

## Anomalous Pigmentation in Invasive and Native Marmosets, *Callithrix jacchus*, *Callithrix penicillata* (Primates, Callitrichidae), and Their Hybrids in Brazil

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### Keywords

Atlantic Forest · Savannah · Leucism · Hybridization · Inbreeding

### Abstract

Leucism is the lack or reduction in pigmentation in the most or parts of the body, but not in the eyes and body extremities. It is extremely rare in primates and has never been reported for *Callithrix*, a genus endemic to Brazil. We searched for individuals of *Callithrix jacchus* and *C. penicillata* with pigmentation anomalies in a systematic survey of three protected areas in the Atlantic Forest, within museum collections in Brazil, and opportunistically during field studies. Since 2008, we have recorded 8 individuals with leucism in small urban and periurban forest patches. Four were from native populations of *C. penicillata* in Cerrado savannahs and of *C. jacchus* in the Caatinga xeric scrubland, and 4 were from populations of hybrids between *C. jacchus* and *C. penicillata* in invaded areas in the coastal Atlantic Forest. We found no pigmentation abnormalities in museum specimens. We hypothesize that the observed leucism may be linked to inbreeding within the native range, but to hybridization within the invaded range, and discuss the likely ecological consequences to leucistic individuals.

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## Introduction

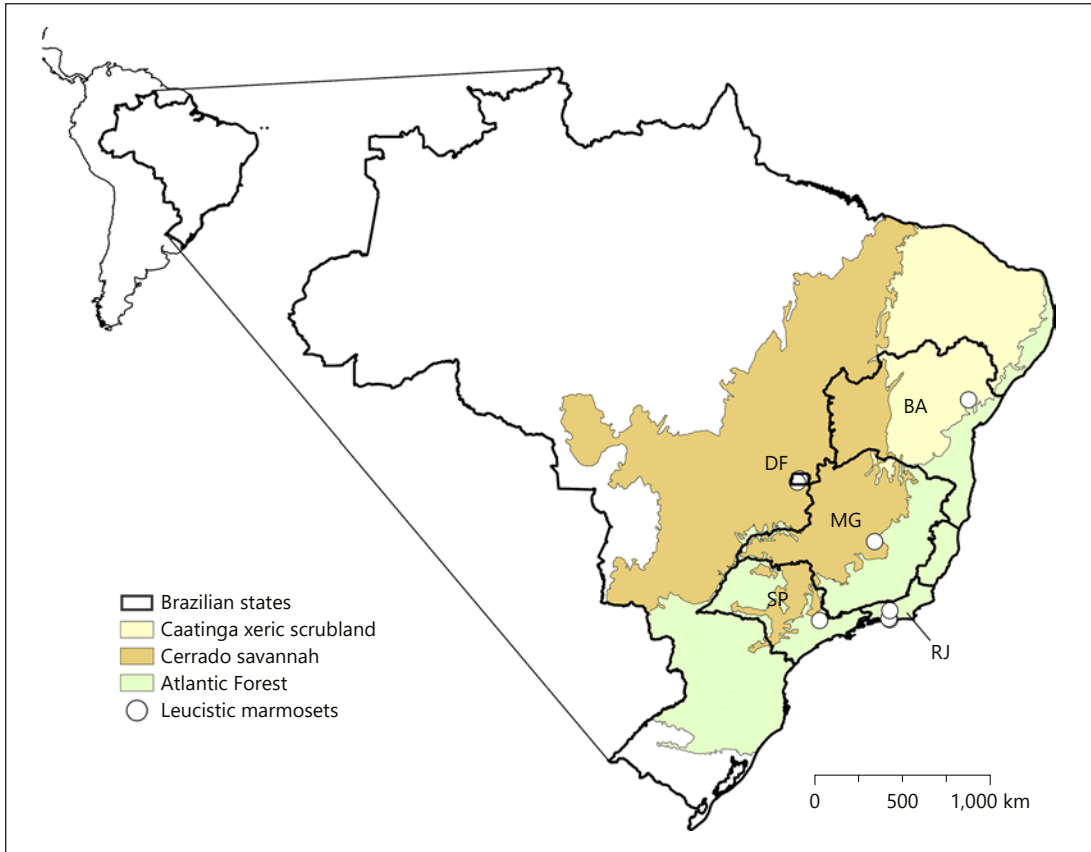
In Neotropical mammals, anomalous pigmentation has been identified in many groups, being more common in marine than in terrestrial species, and considered rare in primates [Abreu et al., 2013]. The pigmentation anomalies that cause abnormal coloration are identified as deficiency (leucism and piebaldism), absence (albinism) or an excess (melanism) of melanin production [Hofreiter and Schöneberg, 2010; Romero et al., 2018]. Only 2 (recent) cases of anomalous pigmentation have been reported in Neotropical primates to date, an adult female brown howler monkey (*Alouatta guariba clamitans*) with leucism [Aximoff and Vaz, 2016] and a juvenile female Central American spider monkey (*Ateles geoffroyi*) with albinism [Espinal et al., 2016]. In both cases, the authors suggest a relationship between the anomalies and increased inbreeding in small local populations [Aximoff and Vaz, 2016; Espinal et al., 2016].

