with numbered aluminum tags. The height was measured with a hypsometer (Vertex, manufactured by Hagl f), and a sample of each tree was collected for further identification and deposited in the ESA Herbarium at the Escola Superior de Agricultura Luiz de Queiroz - Universidade de S o Paulo (Esaq/USP).

### **Diet**

We used the academic databases ‘Scholar Google’, ‘Scopus’, and ‘SciELO’ to conduct a non-systematic research to find all articles, theses, books, and reports that contained tree species that have been seen being consumed by southern muriqui in the APA Barreiro Rico since the 1970s, when the species was first reported for the area (Aguirre, 1971). To complement this list, we used personal field notes from behavioural monitoring conducted in parallel with this study (see Chapter 3). We checked and updated all the species names according to Flora Brasileira 2020 (JBRJ, 2020).

The keywords used, in English and Portuguese, in the research were: ("Brachyteles" OR "Brachyteles sp." OR "Brachyteles spp." OR "Brachyteles arachnoides") AND ("diet" OR "consumption") AND ("Barreiro Rico" OR "Fazenda Barreiro Rico" OR "Farm Barreiro Rico").

### **Data analyses**

Based on the identification and counting of trees, both forest fragments were compared in terms of diversity, horizontal structure, and parametric structure. All the calculations were made considering only the main stem of each tree. To calculate the  $\alpha$ -diversity, we used the Shannon ( $H'$ ) and Simpson ( $D$ ) indices, and to measure the evenness of the species distribution, we used the Pielou ( $J$ ) index (Silva-Junior et al., 2010; Costa et al., 2022). To statistically test differences between fragments in the Shannon, Simpson, and Pielou indices, we calculated these values per sample plot, enabling a proper statistical comparison between fragments using the Welch's t-test. We also used the Mann–Whitney test to analyse species abundances. To estimate plot similarity ( $\beta$ -diversity), we used the S rensen index (Muller-Dumbois; Ellenberg, 1974; Silva-Junior et al., 2010; Boubli; Couto-Santos; Strier, 2011; Corr ea et al., 2014).

To analyse the horizontal structure, we calculated the density, dominance, frequency, Importance Value Index (IVI), and Coverage Value Index (CVI) for each species (Muller-Dumbois; Ellenberg, 1974; Lemos de S ; Strier, 1992; Silva-Junior et al., 2010; Costa et al., 2022). To investigate the parametric structure, we divided all individuals into classes by DBH in 5 cm intervals to examine the distribution of tree sizes (Lemos de S ; Strier, 1992; Costa et

al., 2022). To analyse the parametric structure, we used the chi-square test, and to test the DBH values as a continuous variable, we used the Kolmogorov–Smirnov test. We constructed a rarefaction curve to assess whether the sample size was sufficient to represent the species diversity in both fragments (Muller-Dumbois; Ellenberg, 1974).

## Results

### Estação Ecológica Barreiro Rico – ESEC Barreiro Rico

In the six plots in the ESEC Barreiro Rico, we found 642 individuals divided into 26 families, 51 genera and 68 species. It was not possible to confirm the identification of 11 species. The most abundant families were Myrtaceae (19 species), Fabaceae (7), and Euphorbiaceae (6). The most abundant species is *Copaifera langsdorffii* (69 individuals), followed by *Actinostemon conceptionis* (57), and *Myrcia* sp. 3 (47). Sixteen families and 21 species are represented by only one individual each (Figure 1). The diversity index of Shannon ( $H'$ ) is 3.49, Simpson ( $D$ ) is 0.95, and the Pielou index ( $J$ ) is 0.82.

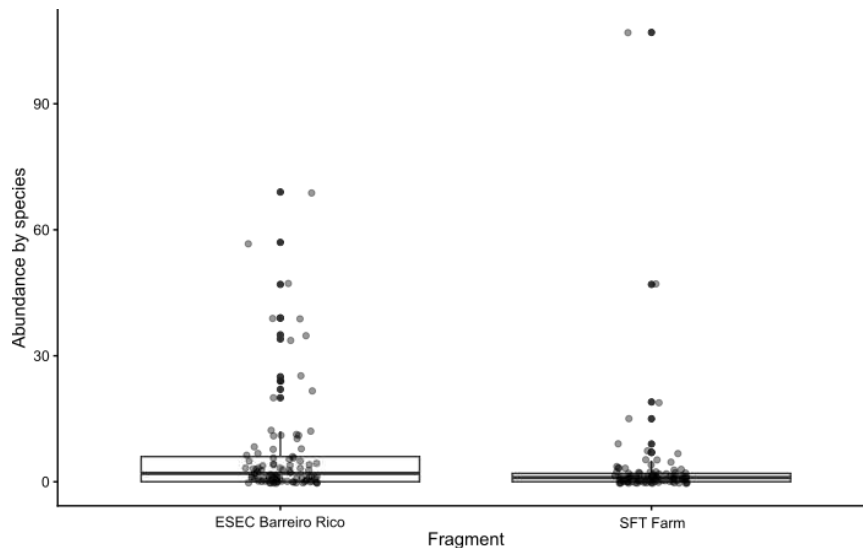
The mean height for the trees found is  $11.33 \pm 5.49$  m (mean  $\pm$  SD). The total value for Basal Area is  $14.83$  m<sup>2</sup>; the three most representative species are *C. langsdorffii* ( $4.03$  m<sup>2</sup>), followed by *Esenbeckia leiocarpa* ( $1.19$  m<sup>2</sup>) and *Maprounea guianensis* ( $0.87$  m<sup>2</sup>). The *C. langsdorffii* also has the biggest Relative Density (10.75), followed by *A. conceptionis* (8.88) and *Myrcia* sp. 3 (7.32). The species with the largest basal area also have the most significant Relative Dominance: *C. langsdorffii* (27.19), *E. leiocarpa* (8.01), and *M. guianensis* (5.86). For the Coverage Value Index, the *C. langsdorffii* (18.97), *A. conceptionis* (5.73) and *E. leiocarpa* (4.94) are the species with the biggest score. The Importance Value Index follows the sequence of Relative Density: *C. langsdorffii* (14.01), *A. conceptionis* (5.18), and *Myrcia* sp. 3 (4.46), with the first being a food resource (Annex 1).

### São Francisco do Tietê Farm – SFT Farm

In the four plots at the SFT Farm, we found 301 individuals, divided into 22 families, 45 genera and 57 species. It was not possible to confirm the identification of four species. The most abundant family was Myrtaceae (11 species), followed by Euphorbiaceae (7), Fabaceae (5) and Lauraceae (5). The three most abundant species are *M. nigra* (107 individuals), *E. leiocarpa* (47), and *Pilocarpus pauciflorus* (19); moreover, 12 families and 29 species are represented by only one individual each (Figure 1). This area's Shannon index ( $H'$ ) is 2.75, the Simpson index ( $D$ ) is 0.84, and the Pielou index ( $J$ ) is 0.68.

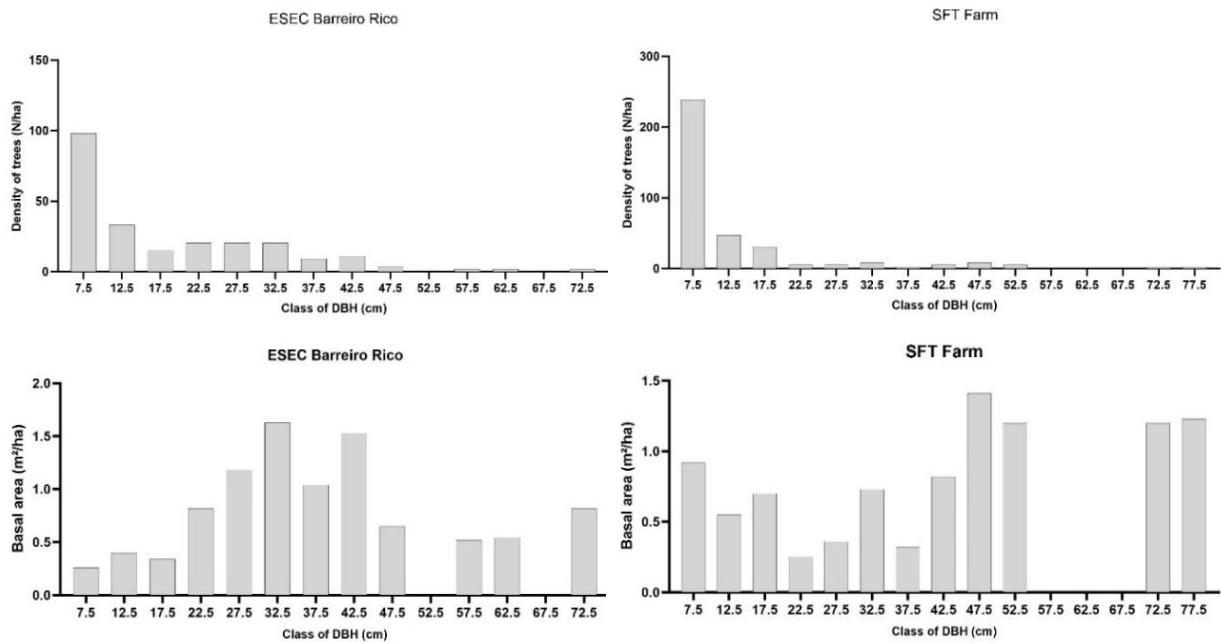


The Shannon index showed no statistically significant difference between the forest fragments from ESEC Barreiro Rico and SFT Farm (Welch t-test,  $t = 1.78$ ;  $df = 7.50$ ;  $p = 0.115$ ) when calculated by plots. But according to the Simpson index ( $t = 3.27$ ;  $df = 7.52$ ;  $p = 0.012$ ), the ESEC Barreiro Rico (0.867) has a higher value than the SFT Farm (0.818), indicating lower dominance and greater uniformity in the individual distribution between species. The Pielou index ( $t = 2.42$ ;  $df = 7.96$ ;  $p = 0.041$ ) indicates that the ESEC Barreiro Rico (0.79) has a significantly higher evenness than the SFT Farm (0.75). This result is corroborated by the distribution of individuals among the species, which revealed a difference between the forest fragments ( $p = 0.0006$ ): a higher proportion of individuals in fewer species at the SFT Farm, and a more even distribution in the ESEC Barreiro Rico (Figure 3).



