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INVASIVE MARMOSETS AND CONSERVATION OF THE BIODIVERSITY IN THE BRAZILIAN ATLANTIC FOREST

Marina T. Zaluar[1,5*], *Felipe Süssekind*[2], *Carlos Eduardo de Viveiros Grelle*[3,4] & *Maria Alice S. Alves*[5]

[1] University of the State of Rio de Janeiro, Postgraduate Program in Ecology and Evolution, Roberto Alcantara Gomes Biology Institute, Rua Boulevard 28 de Setembro, 87, Pavilhão Américo Piquet Carneiro, CEP 20551-030, Rio de Janeiro, RJ, Brazil.

[2] Pontifical Catholic University of Rio de Janeiro, Department of Social Sciences, Postgraduate Program in Social Sciences, Rua Marquez de São Vicente, 225, CEP 22451-900, Gávea, Rio de Janeiro, RJ, Brazil.

[3] Federal University of Rio de Janeiro, Instituto de Biologia, Programa de Pós-graduação em Ecologia, Av. Carlos Chagas Filho, 373, Cidade Universitária, CEP 21941-590, Rio de Janeiro, RJ, Brazil.

[4] Knowledge Center for Biodiversity- INCT/CNPq, Brazil

[5] University of the State of Rio de Janeiro, Department of Ecology, Postgraduate Program in Ecology and Evolution, Roberto Alcantara Gomes Biology Institute, Rua Boulevard 28 de Setembro, 87, Pavilhão Américo Piquet Carneiro, CEP 20551-030, Rio de Janeiro, RJ, Brazil.

E-mails: marinazaluar@hotmail.com (*corresponding author); felipesussekind@puc-rio.br; cevgrelle@gmail.com; masaalves19@gmail.com

Abstract: *Callithrix jacchus* and *Callithrix penicillata* are invasive species in the Atlantic Forest areas of southern and southeastern Brazil, where they were probably introduced through illegal wildlife trafficking and indiscriminate release, and have managed to expand their geographical distribution in a context of habitat loss in the original regions (northeastern and central Brazil, respectively). In the city of Rio de Janeiro, biological invasions shaped the urban forests that grew on the ruins of the sugar cane and coffee plantations that dominated the landscape during the colonial period. The biological invasions unfold, in this case, in goods and human and non-human lives that have formed and reforested the modern metropolis throughout its history. In this context, the aim of this study is to discuss the ecological risks and social dynamics involved in the introduction of marmosets into the Atlantic Forest, pointing out the challenges of managing and conserving biodiversity in anthropized landscapes. In discussing the case of the marmosets, we have inserted broader debates on biological invasions, forest regeneration and socio-environmental conservation, highlighting the need for policies that integrate the ecological and social dimensions of the problem presented. Further studies into the ecology of forests in urban areas could provide new insights into the role of invasive species in anthropized ecosystems.

Keywords: invasive marmosets; anthropocene; anthropized ecosystems; Atlantic Forest

SAGUIS INVASORES E A CONSERVAÇÃO DA BIODIVERSIDADE NA MATA ATLÂNTICA BRASILEIRA: *Callithrix jacchus* e *Callithrix penicillata* são espécies invasoras em áreas de Mata Atlântica do sul e sudeste do Brasil, onde foram introduzidas provavelmente por meio do tráfico ilegal de animais silvestres e da soltura indiscriminada, e conseguiram expandir sua distribuição geográfica em um contexto de perda de habitat nas regiões originais (nordeste e centro do Brasil, respetivamente). Na cidade do Rio de Janeiro, as invasões biológicas deram forma às florestas urbanas que cresceram sobre as ruínas das plantações de cana-de-açúcar e café, que dominaram a paisagem durante o período colonial. As invasões biológicas desdobram-se, neste caso, em mercadorias e vidas humanas e não-humanas que formaram e reflorestaram a metrópole moderna ao longo da sua história. Nesse contexto, o objetivo deste estudo é discutir, a partir de uma revisão da literatura especializada, os riscos ecológicos e as dinâmicas sociais envolvidas na introdução dos saguis na Mata Atlântica, apontando desafios da gestão e conservação da biodiversidade em paisagens antropizadas. Ao discutirmos o caso dos saguis inserimos debates mais amplos sobre invasões biológicas, regeneração florestal e conservação socioambiental, destacando a necessidade de políticas que integrem as dimensões ecológicas e sociais da problemática apresentada. Estudos mais aprofundados sobre a ecologia de florestas em áreas urbanas podem fornecer novos insights sobre o papel das espécies invasoras em ecossistemas antropizados.