Leucism is often attributed to the presence of recessive mutant alleles or to the lack of production of the enzyme involved in melanin biosynthesis [Bensch et al., 2000]. Records of anomalous pigmentation can reflect population health and threats, such as low genetic diversity due to small population size and isolation [Fortes and Bicca-Marques, 2008; Aximoff and Vaz, 2016; Brito and Valdivieso-Bermeo, 2016]. Deforestation, low habitat quality [Kehas et al., 2005], pollution [Moller and Mousseau, 2001], poor-quality diet [Coimbra-Filho and Rocha, 1978], and hybridization events [Berube and Aguilar, 1998; Yazdi, 2002; Arntzen et al., 2014] may be linked to pigmentation anomalies.

The genus *Callithrix* (Erxleben, 1777) has 6 species, all endemic to Brazil [Rylands et al., 2009; Paglia et al., 2012]. The common marmoset, *Callithrix jacchus* (Linnaeus, 1758), and the black-tufted ear marmoset, *Callithrix penicillata* (E. Geoffroy, 1812), are the most abundant and widespread species of the genus. The common marmoset (*C. jacchus*) has a predominately light gray body, with brown and black tones in some parts; the lower back and tail have transverse bands (dark wide rings and light narrow rings), and the forehead has a white spot and tufts of white hair above and in front of the ears [Vivo, 1991]. The black-tufted ear marmoset (*C. penicillata*) has a body with a dark gray color, with striations on the lower back, a dark head, and a lighter blotch on the forehead that is characteristic of the species. The face is black or dark brown, with tufts of long black hair in the shape of a brush. It has an annular tail, with intercalated white and black stripes [Vivo, 1991].

The common marmoset (*C. jacchus*) is native to the xeric scrubland forests (Caatinga biome) and rain forests (Atlantic Forest biome) of northeastern Brazil, and the black-tufted ear marmoset (*C. penicillata*) is native to savannahs (Cerrado biome) in central Brazil [Rylands et al., 1996; Rosa et al., 2017]. Due to pet release, both species are currently widespread outside their native range, in urban and periurban Atlantic Forest fragments in southern and southeastern Brazil [Rosa et al., 2017].

The marmosets are arboreal animals that use fruits, insects, starch/exudate, and even bird eggs as food resources [Faria, 1986; Paglia et al., 2012]. They are also important seed dispersers in the Atlantic Forest [Bufalo et al., 2016]. Invasive populations of marmosets, however, can cause environmental problems, including competition, predation [Rothe, 1999; Begotti and Landesmann, 2008; Modesto and Bergallo, 2008; Galetti et al., 2009; Alexandrino et al., 2012; Aximoff and Carvalho, 2016; Rosa



**Fig. 1.** Location of records of marmosets with leucism in Brazil. States: Bahia (BA), Minas Gerais (MG), Rio de Janeiro (RJ), São Paulo (SP), and Distrito Federal (DF). Records in Caatinga and Cerrado biomes are of *C. jacchus* and *C. penicillata*, respectively, within their native ranges, and records in the Atlantic Forest biome are of hybrids between *Callithrix penicillata* and *Callithrix jacchus* within the invaded range.

et al., 2017], and hybridization with native species [Bicca-Marques et al., 2006; Ruiz-Miranda et al., 2006; Pereira et al., 2008; Aximoff et al., 2016; Rosa et al., 2017].