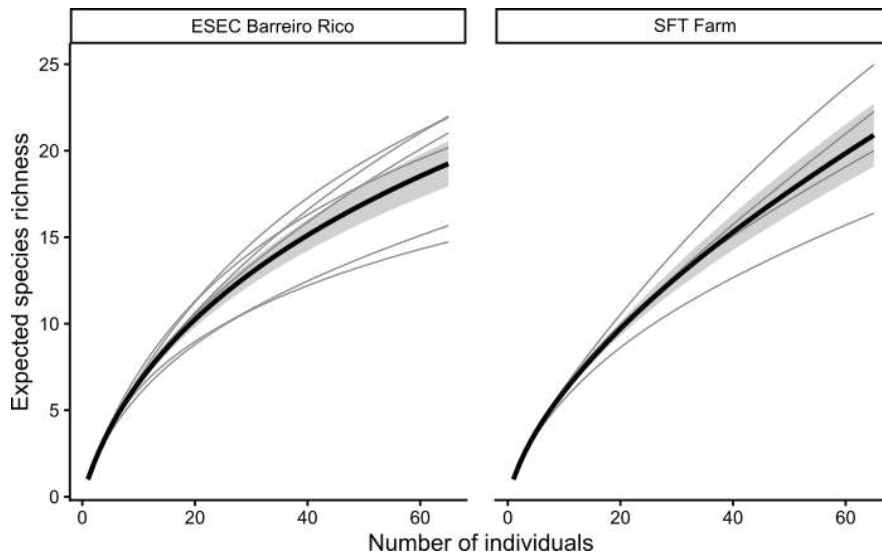
**Figure 3.** Distribution of the abundance per species in both forest fragments.

The number of trees in both areas is more represented in the first DBH classes, exhibiting an inverted "J" structural pattern. Despite the difference observed between the areas, there is no statistical difference in the diametric distribution (Kolmogorov–Smirnov test,  $D = 0.055$ ;  $p = 0.495$  and chi-square test,  $X^2 = 6.75$ ;  $df = 3$ ;  $p = 0.080$ ). In the ESEC Barreiro Rico, the distribution of the basal area is concentrated in the intermediate class. In contrast, in the SFT Farm, the basal area is more evenly distributed across classes, except for the classes between 72.5 and 77.5 cm, which are represented by only one species and one individual each, *C. langsdorffii* and *Cryptocarya aschersoniana*, respectively. In both forest fragments, some classes are not represented by any individual, such as 52.5 and 67.5 in the ESEC Barreiro Rico, and 57.5, 62.5, and 67.5 in the SFT Farm (Figure 4).



**Figure 4.** The density of trees and the basal area distributed in the DBH classes in each forest fragment.

The rarefaction curve, based on the number of individuals per plot for each forest fragment, indicates that the ESEC Barreiro Rico shows a clear deceleration after the fifth plot and a progressive reduction in standard deviation. The SFT Farm shows a continuous increase up to the fourth plot, with no evident stabilization (Figure 5). In terms of diversity, these results show that the ESEC Barreiro Rico is well represented, while the SFT Farm is underrepresented.



**Figure 5.** Rarefaction curves based on individuals, showing the average pattern of species accumulation in each fragment (ESEC Barreiro Rico and SFT Farm) represented by the black line, with the variation between plots represented by the gray lines.

## Diet

In addition to our data on feeding species (Chapter 3), we found five articles (Torres de Assumpção, 1983; Milton, 1984; Martins, 2005b, 2005c, 2008), one book (Aguirre, 1971), and one master's thesis (Azevedo-Lopes, 2000), all dated between 1971 and 2008. All feeding registers presented in these studies, including our field notes, were compiled in Table 2, with family and species name, and the consumed item, when available.

Based on the literature found, we had 61 species reported as food resources for the southern muriqui in the APA Barreiro Rico since 1971. In our inventory at ESEC Barreiro Rico, 230 individuals of 20 species were registered, representing 35.82% of all sampled trees in this area and totaling a basal area of 9.51m<sup>2</sup>. At SFT Farm, 194 individuals distributed into 18 species were registered, representing 64.45% of all sampled trees in this area and totaling 5.01m<sup>2</sup> of basal area. Moreover, 34 species previously reported as food resources were not found in our inventory in either place.

**Table 2.** List of the species ever registered in the diet of *Brachyteles arachnoides* in the Barreiro Rico Region. L = leaves, YL = young leaves, ML = mature leaves, SL = senescent leaves, FB = flower buds, F = flowers, Fr = fruit, UF = unripe fruits, RF = ripe fruits, S = seeds, N = nectar and Un = unidentified. The species with <sup>1</sup> were found at the ESEC Barreiro Rico, and the species with <sup>2</sup> were found at the SFT Farm.

Family	Scientific name (Former name)	Consumed item	Source
ANACARDIACEAE	<i>Astronium graveolens</i> Jacq. <sup>12</sup>	Un	Martins, 2005
ANNONACEAE	<i>Annona cacans</i> Warm. <sup>2</sup>	Un	Azevedo-Lopes, 2000
	<i>Duguetia lanceolata</i> A. St.-Hil. <sup>1</sup>	FB, F, RF, S	Assumpção, 1983; Milton, 1984; Azevedo-Lopes, 2000; Martins, 2005; Martins, 2008
	<i>Xylopia brasiliensis</i> Spreng. <sup>2</sup>	ML	Milton, 1984; Azevedo-Lopes, 2000; Martins, 2005; This study
APOCYNACEAE	<i>Aspidosperma camporum</i> Müll.Arg. ( <i>Aspidosperma nemorale/memorale</i> ) <sup>12</sup>	Fr	Assumpção, 1983; Azevedo-Lopes, 2000; Martins, 2008
	<i>Aspidosperma polyneuron</i> Müll. Arg. ( <i>Aspidosperma peroba</i> )	ML, Fr	Aguirre, 1971; Milton, 1984; Martins, 2005; Martins, 2008; This study
	<i>Aspidosperma tomentosum</i> Mart. & Zucc.	Un	Martins, 2008
	<i>Tabernaemontana hystrix</i> ( <i>Peschiera fuchsiaefolia</i> )	Un	Azevedo-Lopes, 2000
ARECACEAE	<i>Euterpe edulis</i> Mart.	YL	Aguirre, 1971
	<i>Syagrus romanzoffiana</i> (Cham.) Glassman	Fr	Martins, 2008