Palavras-chave: saguis invasores; antropoceno; ecossistemas antropizados; Mata Atlântica

INTRODUCTION

Invasive species are organisms that are intentionally or unintentionally introduced by human action in places outside their original distribution area where they establish themselves, reproduce and disperse to new areas from their point of introduction (Blackburn *et al.* 2011). Biological invasion is a process that includes transport (by human activities or by the expansion of natural range areas as a way to overcome natural barriers), introduction, establishment, expansion and persistence of populations of an introduced species (Blackburn *et al.* 2011). By overcoming its geographic barrier, the species may not survive or may become established and persist in the new area (Ziller & Zalba 2007).

Callithrix Erxleben, 1777 (Primates: Callithrichidae), is a genus of marmosets with six species that are parapatrically distributed in Brazil (Kinzey 1982, Rylands *et al.* 1996, Braz *et al.* 2019). *Callithrix jacchus* (Linnaeus 1758) (Primates: Callithrichidae) is native to the Caatinga and Atlantic Forest biomes in Northeastern Brazil and *Callithrix penicillata* (É. Geoffroy, 1812) (Primates: Callithrichidae) is native to the Cerrado biome, and both species were introduced to South and southeast Brazil within the Atlantic Forest biome (Kinzey 1982). *Callithrix penicillata* has the largest original geographic distribution among the species of the genus (Coimbra-Filho 1983), is able to survive in more seasonal and less productive habitats, and is considered the most ecologically successful species among the callitrichids, both in terms of geographic distribution and population density (Stevenson & Rylands 1988). These two species, like other callitrichids, have adaptation of the dental anatomy and are capable of drilling the trunk to feed on the exudates of certain trees, along with a digestive tract adapted for this behavior, known as gummivory (Coimbra-Filho *et al.* 1980, Mittermeier *et al.* 1982). However, *C. jacchus* and *C. penicillata* are more efficient at using exudates than other callitrichids (Rylands 1993, Rylands *et al.* 1996). In addition to a very diverse and generalist diet, gumivory is pointed out as one of the adaptations of marmosets that favours the establishment of populations and survival in diverse environments, even those with low availability of food resources, including disturbed and urban areas (Oliveira & Grelle 2012, Zaluar & Vale 2021, Zaluar *et al.* 2022). It is important to note that *C. aurita* and *C. flaviceps* also present gumivory but with a lower efficiency than *C. jacchus* and *C. penicillata* (Rylands 1993, Rylands *et al.* 1996).

As in other wildlife cases, the introduction of *C. jacchus* and *C. penicillata* in the southern and southeastern regions of Brazil is associated with illegal wildlife trade, expansion of geographical distribution due to the loss of habitat in the original regions, and the indiscriminate release of these species (Bruno & Bard 2016). Wild animal trafficking is considered the third largest illicit activity in the

world, and cities such as Rio de Janeiro and São Paulo are among the main destinations in Brazil for illegally traded wild animals (Bruno & Bard 2016, Velden 2018). Young marmosets were often captured in their original distribution and taken to large cities in Southeast Brazil, particularly Rio de Janeiro, to be traded as pets (Mittermeier *et al.* 1982). *Callithrix jacchus* and *C. penicillata* are species with very flexible ecologies and occur in areas with different characteristics (Rylands 1993, Rylands *et al.* 1996). They are present in secondary forests, clearings, edge environments, and degraded and fragmented areas and currently occur in the Brazilian biomes of the Atlantic Forest, Cerrado and Caatinga (Sussman & Kinzey 1984, Rylands 1996). Modified and anthropized environments are invaded more quickly because they facilitate the establishment of generalist species with a life history associated with humans (Delariva & Agostinho 1999, Espíndola & Júlio-Júnior 2007). It is therefore expected that highly fragmented and modified ecosystems, such as those occurring in the Atlantic Forest biome, are susceptible to bioinvasion and the impacts caused by invasive species (Marques & Grelle 2021).