Here we report the first cases of leucism in marmoset species, in both native and invaded habitats.

## Methods

We searched for individuals of *C. jacchus* and *C. penicillata* with pigmentation anomalies in three ways: (1) a systematic survey of the Atlantic Forest, (2) examining museum collections in Brazil, and (3) opportunistically during field studies.

The systematic survey on invasive populations of marmosets was carried out in three protected areas in Rio de Janeiro City, within the Atlantic Forest. All protected areas are dominated by secondary submontane rain forest with a high density of exotic tree species. The Tijuca Na-

**Table 1.** Records of marmosets with leucism in northeastern and southeastern Brazil between 2008 and 2016

Species	Date	Location	Range	Latitude	Longitude
<i>Callithrix jacchus</i>	08/08/2008	Ichu, BA	Native	11°44'41" S	39°11'30" W
<i>Callithrix penicillata</i>	07/21/2016	Belo Horizonte, MG	Native	18°58'38" S	44°00'05" W
<i>Callithrix penicillata</i>	08/02/2018	Brasília, DF	Native	15°45'50" S	47°50'08" W
<i>Callithrix penicillata</i>	26/06/2018	Brasília, DF	Native	15°56'01" S	47°57'16" W
<i>Callithrix penicillata</i> / <i>C. jacchus</i> hybrid	12/26/2014	Rio de Janeiro, RJ	Invaded	22°58'33" S	43°13'43" W
<i>Callithrix penicillata</i> / <i>C. jacchus</i> hybrid	01/12/2016	Rio de Janeiro (Grajaú State Park), RJ	Invaded	22°55'25" S	43°16'18" W
<i>Callithrix penicillata</i> / <i>C. jacchus</i> hybrid	07/12/2016	Petrópolis, RJ	Invaded	22°30'47" S	43°13'11" W
<i>Callithrix penicillata</i> / <i>C. jacchus</i> hybrid	12/20/2015	Itatiba, SP	Invaded	23°01'12" S	46°48'51" W

Brazilian states: Bahia (BA), Minas Gerais (MG), Distrito Federal (DF), Rio de Janeiro (RJ), and São Paulo (SP).

tional Park is one of the largest urban forests in the world [Bandeira, 1994], with 3,953 ha, while the other two protected areas, the Grajaú State Park and the Rio de Janeiro Botanical Garden, are small patches of forest (approx. 55 ha) connected to the Tijuca National Park. The systematic survey encompassed more than 900 h of sampling [see Zaluar et al., 2014, and Zaluar, 2015, for details].

We also examined approximately 200 marmoset specimens deposited in the most important mammal collections in Brazil: the Zoology Museum at the São Paulo University (MZUSP), the National Museum at the Federal University of Rio de Janeiro (MNUFRJ), the João Moojen Museum at the Federal University of Viçosa, and the Mammal Collection at the State University of Santa Cruz. MZUSP and MNUFRJ are the natural history museums with the largest mammal collections in the country.

Finally, we recorded *Callithrix* with pigmentation anomalies opportunistically during field studies with other aims. We collected records in five Brazilian cities within four states: Bahia, Rio de Janeiro, São Paulo, and Minas Gerais (Fig. 1). The records from Bahia and Minas Gerais states are within the species' native range: in the Caatinga biome of *C. jacchus* and the Cerrado biome of *C. penicillata*, respectively. The records from Rio de Janeiro and São Paulo, on the other hand, are within invaded areas in the Atlantic coastal rain forest.

## Results

We recorded 8 marmoset individuals with abnormal pigmentation: half within the species' native range (1 *C. jacchus* and 3 *C. penicillata*) and half within the invaded range (*C. jacchus*/*C. penicillata* hybrids). One of the records was from the systematic survey and the remainder from opportunistic encounters. No individual with leucism was found in the museum collections visited.