BORAGINACEAE	<i>Cordia sellowiana</i> Cham. <sup>1</sup>	Fr	Martins, 2008
CANNABACEAE	<i>Celtis spinosa</i> Spreng	Fr	Martins, 2005; Martins, 2008
CARICACEAE	<i>Jacaratia spinosa</i> (Aubl.) A. DC. <sup>2</sup>	Fr	Martins, 2005; Martins, 2008
COMBRETACEAE	<i>Terminalia glabrescens</i> Mart. ( <i>Terminalia brasiliensis</i> ) <sup>1</sup>	S	This study
ELAEOCARPACEAE	<i>Sloanea hirsuta</i> (Schott) Planch. ex Benth ( <i>Sloanea monosperma</i> )	Fr	Martins, 2005; Martins, 2008
ERYTHROXYLACEAE	<i>Mabea fistulifera</i> Mart. <sup>1</sup>	F, N	Assumpção, 1983; Martins, 2005
EUPHORBIACEAE	<i>Alchornea triplinervia</i> (Spreng.) Müll.Arg. <sup>2</sup>	Un	Azevedo-Lopes, 2000
	<i>Croton floribundus</i> Spreng. <sup>12</sup>	YL, FB, F, UF	Milton, 1984; Azevedo- Lopes, 2000; Martins, 2005; This study
	<i>Maprounea guianensis</i> Aubl. <sup>12</sup>	ML, UF	This study
	<i>Pachystroma longifolium</i> (Nees) I.M. Johnst. ( <i>Pachystroma iliafolium/ilicifolium</i> ) <sup>2</sup>	UF	Milton, 1984; Martins, 2005; Martins, 2008
FABACEAE	<i>Copaifera langsdorffii</i> Desf. <sup>12</sup>	L, YL, ML, UF, RF	Assumpção, 1983; Milton, 1984; Azevedo-Lopes, 2000; Martins, 2005; This study
	<i>Hymenaea courbaril</i> L. <sup>1</sup>	L, YL, ML, UF, RF	Assumpção, 1983; Milton, 1984; Azevedo-Lopes, 2000; Martins, 2005; Martins, 2008; This study
	<i>Inga striata</i> Benth.	UF	Milton, 1984; Azevedo- Lopes, 2000; Martins, 2005; Martins, 2008
	<i>Piptadenia gonoacantha</i> (Mart.) J. F. Macbr. <sup>2</sup>	ML	Milton, 1984; This study
LAURACEAE	<i>Cryptocaria</i> sp. <sup>1</sup>	Un	Azevedo-Lopes, 2000
	<i>Cryptocarya moschata</i> Nees & Mart.	RF	Assumpção, 1983; Martins, 2005
	<i>Lauraceae</i> sp. <sup>1</sup>	FB, F	Milton, 1984
	<i>Nectandra</i> sp.	Un	Azevedo-Lopes, 2000
	<i>Ocotea</i> sp. <sup>2</sup>	ML	Aguirre, 1971; Milton, 1984; Azevedo-Lopes, 2000
	<i>Ocotea acutifolia</i> (Nees) Mez	Un	Azevedo-Lopes 2000
	<i>Ocotea catharinensis</i> Mez	Un	Martins, 2005
	<i>Ocotea corymbosa</i> (Meisn.) Mez <sup>12</sup>	Fr	Martins, 2005; Martins, 2008
	<i>Ocotea spixiana</i> (Nees) Mez	YL, UF	Assumpção, 1983
<i>Ocotea velutina</i> (Nees) Rohwer ( <i>Ocotea brasiliensis</i> )	UF, RF	Martins, 2005; This study	
LECYTHIDACEAE	<i>Cariniana estrellensis</i> (Raddi) Kuntze	Un	Martins, 2005
MELASTOMATACEAE	<i>Mouriri</i> sp.	YL, ML, Fr	Assumpção, 1983; Milton, 1984; Azevedo-Lopes, 2000

	<i>Mouriri chamissoana</i> Cogn.	Fr	Aguirre, 1971
	<i>Mouriri glazioviana</i> Cogn.	ML	Martins, 2005; This study
MELIACEAE	<i>Cabralea</i> sp.	Un	Azevedo-Lopes, 2000
MORACEAE	<i>Ficus</i> sp.	RF	Milton, 1984; Martins, 2005
MYRTACEAE	<i>Campomanesia</i> sp.	Fr	Martins, 2005; Martins, 2008
	<i>Eugenia</i> sp. 1 <sup>12</sup>	Fr, RF	Assumpção, 1983; Martins, 2005; Martins, 2008
	<i>Eugenia florida</i> DC.	RF	This study
	<i>Eugenia ligustrina</i> <sup>12</sup>	Fr	Martins, 2005; Martins, 2008
	<i>Eugenia pyriformis</i> Cambess.	Fr	Martins, 2005; Martins, 2008
	<i>Eugenia ramboi</i> D.Legrand	RF	This study
	<i>Myrciaria</i> sp.	UF, S	Milton, 1984
	<i>Myrciaria floribunda</i> (H.West ex Willd.) O.Berg <sup>1</sup>	RF	This study
	<i>Myrtaceae</i> sp.	ML, RF	Milton, 1984; This study
	<i>Nectandra oppositifolia</i> Ness	F	This study
	<i>Neomitranthes obscura</i> (DC.) N.Silveira	RF	Martins, 2005; Martins, 2008
	<i>Psidium</i> sp.	F	Martins, 2005
	<i>Psidium sartorianum</i> (O.Berg) Nied.	UF	This study
PHYLLANTHACEAE	<i>Gonatogyne brasiliensis</i> (Baill.) Müll.Arg.	YL	Assumpção, 1983; Martins, 2005
	<i>Savia dictyocarpa</i> Müll. Arg. ( <i>Securinega guaraiuva</i> ) <sup>12</sup>	ML	Milton, 1984; Azevedo-Lopes, 2000; Martins, 2005
RUBIACEAE	<i>Rudgea</i> sp.	Fr	Martins, 2005; Martins, 2008
RUTACEAE	<i>Esenbeckia leiocarpa</i> Engl. ( <i>Raputia alba</i> ) <sup>12</sup>	ML, Fr, UF, S	Aguirre, 1971; Assumpção, 1983; Milton, 1984; Martins, 2005; Martins, 2008; This study
	<i>Metrodorea nigra</i> A.St. Hil. <sup>12</sup>	YL, Fr	Martins, 2008; This study
	<i>Zanthoxylum rhoifolium</i> Lam.	Un	Martins, 2005
STYRACACEAE	<i>Styrax pohlii</i> A. DC.	Fr	Martins, 2008
VOCHYSIACEAE	<i>Qualea multiflora</i> Mart. ( <i>Qualea jundiahy</i> ) <sup>1</sup>	ML, YL	Assumpção, 1983; Martins, 2005; This study

## Discussion

We found that both forest fragments are similar in some variables and different in others. In relation to the diametric distribution of trees, there is no difference between the forest fragments; the larger trees are equally distributed in both sites. In contrast, the proportion of

food resource trees in the SFT Farm is higher than in the ESEC Barreiro Rico, while the proportion of basal area is similar between fragments. Also, when we analyze the diversity of the forest fragments, the ESEC Barreiro Rico has higher scores.

The parametric structure of both fragments is similar; neither has a higher rate of larger trees in its plots. The basal area in both fragments is largely represented by a single species; in the ESEC Barreiro Rico, *C. langsdorffii* represents 27.2% of the total basal area of the fragment. Also, it has the highest scores in volume (29.3%), relative density (10.75%), relative dominance (27.19%), Coverage Value Index (18.97), and Importance Value Index (14.01), and it's found in all sample plots. In the SFT Farm, the *E. leiocarpa* is very present representing 30% of the basal area, has the highest score in relative dominance (29.96%), the second highest scores in the relative density (15.61%) behind *M. nigra* (35.55%), very close Coverage Value (27.79) and Importance Value index (16.56) with *M. nigra* (22.13 and 16.22, respectively) and both species are present in all sample plots.

At the same time, these fragments are similar in their parametric and horizontal structures. Still, they differ in species, which can play a very important role in the occurrence of the southern miqui. *Copaifera langsdorffii* in the ESEC Barreiro Rico is the most common species, has larger trees, and is present in all sampled areas, making it an easily accessible resource. In the SFT Farm, two species, *E. leiocarpa* and *M. nigra*, divide the highest scores in the horizontal structure. All three species are considered food resources for the southern miqui and are the most available trees (Milton, 1984; Martins, 2005c, 2008).

The comparison between the species consumed reported in the literature and the food resources in our inventory indicates that the SFT Farm has a higher proportion of trees that could be consumed than the ESEC Barreiro Rico, contrary to our hypothesis. When we compare the basal area of food resources with the total basal area, the results indicate that both fragments have a similar proportion. But when we analyse this data together, we can infer that the food resource trees in the ESEC Barreiro Rico have larger diameters and consequently provide larger food patches for them to explore, which is known to be of their preference (Milton, 1984; Strier, 1987; Silva-Junior et al., 2009).

The Shannon, Simpson, and Pielou indices analysed indicate that the ESEC Barreiro Rico fragment is more diverse and has a more balanced species distribution. Statistically, when analysed at the sample plot level, the ESEC Barreiro Rico still has higher scores for the Simpson and Pielou indices. Corroborating that ESEC Barreiro Rico has a more structured community,

with greater diversity and less dominance by any single species. Similar Shannon index values were found in other areas of the Semideciduous Seasonal Forest. A higher value for the Shannon index was found in Caratinga – Minas Gerais ( $H' = 4.6$ ), where a bigger group of Northern muriqui inhabits, and it may be a positive point for their existence in that area (Cesar; Leitão-Filho, 1990; Ivanauskas; Rodrigues; Nave, 1999; Durigan et al., 2000; Boubli; Couto-Santos; Strier, 2011; Souza; Meira Neto; Souza, 2013).

We cannot ignore that the number of plots can significantly influence the results, especially for the calculated diversity and evenness indices. The results indicate that the sampling effort in the SFT Farm may not have been sufficient to capture the full extent of local diversity. Besides, we also cannot discard other aspects present in the SFT Farm that was not considered until now: the surrounding pasture with cattle accessing parts of the forest, the legalized hunting of invasive species (wild pig - *Sus scroffa*), the presence of an unpaved road with occasional vehicles transit in the middle of the forest fragment, the logging in the past and the greater vulnerability to forest fires that have historically affected the area. The legal hunting of wild pigs is concerning because one commonly used method is the use of trained dogs to pursue and guide the target to the hunters (Rosa; Fernandes-Ferreira; Alves, 2018). In addition to the presence of hunting dogs in forest fragments, the noise of weapons may negatively affect the occurrence of the southern muriqui. In addition, future research could study other forest variables, such as canopy connectivity, the presence and diversity of lianas, and the edge effects.