Velden (2018) noted that in the past, there was a wide circulation of native fauna species in street markets throughout Brazil, including the Praça Mauá market in Rio de Janeiro, although the situation has been partially controlled since the establishment of the Law on the Protection of Fauna in 1967. One of the consequences of this is that some of these animals, removed from the environments where they live, return to the wild out of their original distribution, becoming invaders.

In 2011, *C. jacchus* and *C. penicillata* were included in the Brazilian list of invasive species (Rocha *et al.* 2011), and since 2012, these species have been included in the Global Invasive Species Database (2023). There are a number of traits that characterize invasive species, including easy reproduction, rapid growth, competitive vigor, flexibility to adapt to different environments, a short juvenile period, the production of abundant offspring, dominance capacity, and a generalist diet, among others that have been identified in different studies (Mack *et al.* 2000, Ziller & Zalba 2007, Ziller & Dechoum 2013, Zaluar & Vale 2021, Zaluar *et al.* 2022). This is one of the first review studies to focus on the socio-biodiversity of invasive marmosets.

DESCRIPTION OF THE PROBLEM

Within the literature concerning invasive species, two main explanations are evoked in the discussion of management and control policies for invasive marmosets in invaded areas. The first is related to the fact that they prey on small animals, particularly birds and eggs, which can be a problem for native species in the Atlantic Forest. The second concerns the interactions of these invasive marmosets with other primate species in invaded regions, including competition and the threat of disease introduction (BPBES 2024). We explore below the topics of predation and hybridization involving Atlantic Forest species before revisiting the issue of invasion, examining the case of marmosets in their socio-environmental context.

Callithrix jacchus and *C. penicillata* are strongly susceptible to hybridization, a process that becomes common in the new environments in which both species were introduced (Coimbra-Filho 1971). Recent research has indicated that virtually all individuals of *C. jacchus* and *C. penicillata* in the state of Rio de Janeiro are genetically hybrids (Aximoff *et al.* 2019). Since their introduction, the range of marmosets have expanded, both in lowland and highland regions, where many generations of fertile hybrids have been formed (Aximoff *et al.* 2019, Nogueira *et al.* 2022). Many years ago, Coimbra-Filho (1971) drew attention to an additional problem: the impact of hybridization on another primate species of the same genus, *Callithrix aurita* (E. Geoffroy 1812) (Primates: Callithrichidae). This species is known to be poorly adapted to anthropized environments, live in areas of higher altitudes and is already considered to be threatened with extinction (Coimbra-Filho 1971a, 1983b, Norris *et al.* 2011, Detogne *et al.* 2017). *Callithrix aurita* (Primates: Callithrichidae) is currently categorized as "Endangered" (IUCN 2024).

Since the beginning of this debate in the 1970s, the management of invasive species has also raised a series of discussions in the context of the conservation of what is probably the most emblematic species for the conservation of the Atlantic Forest biome, the golden lion tamarin, *Leontopithecus rosalia* (Elliot 1913) (Primates: Callithrichidae). This species is restricted to very few remaining fragments of its original habitat, the lowland Atlantic Forest of Rio de Janeiro state, which is now a mosaic of protected forest fragments and forest fragments composed

of protected and unprotected areas (Bragança & Menegassi 2022). It was on the verge of extinction in the 1970s, and its recovery is a paradigmatic case for the conservation of threatened primate species, internationally recognized as a successful program involving the reintroduction of captive specimens (Chrulew 2017).