Four marmoset individuals with abnormal pigmentation were opportunistically recorded within their native range. An adult male of *C. jacchus* was recorded in the city of Ichu, in Bahia State, in the Caatinga biome, in a periurban fragment within a riparian forest, about 500 m away from downtown (Table 1). It had an almost completely white pelage and facial pigmentation, with some spots of the normal coloration remaining on the back. Additionally, 3 individuals of *C. penicillata* were recorded in cities within the Cerrado biome. One was recorded in the municipality of Belo Horizonte, Minas Gerais, within the Cerrado biome (Table 1). We were not able



Color version available online

**Fig. 2.** *Callithrix* sp. with leucism in the Atlantic Forest of southeastern Brazil. **a, e** *C. jacchus* female in Grajaú State Park. **b** Individual recorded in Gávea district, Rio de Janeiro City (Rio de Janeiro state – RJ). **c** Individual recorded in Petropolis City (RJ). **d, f** Individual recorded in Itatiba City (São Paulo state). **g** *C. jacchus* individual with normal coloration in Grajaú State Park.

to determine the sex of the individual, which had a predominantly white body, with pinkish paws and face and a single grayish stripe along its back. This marmoset was registered in a group of 10 individuals. We recorded 4 other black-tufted ear marmoset (*C. penicillata*) groups in the region, none of which appeared to contain individuals with visible pigmentation abnormalities.

The other 2 *C. penicillata* individuals with leucism were recorded in the city of Brasília, in the Federal District. The first individual was an adult recorded in a residential area with many gardens with fruiting trees and, therefore, a large population of *C. penicillata*. The leucistic individual formed part of a group of 8 more individuals with regular coat color. The second leucistic individual, apparently a juvenile, was recorded in a more peripheral area of the city, close to some protected areas such as the Brasília Botanical Garden [Rodrigues et al., 2016]. It was in a group with 6 other recorded individuals with regular coat color.

Four hybrids between *C. jacchus* and *C. penicillata* with abnormal pigmentation were recorded in the invaded range, within the Atlantic Forest biome. One hybrid adult female was recorded during the systematic survey in the Grajaú State Park, Rio de Janeiro (Table 1). It had coloration close to that of a normal *C. jacchus* individual (Fig. 2g), but with a slightly lighter coat (Fig. 2a, e). This female was one of the 7 individuals of the only group recorded in Grajaú State Park. The group uses areas close to the park manager's house and recreation areas where we observed the marmosets being fed by park visitors. We recognized another group with 6 marmosets in an urban environment around 500 m from the Grajaú State Park border. Because of the presence of the anomalous individual, we could easily recognize and differentiate the two groups. We have not observed any interaction between the groups, although the group observed inside the Grajaú State Park has also been recorded using the surrounding urban environment.

The other 3 records of hybrids with abnormal pigmentation in the invaded range were made opportunistically (Table 1), and we were not able to determine the sex of individuals. One record in Rio de Janeiro city, in Rio de Janeiro state had normal pigmentation with many white patches throughout the body. Two other individuals, one in Petrópolis city, in Rio de Janeiro state (Fig. 2c), and the other in Atibaia city, in São Paulo state (Fig 2d, f, Table 1), had an almost completely white pelage and pigmentation of the face, with some spots of normal coloration still on the back. All individuals with anomalies were registered in groups with other marmosets with nonanomalous pigmentation.

## Discussion

The abnormal pigmentation records reported in this study point to leucism [Fertl and Rosel, 2002]: the partial or total absence of pigmentation on the whole body, which is white, whitish or yellowish white in color, but with the eyes and/or body extremities maintaining dark pigmentation [Miller, 2005]. Leucism is considered rare in primates [Aximoff and Vaz, 2016; Espinal et al., 2016], and our study confirms this rarity, as these are the first records of leucism in marmosets, despite being one of the most studied primate groups in Brazil [Rylands et al., 2009] and with no record in museum collections.