The history of forest fires in the area might have significantly influenced the absence of southern muriquis in the region. Studies with the black lion tamarin (*Leontopithecus chrysopygus*) showed that, depending on its size and shape, forest-fire-affected fragments can take from 20 to 50 years to return to the carrying capacity conditions that existed before the fire (Forero-Sánchez et al., 2025). In the last few years, sugarcane plantations, known for pre-harvest burnings (Uriarte et al., 2009), have been replaced by citrus in the region (Elias, J. M., personal communication), so the risk of uncontrolled wildfires reaching the forest has been decreasing. Considering that the generation length of muriquis is 20 years (Talebi et al., 2021) and the time needed to recover from forest fires, the impact on the species' survival can be very significant.

We can conclude that the forest fragments analysed here show only small differences in the variables studied, not as the differences we expected to find. When considering other environmental variables, such as legal hunting and forest fires, we can infer that forest fires had a significant negative effect on forest fragments in the APA Barreiro Rico, influencing

muriquis' habitat preference. So, preventing these fires from reaching the forest fragments is essential for maintaining forest quality and guaranteeing habitat for muriquis and many other species.

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<i>Myrcia splendens</i>	1	1	0.003	1.852	0.156	0.005	0.018	16.667	0.680	0.087	0.285	1	1	0.003	1.111	0.332	0.003	0.041	10	1.099	0.187	0.491
<i>Myrcia</i> sp. 1	6	3	0.129	11.111	0.935	0.239	0.869	50	2.041	0.902	1.282	2	1	0.145	2.222	0.664	0.161	1.986	10	1.099	1.325	1.250
<i>Myrcia</i> sp. 2	1	1	0.045	1.852	0.156	0.084	0.305	16.667	0.680	0.230	0.380											
<i>Myrcia</i> sp.3	47	4	0.496	87.037	7.321	0.918	3.343	66.667	2.721	5.332	4.462											
<b><i>Myrciaria floribunda</i></b>	8	2	0.043	14.815	1.246	0.079	0.287	33.333	1.361	0.767	0.965											
<i>Nectandra megapotamica</i>	2	2	0.080	3.704	0.312	0.149	0.542	33.333	1.361	0.427	0.738	1	1	0.011	1.111	0.332	0.012	0.152	10	1.099	0.242	0.528
<i>Neomitranthes glomerata</i>	8	4	0.054	14.815	1.246	0.100	0.366	66.667	2.721	0.806	1.444	1	1	0.008	1.111	0.332	0.009	0.105	10	1.099	0.219	0.512
<b><i>Ocotea corymbosa</i></b>	5	3	0.107	9.259	0.779	0.198	0.721	50	2.041	0.750	1.180	2	2	0.071	2.222	0.664	0.079	0.970	20	2.198	0.817	1.277
<b><i>Ocotea</i> sp.</b>												1	1	0.062	1.111	0.332	0.069	0.848	10	1.099	0.590	0.760
<i>Ormosia arborea</i>												1	1	0.005	1.111	0.332	0.005	0.064	10	1.099	0.198	0.498
<i>Ouatea castaneifolia</i>	4	3	0.036	7.407	0.623	0.067	0.244	50	2.041	0.434	0.969											
<b><i>Pachystroma longifolium</i></b>												5	2	0.550	5.556	1.661	0.611	7.522	20	2.198	4.592	3.794
<i>Pera glabrata</i>	3	2	0.267	5.556	0.467	0.494	1.800	33.333	1.361	1.134	1.209											
<i>Pilocarpus pauciflorus</i>	10	1	0.068	18.519	1.558	0.126	0.460	16.667	0.680	1.009	0.899	19	4	0.247	21.111	6.312	0.274	3.373	40	4.396	4.843	4.694
<b><i>Piptadenia gonoacantha</i></b>												1	1	0.003	1.111	0.332	0.003	0.035	10	1.099	0.184	0.489
<i>Piptocarpha</i> sp.	1	1	0.018	1.852	0.156	0.033	0.119	16.667	0.680	0.137	0.318											
<i>Plinia cauliflora</i>	1	1	0.002	1.852	0.156	0.004	0.013	16.667	0.680	0.085	0.283	1	1	0.003	1.111	0.332	0.003	0.036	10	1.099	0.184	0.489
<i>Pterogyne nitens</i>												1	1	0.005	1.111	0.332	0.006	0.069	10	1.099	0.200	0.500
<b><i>Qualea multiflora</i></b>	1	1	0.288	1.852	0.156	0.534	1.945	16.667	0.680	1.051	0.927											
<i>Randia armata</i>												1	1	0.003	1.111	0.332	0.003	0.037	10	1.099	0.185	0.490
<i>Rhamnidium elaeocarpum</i>												1	1	0.002	1.111	0.332	0.003	0.032	10	1.099	0.182	0.488
<i>Roupala montana</i>	2	2	0.007	3.704	0.312	0.013	0.048	33.333	1.361	0.180	0.573											
<i>Rudgea jasminoides</i>	34	4	0.183	62.963	5.296	0.339	1.237	66.667	2.721	3.266	3.085	1	1	0.005	1.111	0.332	0.006	0.070	10	1.099	0.201	0.501
<b><i>Savia dictyocarpa</i></b>	22	3	0.522	40.741	3.427	0.967	3.522	50.000	2.041	3.474	2.996	1	1	0.042	1.111	0.332	0.046	0.568	10	1.099	0.450	0.666
<i>Seguiera</i> sp.	1	1	0.006	1.852	0.156	0.012	0.043	16.667	0.680	0.099	0.293											
<i>Tabernaemontana catharinensis</i>												5	1	0.077	5.556	1.661	0.086	1.054	10	1.099	1.357	1.271
<i>Tapirira guianensis</i>	1	1	0.003	1.852	0.156	0.006	0.020	16.667	0.680	0.088	0.285											
<b><i>Terminalia glabrescens</i></b>	4	3	0.364	7.407	0.623	0.674	2.453	50.000	2.041	1.538	1.706											
<i>Trichilia catigua</i>												2	1	0.006	2.222	0.664	0.007	0.080	10	1.099	0.372	0.614
<i>Trichilia pallida</i>	2	1	0.008	3.704	0.312	0.014	0.052	16.667	0.680	0.182	0.348											
<i>Unclassified</i>	11	4	0.322	20.370	1.713	0.596	2.170	66.667	2.721	1.942	2.201	4	2	0.138	4.444	1.329	0.153	1.883	20	2.198	1.606	1.803
<i>Vitex polygama</i>	2	2	0.030	3.704	0.312	0.055	0.200	33.333	1.361	0.256	0.624											
<i>Vochysia tucanorum</i>	1	1	0.045	1.852	0.156	0.084	0.305	16.667	0.680	0.230	0.380											
<b><i>Xylopia brasiliensis</i></b>												1	1	0.005	1.111	0.332	0.006	0.074	10	1.099	0.203	0.502

<i>Zeyheria tuberculosa</i>												2	1	0.046	2.222	0.664	0.051	0.632	10	1.099	0.648	0.798
Total	642	147	14.826	1188.889	100	27.456	100	2450	100	100	100	301	91	7.312	334.444	100	8.124	100	910	100	100	100

### 3. Behaviour and diet from a small group of Southern Muriqui in the ESEC Barreiro Rico, Anhembi, SP

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#### Abstract

The southern muriqui (*Brachyteles arachnoides*), an Endangered primate from the Atlantic Forest in south-eastern Brazil, is present in the public protected area, Estação Ecológica Barreiro Rico (ESEC Barreiro Rico). At this site, there is only one small group composed of one adult male, two adult females, and two infants, one male and one female. This work aims to understand their behaviour and diet, and to examine how this group uses the space. Between July 2023 and August 2024, we monitored this group, recording their location, behaviour and height in the tree. In our analysis, we used 28 days of observations with more than 10 scans, totaling 861 scans, from only the adults in the group. We also monitored 642 trees with DBH > 5cm in 6 plots distributed along pre-existing trails to study the phenology of the food-resource trees (N=230) and compare it with their diet. They use mostly taller trees (15-20 m), their home range is 86.56 ha, and the core area is 49.03 ha. They spent most of their time resting (58.21%), feeding (20.79%), locomoting (15.04%), and socializing (2.12%). From the 262 feeding registers, 192 were from 22 identified species; the most frequent were lianas and trees such as *Hymenaea courbaril* and *Copaifera langsdorffii*. There is no significant difference in their diet by item between the wet and dry seasons. Leaves and fruits are the most consumed items (37.13% and 34.31%, respectively), followed by seeds (12.96%) and flowers (7.85%). Item ingestion differs from availability; characterizing them as selective consumers, they had a strong preference for certain items, such as ripe fruit and flowers. This information can be very helpful while making decisions about a management plan to conserve this species locally, as this is a unique population.

#### Key words

Behavioural monitoring; Phenology; *Brachyteles arachnoides*; Diet; Activity budget.

## Introduction

The southern miqui ( *Brachyteles arachnoides* ) is a primate endemic to the Atlantic Forest in south-eastern Brazil. It is listed as Critically Endangered by the IUCN due to habitat loss, epizootic disease, and hunting ( Talebi et al., 2021 ). The *B. arachnoides* is one of the largest primates in the Americas ( Aguirre, 1971 ), weighing up to 10 kg and measuring around 1.2 m, tail included ( Lemos de Sá; Glander, 1993 ). It is arboreal and herbivorous, preferring the dossel of taller trees and feeding mainly on fruits and leaves, rarely using the ground ( Milton, 1984 ). This species is included in public policies ( e. g., Plano de Ação Nacional para a Conservação dos Primatas da Mata Atlântica e das Preguiças-de-Coleira and Programa de Manejo Poplacional do Miqui do Sul ) that protect endangered primates and sloth species from the Atlantic Forest, integrate management actions and guarantee viable populations for those species ( ICMBio, 2025a, 2025b ).

An estimated 1,300 southern miquis are in the wild, distributed across 40 locations in the states of Paraná, São Paulo, Rio de Janeiro, and Minas Gerais ( Melo; Jerusalinsky, 2024 ). The Área de Proteção Ambiental ( APA ) Barreiro Rico, located in the countryside of São Paulo state, is one of these locations. Besides the rich biodiversity present ( Fundação Florestal, 2021 ), this population is considered a priority for monitoring due to its population size, geographical importance as the westernmost population, and ecological uniqueness ( Strier et al., 2017 ). In the 30,142 ha of the APA Barreiro Rico, only 3,818 ha are forest fragments surrounded by pasture and plantations, and large forest fires have occurred throughout history ( Robbi et al., 2025 ).

The last behavioural research with miquis in the APA Barreiro Rico, took place more than 20 years ago ( Martins, 2005c ), which is enough time for major changes to occur, and a primate survey in 2021 ( Hileia, 2022 ) indicated a decline in the population in the area. Our objective is to study the behaviour of a small group at the Estação Ecológica ( ESEC ) Barreiro Rico to understand how they have been living in this fragment to protect this species locally, and to assess whether there is seasonality in food availability in the forest and in their behaviour and diet.

## Methods

### Study site

The study was carried out at the Estação Ecológica Barreiro Rico (ESEC Barreiro Rico – 22°40' S 48°08' W), a fragment of 292.8 ha of Atlantic Forest Semidecidual Seasonal Forest, located in the city of Anhembi, São Paulo, Brazil (Fundação Florestal, 2021). It is a forest fragment, mainly surrounded by pasture, eucalyptus, and citrus plantations (Fundação Florestal, 2021). The altitude varies from 510 to 575 meters, and the terrain is generally flat, with only a small spring in the extreme southwest of the ESEC Barreiro Rico. The region's climate is Cfa, a humid subtropical zone without a dry season, with a hot summer, an average annual precipitation of 1,288 mm, and mean temperatures of 20.6°C (Alvares; Stape; Sentelhas, 2013). Although there are no defined seasons under this classification, it is possible to observe months with lower humidity and temperatures considered here as a poor or dry season, from May to August, and wetter and hotter months considered here as a rich or wet season, from September to April (Fundação Florestal, 2021).

### **Data collection**

*Phenology.* We installed 6 plots (900 m<sup>2</sup> each) in the ESEC Barreiro Rico, alongside the three pre-existing trails, avoiding open areas and areas with a high density of lianas, to monitor trees and compare them with the observed diet. All trees with a diameter at breast height (DBH) greater than 5 cm were marked with aluminum tags and measured. A sample of every tree was collected, identified, and deposited in the ESA Herbarium at the Escola Superior de Agricultura Luiz de Queiroz - Universidade de São Paulo (Esalq/USP). We followed the protocol used by the NewFor Project (Projeto NewFor, 2021); therefore, we did not consider lianas in our botanical study.

The trees were monitored monthly for a year, between September 2023 and August 2024, and the phenophases observed were 'young leaves', 'senescent leaves', 'flower buds', 'flowers', 'unripe fruits', and 'ripe fruits' (Fournier, 1974). They were categorized from 0 to 4, where '0' is 0% of a phenophase, '1' is 1-25%, '2' is 26-50%, '3' is 51-75% and '4' is 76-100%, resulting in a final score for each phenophase for each tree, from which we calculated the final proportion of that phenophase for each month (Fournier, 1974; Morellato et al., 2000).

*Behaviour.* The systematic behavioural observations took place between July 2023 and August 2024 (Table 1). In 2023, during the first 7 months, we walked along the three pre-existing trails (550, 800 and 1050 m each) to search for the muriqui group. In 2024, we had access to a thermal drone (DJI Mavic 2 Enterprise Advanced) for seven months to assist in the search, and conducted manual flights over the forest (see Chapter 1). When we located the

group, we obtained their coordinates, entered the forest to find them on foot, and then followed them throughout the day.

The months without register, such as August, October and November 2023 and June 2024, were months when we couldn't find the group or reach them due to the lack of trails and the high density of lianas in the forest, which made it impossible to enter. To identify sex and estimate developmental stages, we used images and descriptions already published (Strier et al., 2017).

**Table 1.** Number of scans, registers and days of our behavioural monitoring. The months selected for data analysis in this study are marked with an \*.

	2023						2024							
	Jul	Aug	Sep	Oct	Nov	Dec	Jan*	Feb*	Mar*	Apr*	May	Jun	Jul	Aug*
<b>Scans</b>	107	0	127	0	10	0	168	154	184	183	62	0	94	188
<b>Registers</b>	243	0	285	0	32	0	216	388	508	536	159	0	233	466
<b>Days</b>	3	0	5	0	1	0	7	6	6	6	2	0	4	6
<b>Scans/day</b>	35.6	0	25.4	0	32	0	24	25.6	30.6	30.5	31	0	23.5	31.3

We conducted scan samples to take notes on their behaviour. Every 15 minutes, we observed them for five minutes and noted what they were doing, so that each hour we had four scans (Altmann, 1974; Milton, 1984; Strier, 1987; Martins, 2005c). We based our behaviour notes on the ethogram from 'Projeto Muriqui de Caratinga' (Strier, 2018), dividing it into five categories (Feed, Rest, Locomotion, Social, and Indefinite). The indefinite category encompasses behaviours that were not directly observed, but the individual's location and identification were known; therefore, these were moments when the individual was hidden behind clumps of leaves.

We used only days with 10 or more scans to calculate the frequency of each behaviour for each scan, then computed daily and monthly percentages of each observed category to reduce sampling bias (Milton, 1984; Strier, 1987; Martins, 2005c). That way, it was possible to calculate the general activity budget for the adults from the muriqui group. The number of scans, registers and days per month are shown in Table 1. The same calculations used in the behaviour analysis were also applied to determine the group's diet, identifying the most-consumed items (Martins, 2005c).

We divided their height in the tree into 7 categories (0 = 0 m; 1 = 0.1-1.99 m; 2 = 2-4.99 m; 3 = 5-9.99 m; 4 = 10-14.99 m; 5 = 15-20 m; 6 > 20 m), also based in the manual used by 'Projeto Muriqui de Caratinga' (Strier, 2018), and their height was visually estimated to determine the one most used for them.

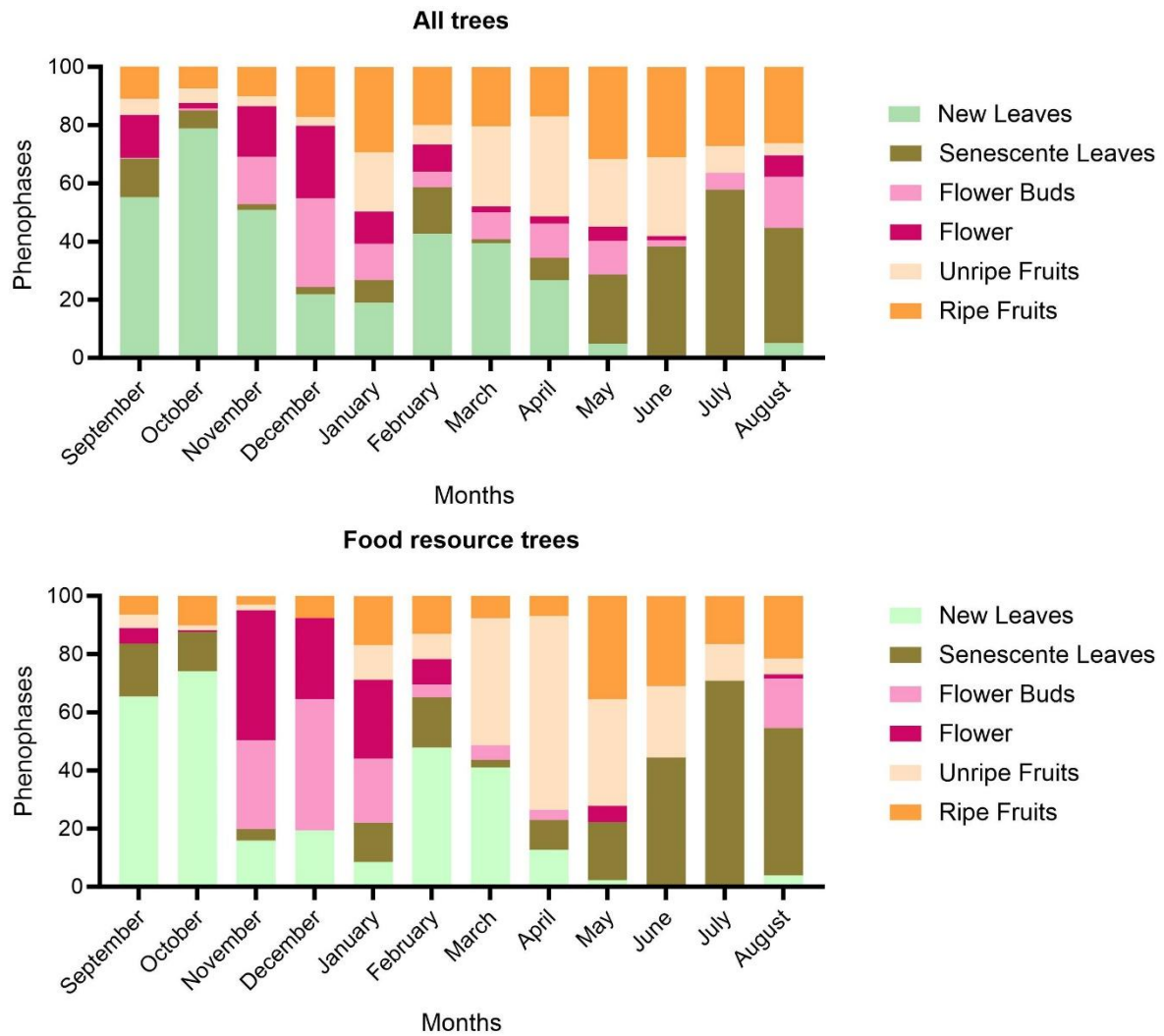
*Home range.* The group's exact geographical location was marked with a handheld GPS, and all the points were plotted on a map in QGIS Desktop 3.30.3. The home range was calculated using the Minimum Polygon Convex (MPC) method in QGIS with the Convex Hull tool. And the core area was calculated using the Kernel Density Estimation tool with a radius of 60 meters (Fortes; Bicca-Marques, 2005; Melo et al., 2026).