Leucism can be attributed to genetic [Fortes and Bicca-Marques, 2008; Aximoff and Vaz, 2016; Brito and Valdivieso-Bermeo, 2016] and environmental causes [Moller and Mousseau, 2001, Kehas et al., 2005; Talamoni et al., 2017]. It has been more prevalent in small and isolated populations due to inbreeding depression [Bensch et al., 2000]. Because endogamy leads to fixation of recessive alleles, due to small and isolated group size, it results in low genetic variability, which often causes pigmentation anomalies [Fortes and Bicca-Marques, 2008; Aximoff and Vaz, 2016; Brito and Valdivieso-Bermeo, 2016]. All our records of marmosets with leucism were in small, isolated forest patches within urban environments. For the two records of leucism within the marmosets' native range, a link with inbreeding depression is plausible. Inbreeding, however, is unlikely in the invaded range in the Atlantic Forest, where the common (*C. jacchus*) and black-tufted ear marmoset (*C. penicillata*) have established self-sustaining populations [Rosa et al., 2017] and produced fertile hybrids [Cunha and Vieira, 2004; Cunha et al., 2006; Bruno and Bard, 2016].

The four records of marmosets with leucism in the Atlantic Forest are, indeed, from hybrids, which should be more prone to some sort of outbreeding, rather than inbreeding depression [Lynch, 1991]. Hybridization has been reported as a cause of unusual color and body malformation in a number of animal species [Arntzen and Wallis, 1991; Berube and Aguilar, 1998; Yazdi, 2002, Arntzen et al., 2014]. For these hybrid individuals, therefore, a link between leucism and hybridization is more plausible.

Leucism may also be associated with adverse environmental conditions. Both common (*C. jacchus*) and black-tufted ear marmosets (*C. penicillata*) are considered ecologically successful due to their large geographical distribution, efficient habitat exploration, high behavioral plasticity, ability to use different food resources and high population density [Stevenson and Rylands, 1988; Leite et al., 2011; Mittermeier et al., 2013]. Hence, they are known to settle easily, even in urban environments. Urban areas, however, are considered to have low habitat quality and poor-quality diet for primates, which can induce permanent or temporary sublethal effects, including alterations in body pigmentation [Coimbra-Filho and Rocha, 1978; Kehas et al., 2005].

Regardless of the possible cause behind the cases of leucism reported here, it may reduce the fitness of leucistic individuals. One possible disadvantage is the reduction or loss of natural camouflage from predators, which may interfere with individual survivorship [Caro, 2005]. Due to excessive exposure, the individuals are expected to be rapidly removed from the population by predation or even human interest in exotic pets [Sazima and Di-Bernardo, 1991; Nkosi and Twala, 2002]. Curiously, however, all but one of our records were from adult individuals, indicating that they have managed to escape predation thus far. On the other hand, it may just be the result of low predator pressure. In urban forests in Rio de Janeiro State, for instance, low marmoset predation rates have been reported, due to the decline in the population of their main natural predators, e.g., hawks, *Boa constrictor* and wild felines [Bruno and Bard, 2016]. Alterations in intraspecific interactions, such as ostracism, can also occur [Slavík et al., 2015], although we did not observe this behavior in the populations studied. Leucistic individuals can also have an increased risk of diseases, as happens with albino individuals [Bridge et al., 2014].

These are the first records of leucism in marmosets. Further investigations with a specific focus on these anomalies must be carried out in order to better understand the causes and consequences of their occurrence in marmosets. These studies must

be carried out both in the Atlantic Forest, where these species are alien invaders, and in the Cerrado and Caatinga, where they are native, as we hypothesize that the observed pigmentation anomalies may be linked to hybridization in the first location and inbreeding in the latter.

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## Statement of Ethics

The authors have no ethical conflicts to disclose.

## Disclosure Statement

The authors have no conflicts of interest to declare.

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## Author Contributions

I.A., M.M.V. and M.Z. conceived the ideas and designed the methodology; I.A., M.Z., A.P., P.A.B., T.A.M., C.A.R., L.C.O., D.S.T. and M.M.V. contributed with records; M.M.V. and M.Z. did the mapping; I.A., M.M.V., M.Z. and C.A.R. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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