*Analyses.* All statistical analyses were performed using the software R. To analyse phenological seasonal patterns and identify differences between categories, we used a generalized linear mixed model (GLMM) with a negative binomial distribution. The model included cyclical seasonal terms, represented by sine and cosine functions of the months, as well as the interaction between seasonality and item category.

To test for seasonality in behaviour, we considered a wet season (January to March) and the dry season (April and August). We used generalized linear mixed models with a binomial distribution. To test seasonality in the diet between wet and dry seasons, we calculated the Shannon index to estimate monthly diet diversity, then used a generalized linear mixed model with a Gaussian distribution to test for significant variation. To test if there is a selectivity in the diet, we used the chi-square test, the p-value was obtained by Monte Carlo simulation (9,999 replicas), and the categories were identified as selected or avoided through the analysis of standardized residuals, considering values greater than +2 as positive selection and less than -2 as avoidance. To test the vertical use, we examine the association between behaviour and height using a generalized linear mixed model (GLMM) with a binomial distribution.

## **Results**

*Phenology.* A total of 642 trees were monitored, and the phenophases of all trees and the species considered food resources (N=230) (see Chapter 2) are similar (Figure 1). New leaves were registered more frequently during the beginning and the end of the wet season, in September and October, and in February and March. Flowers and flower buds were more present between November and January, a rainy period. Ripe fruits are relatively constant throughout the year and more pronounced from November to January. Unripe fruits start to appear more after the flowering season, from March to June, in the autumn. The senescent leaves were recorded most frequently during the dry season, between June and August.



**Figure 1.** Percentage of food items' availability from all trees and the food resource species present in the ESEC Barreiro Rico between September 2023 and August 2024.

The statistical analysis revealed distinct availability patterns throughout the year for some items from food resource trees. New leaves had significantly higher average availability than the other categories ( $\beta = 0.965$ ;  $p = 0.008$ ). Unripe fruits, in turn, showed significant seasonal variation ( $\beta = -1.348$ ;  $p = 0.029$ ). Ripe fruits did not show a significant main effect, although they indicated a seasonal trend ( $\beta = -0.789$ ;  $p \approx 0.082$ ). In contrast, senescent leaves and flowers showed no significant effects ( $\beta = 0.211$ ;  $p > 0.6$  and  $\beta = -0.061$ ;  $p \approx 0.88$ , respectively).

*Group size.* In July 2023, the group consisted of two adult males, one adult female, and a recently born male infant. In August 2023, one adult male was found dead with signs of bites in the back and left shoulder that prevented him from moving through the trees, causing his fall. The group was sighted again in November 2023, with a nulliparous female as a new member

who was not habituated to human presence. In July 2024, the second female gave birth to a female infant, bringing the group size to five individuals: one male adult, two female adults with infants, one male, and one female.

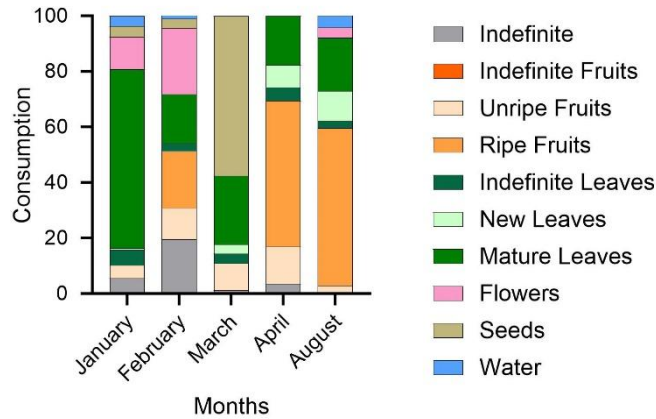
*Activities.* Only five months had adequate sampling to meet our criteria for behavioural analyses: January, February, March, April, and August. We considered 28 days of observation in our analysis. The adults in the group spent most of their time resting ( $58.21\% \pm 2.07$ ), followed by feeding ( $20.79\% \pm 2.41$ ), locomotion ( $15.04\% \pm 0.56$ ), indefinite ( $3.84\% \pm 1.43$ ), and social ( $2.12\% \pm 0.47$ ) (Table 2). Drinking water is included in the feeding category, and we observed them drinking from tree holes and licking leaves during light rain. No sexual behaviour was observed. There was a significant seasonal variation in ‘resting’, where it was higher during the poor season ( $\beta = 0.282 \pm 0.137$ ;  $z = 2.05$ ;  $p = 0.041$ ); the other categories showed no significant seasonal variation, indicating a redistribution of the behavioural budget for these categories.

**Table 2.** Activity budgets for the southern muriqui group at ESEC Barreiro Rico over the months are shown as percentages and standard deviations.

	<b>Feed</b>	<b>Rest</b>	<b>Locomotion</b>	<b>Social</b>	<b>Indefinite</b>
<b>January</b>	15.90 ± 2.8	58.90 ± 5.49	15.50 ± 2.39	0.64 ± 0.64	9.06 ± 6.07
<b>February</b>	18.77 ± 2.72	56.11 ± 4.54	17.02 ± 2.67	3.31 ± 1.47	4.79 ± 0.64
<b>March</b>	30.02 ± 3.09	51.45 ± 2.51	14.23 ± 2.17	2.71 ± 0.98	1.58 ± 0.79
<b>April</b>	19.76 ± 1.96	61.32 ± 1.48	14.46 ± 2.27	2.45 ± 0.94	2.00 ± 0.76
<b>August</b>	19.47 ± 3.22	63.26 ± 3.49	13.98 ± 2.17	1.52 ± 0.53	1.78 ± 1.23
<b>Total</b>	20.79 ± 2.41	58.21 ± 2.07	15.04 ± 0.56	2.12 ± 0.47	3.84 ± 1.43

*Diet.* Despite differences observed in consumption across the months analysed, the items consumed are not statistically different between wet and dry seasons ( $\beta = -0.173 \pm 0.112$ ;  $z = -1.54$ ;  $p = 0.125$ ). The muriqui group consumed more leaves and fruits ( $37.13\% \pm 8.66$  and  $34.31\% \pm 12.53$ , respectively), followed by seeds ( $12.96\% \pm 11.20$ ), flowers ( $7.85\% \pm 4.54$ ), indefinite ( $4.07\% \pm 3.23$ ), and drinking ( $1.82\% \pm 0.92$ ). When dividing the leaves and fruits into mature and new leaves and ripe and unripe fruits, they eat more mature leaves ( $28.75\% \pm 7.37\%$ ) and ripe fruits ( $25.99\% \pm 10.06\%$ ). The observed water consumption was from tree holes where rainwater accumulated and by licking leaves during a light rain after a long period without precipitation. Leaves were always consumed, and fruit consumption was low only in January and in March when mature leaves ( $64.50\% \pm 7.51$ ) and seeds ( $57.63\% \pm 5.78$ ) were very high, respectively. In January, mature leaves predominated; in February, consumption was

well distributed across some categories; in March, seed consumption was at its highest; and in April and August, there was a great intake of ripe fruits (Figure 2).



**Figure 2.** The percentage of items registered that were being consumed during the behavioural monitoring.

All lianas whose species we could not identify were grouped into a single category, here named “lianas”. In total, 22 species were identified as consumed; the three most common are lianas, *Hymenaea courbaril* and *Copaifera langsdorffii*. We identified 11 species consumed in the mature leaves category, with lianas, *Qualea multiflora*, and *H. courbaril* as the most consumed. The new leaves category is mainly represented by lianas, but *Croton floribundus*, *H. courbaril*, and *Aspidosperma polyneuron* were also recorded. Unripe fruits are more diversely consumed (nine species) when compared with ripe fruits (four species); the unripe fruits of *H. courbaril* and the ripe fruits of *C. langsdorffii* predominate in the intake records. The flowers consumed are entirely from lianas, represented by *Bignonia* sp., *Cuspidaria pulcra*, *Dolichandra* sp., *Fredericia chica* and *Macropsychanthus violaceus*. Only two species had their seeds consumed: *Esenbeckia leiocarpa*, the most consumed, and *Amphilogium crucigerum* (Table 3).

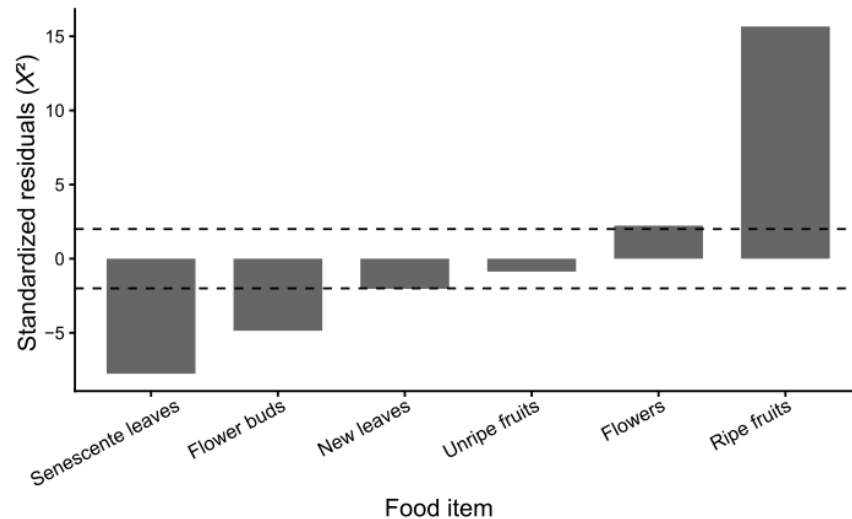
We compared our diet registers with tree production for the same months. The most consumed item in January was mature leaves, followed by flowers. Although flower production from tree resource species was high in January, these flowers were not observed to be consumed; all the flowers eaten were from lianas. In February, the production of new leaves was predominant, especially in *C. langsdorffii* trees, while the consumption of liana flowers was most pronounced, followed by the intake of ripe fruits from *Eugenia ramboi* (species not found in our plots). In March, both production and consumption of unripe fruits and seeds are from *E. leiocarpa*; they eat the seeds from the unripe fruits and discard the fruit itself. In April, ripe fruits of *C. langsdorffii* were highly consumed, and the unripe fruits of this species were

predominant in the phenology. In August, there was a predominance of senescent leaves, but the second-highest production was of ripe fruits, mainly of *C. langsdorffii*, which is the most-consumed item by the muriquis in this month.

**Table 3.** Plant species and items registered as being consumed by the muriquis at ESEC Barreiro Rico during the behavioural monitoring. Lianas are marked with an \*.

Species	Unidentified food item	Leaves		Fruits		Flowers	Seeds
		New	Mature	Unripe	Ripe		
<i>Amphilogium crucigerum</i> *				X			X
<i>Aspidosperma polyneuron</i>		X	X				
<i>Bignonia</i> sp.*			X			X	
<i>Copaifera langsdorffii</i>			X	X	X		
<i>Croton floribundus</i>		X		X			
<i>Cuspidaria pulcra</i> *						X	
<i>Dolichandra</i> sp.*						X	
<i>Esenbeckia leiocarpa</i>			X	X			X
<i>Eugenia ramboi</i>					X		
<i>Fredericia chica</i> *						X	
<i>Hymenaea courbaril</i>		X	X	X	X		
<i>Macropsychanthus violaceus</i> *						X	
<i>Maprounea guianensis</i>	X		X	X			
<i>Mouriri glazioviana</i>			X				
<i>Myrtaceae</i> sp.			X				
<i>Nectandra opositifolia</i>				X			
<i>Pereskia aculeata</i>					X		
<i>Pilocarpus pauciflorus</i>				X			
<i>Psidium sartorianum</i>				X			
<i>Qualea multiflora</i>			X				
<i>Thaumatococcus bipinnatifidum</i>			X				
<i>Xylopia brasiliensis</i>			X				

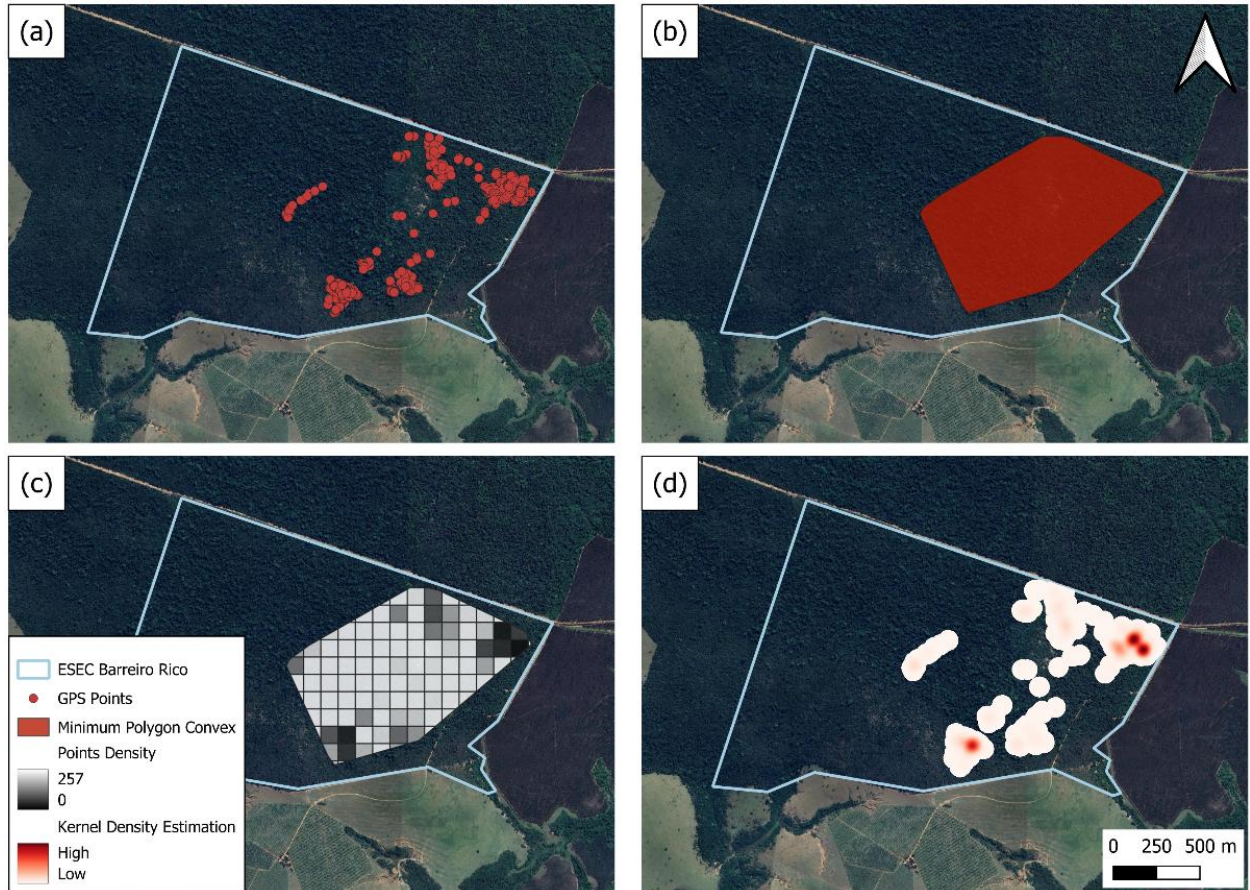
For the months analysed, consumption differed statistically from resource availability ( $X^2 = 283.01$ ,  $df = 5$ ,  $p = 0.0001$ ), indicating selective consumption of items. The analysis of standardized residuals (Figure 3) revealed strong positive selection for ripe fruit (residual = 15.66) and moderate selection for flowers (residual = 2.23). In contrast, senescent leaves (residual = -7.76), flower buds (residual = -4.86), and new leaves (residual = -2.03) were significantly avoided. Consumption of unripe fruits did not differ from availability (residual = -0.87).



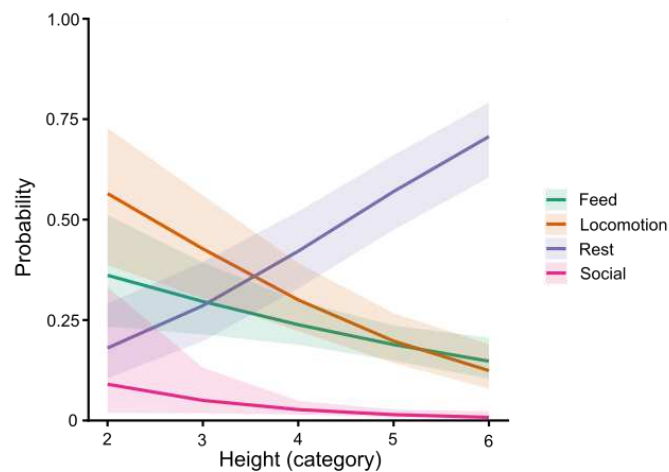
**Figure 3.** Analysis of standardized residuals showing preferences for consumed items.

*Home range.* There was 1297 GPS points registered during the whole study period. Despite the ESEC Barreiro Rico being connected to the forest fragment of another property, the muriqui group does not use the entire available area (683.09 ha); their home range, according to the MPC, is 84.42 ha, and the core area, according to the Kernel Density Estimation, is 49.03 ha (Figure 4).

*Vertical use.* The group was observed more frequently at heights between 15 and 20 meters (category 5), whereas all trees in our plots had a mean height of  $11.33 \pm 5.49$ m. The analyses show a positive relation between rest and height, indicating a preference for resting in the taller trees ( $\beta = 0.599$ ;  $p < 0.001$ ). And also, a negative relation between height and active behaviours, such as feeding ( $\beta = -0.296$ ;  $p = 0.006$ ), locomotion ( $\beta = -0.554$ ;  $p < 0.001$ ), and social ( $\beta = -0.635$ ;  $p = 0.044$ ), indicating that they prefer median to low heights to perform activities from these behavioural categories (Figure 5).



**Figure 4.** Location of home range and core area of the ESEC Barreiro Rico group during monitoring, July 2023 – August 2024. (a) GPS points registered during monitoring, (b) home range according to the Minimum Polygon Convex, (c) points density distributed in a 100 m grid, and (d) Kernel Density Estimation.



**Figure 5.** Results from the analysis of vertical use, associating the behavioural category with the height category.

## Discussion

The small and only group of southern muriquis found at the ESEC Barreiro Rico comprises one adult male, two adult females with one infant each, and a male and a female. This group spent most of their time resting, followed by feeding, locomoting, and other

activities. Their diet can be considered selective, as they prefer ripe fruits and flowers. The phenology indicates that consumption is consistent with production, and some items exhibit clear seasonal patterns. They eat more leaves and fruits, followed by seeds and flowers.

*Phenology.* Lianas were not measured in the phenology studies because the protocol did not consider them. Still, they were among the most important food resources for the southern miqui in the ESEC Barreiro Rico, as previously documented (Milton, 1984). New leaves are the most abundant and consistent resource throughout the study period, while for the unripe fruits, there may be months with greater abundance, but without robust statistical evidence. The most preferred item, ripe fruits, did not show a significant increase, although it tends to be seasonal. Flowers and senescent leaves remain relatively constant throughout the year, despite variation in quantity across months, with no clear peaks detected in the analysis.

Although the model did not detect a statistically significant seasonal pattern in the flowers and senescent leaves, the descriptive phenological analysis indicated apparent peaks in certain months (Figure 1). This apparent discrepancy can be explained by the model's use of a harmonious structure (sine and cosine) to represent seasonality, thereby capturing smooth, regular cyclical patterns throughout the year. Therefore, more abrupt variations, concentrated within a few months or heterogeneous across species, may not be captured by this approach, resulting in a lack of statistical significance even in the face of visible fluctuations.

*Activities.* The miqui group studied spent most of their time resting, followed by feeding and traveling, as reported for the other group studied in 1982-1983 at the APA Barreiro Rico (Milton, 1984), in Parque Estadual Carlos Botelho (Talebi; Lee, 2010) and for the northern miqui (*Brachyteles hypoxanthus*) in Caratinga, Minas Gerais (Strier, 1987). Miqui are known to start moving later in the morning, mainly in the coldest months, and stop to rest in the middle of the day (Milton, 1984; Strier, 1987). There were no differences in the behavioural categories between the dry and wet seasons, except for resting, which was high in the dry season. The dry season is also the coldest, so this increase in resting may be explained by the decrease in temperature.

*Diet.* In the ESEC Barreiro Rico, we found that miqui ate more leaves but had a similar fruit consumption, unlike Strier (1991), a study in the same type of forest but with northern miqui, found that leaves were the most consumed items; similar results were found by Milton (1984), where leaves were the largest part of their diet, but fruits were not in similar proportions. She also noted that they ate more unripe fruit, as ripe fruit was rare in the forest.

The difference in the consumption and in the availability of fruits in those studies may be explained by annual differences in tree production, as observed for the *C. langsdoffii* for example, a very consumed species in their diet and very common in the forest, which production of fruits can be high in one year and low or absent in the following years (Pedroni; Sanchez; Santos, 2002). Another factor that influences this difference is climate change, which alters temperatures and precipitation, mainly affecting the reproductive phenophases of many trees, such as *Myrcia* species (Dos Santos-Neto et al., 2026).

Martins (2005) found a seasonal difference in the diet of muriquis in the APA Barreiro Rico; for the southern muriquis from Parque Estadual Carlos Botelho, Carvalho et al (2004) did not find a seasonal difference, as we did not, but they argue that this can be explained by the evergreen forest, where fruits are more available throughout the year. This divergence might be different if we had more sampled months across the year to analyse more data.

When relating diet to phenology, we see that this group of muriquis prefers specific items in their diet and does not rely solely on what is most readily available in the forest, confirming them as selective consumers (Strier, 1991). The production and consumption of items coincide in the same months, but the consumption of some, like ripe fruits and flowers, is more pronounced than their availability would suggest. Mature leaves were not used in this association because they were not analysed in the phenology study. However, we can infer that they are very popular, as they are the most consumed item when calculating the proportion of consumed items and yield a close result compared with fruits.

*Home range.* The calculated core area is 49.03 ha; this result is within the range reported in other studies. In Caratinga, four groups, ranging from 48 to 130 individuals, had core areas of 21 to 86 ha (Lima; Mendes; Strier, 2019). Milton (1984) observed, in the APA Barreiro Rico, a core area of 4 ha of the home range for a group of 7 females and their offspring, while males formed subgroups and explored different areas, so this number does not correspond to the core area of the entire group. Probably, the absence of other groups and subgroups using the same forest provides more area for the small group at ESEC Barreiro Rico to explore. The group also does not use the area in regeneration (due to a forest fire in 2018), but it seems to have been part of its home range, as they approach the degraded area and stay on the edge where taller trees remain.

*Vertical use.* As noted by Milton (1984), the southern muriquis prefer the taller trees in the forest. Our study shows that these preferences are more closely related to resting, while

feeding and traveling are more common at lower heights. Still, they have never been observed on the ground at the APA Barreiro Rico. The taller trees commonly have larger branches and are more stable on windy days, making them more comfortable to rest in, besides providing security against terrestrial predators, such as ocelots and pumas (Bianchi; Mendes, 2007; Santos et al., 2014). Feeding and traveling can be related to lower heights, given the median height of this forest ( $11.33 \pm 5.49\text{m}$ ), thereby increasing the availability of branches for brachiation between them and their access to smaller trees and the canopies of taller trees at the same time, which serve as a food source.

All these results provide a current perspective on how the small southern murrelet group survives in the forest at ESEC Barreiro Rico and on how similar it is to the other murrelet groups. Based on this information, we understand which plant species are very important to their diet, which items they prefer and consume most, and which areas they use most, and this can assist in the implementation of public policies that protect the southern murrelet. Focusing on strategies to protect even more of the area they inhabit, planting new trees they can consume in the future, ensuring they have the resources to thrive and implementing management and conservation actions to protect the southern murrelet in the APA Barreiro Rico.

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## Conclusion

The southern muriqui population from APA Barreiro Rico has unique characteristics, due to its location and isolation from other populations, inhabits a very biodiverse forest fragment, and it has cultural significance for the surrounding cities. Protecting the muriqui in this area is challenging, as it is surrounded by large properties with pasture, sugarcane, citrus, and eucalyptus plantations, and by a history of forest fires, which have been successfully combated by Fundação Florestal and a network created for this purpose.

Besides the small increase in size registered in the last few years for one group in this research, we observed a tendency to decrease population size over the last few decades, disappearing from some forest fragments or decreasing in size in others, which raises concern. This research brings updated population size data from APA Barreiro Rico that can influence the population management and motivate the creation of more canopy bridge; on the behaviour and diet of one small group, creating a list of food species that could be the focus of forest restoration in the region; and we also sought to understand better some forest variables that may explain the disappearance from some forest fragments, such as the forest fires that occurred causing the loss of tree biomass.

To help this population thrive again in this area, conservation plans and management actions must be based on scientific information from this and other recent research focused on the biodiversity of APA Barreiro Rico. So, all our results will be shared with the local government to guide planning and management decisions, and to provide up-to-date information on this species at the APA Barreiro Rico, thereby helping to save the species from local extinction.