Notably, as a term of comparison, we can cite another invasive species introduced in the municipality of Niterói, the golden-faced lion tamarin, *Leontopithecus chrysomelas* (Kuhl 1820) (Primates: Callithrichidae). Native to southern Bahia and northeastern Minas Gerais, the species was introduced approximately twenty years ago in the forest around the city of Niterói, Rio de Janeiro state, which is located approximately 90 km from the range of the golden lion tamarin occurrence (Kierulff *et al.* 2022). In 2009, a capture and relocation program was set, in which specimens were relocated to their native range in southern Bahia, in which approximately one thousand individuals had already been relocated (Kierulff *et al.* 2022).

Callithix jacchus, *C. penicillata* and their hybrids (*Callithrix* spp.) are present in the native areas of the golden lion tamarin. Although there is no risk of hybridization, they are pointed out as threats to the species because of competition for food and space (Cerqueira *et al.* 1998, Bicca-Marques *et al.* 2006, Ruiz-Miranda *et al.* 2006). There are occasional management initiatives, however, the population size and wide distribution of *Callithrix* spp. make the removal of individuals of marmosets much more difficult than in the case of the golden-faced lion tamarin. The fact that they are hybrids, in this case, would also prevent any relocation initiative, such as the one that happens in the aforementioned case. Additionally, the legislation prevents captured and manipulated exotic animals from being released from their original areas (Lei de Crimes Ambientais - Lei 9605/98, Decreto 3179/99, Art. 61), which limits actions such as castration and release in the invaded areas.

Despite the concern in the field of conservation regarding the impacts caused by invasive marmosets, few studies have described changes in birth and mortality rates of prey species (Zaluar & Vale 2021). However, in the literature, there is a negative impact of predation by invasive marmosets on the antbirds *Formicivora serrana littoralis* (Passeriformes: Thamnophilidae), which is restinga-dependent, endemic to the Atlantic forest and restricted to the state of Rio de Janeiro, Brazil, and *Thamnophilus ambiguous* (Passeriformes: Thamnophilidae), which is endemic to the Atlantic Forest (Vale *et al.* 2018). The first one is categorized as threatened in the Red Lists of Brazil (MMA 2022) and of Rio de Janeiro (Alves *et al.* 2000). Data from the natural nests of *F. s. littoralis* and *T. ambiguus*, including active and inactive nests (with eggs of the domestic canary, *Serinus canaria* [Passeriformes: Fringillidae]) monitored by camera traps, indicated that the invading marmosets preyed on 81% of the 16 nests whose predators were identified (Ballarini *et al.* 2021).

However, recent studies showed a generally low rate of bird predation by marmosets in both native and invaded areas, which can be explained, at least in part, by the fact that marmosets preferentially occur in fragmented and disturbed forests, as well as in edge areas (Zaluar & Vale 2021, Zaluar *et al.* 2022). These areas are predominantly home to common birds that are well adapted to disturbance (Stotz *et al.* 1996, Banks-Leite *et al.* 2010), which would therefore be less sensitive to negative impacts from marmosets (Zaluar & Vale 2021). However, Ballarani *et al.* (2021) reported a high impact of nest predation by invasive marmosets on two taxa of bird species that are endemics to the Atlantic Forest (Vale *et al.* 2018) co-occurring in the Massambaba restinga in Rio de Janeiro, Brazil, *Formicivora s. littoralis* and *Thamnophilus ambiguus*.

Although the scientific literature often argues that invasive marmosets negatively affect avifauna, there are indications that invasive marmosets may not pose a relevant threat at the local scale, especially in edge environments and disturbed forests where they are commonly found. On the other hand, a study conducted in Tijuca Forest, Rio de Janeiro, Brazil, reported a significant reduction in bird acoustic complexity in areas with greater presence of marmosets (Zaluar *et al.* 2022). The authors of the study were unable to determine, however, whether this impact occurs directly through high predation of birds by marmosets or indirectly through "fear ecology", which could result in behavioral changes in the vocalization repertoire of birds due to the predator presence.

Moreover, predation of birds by marmosets is a concern not only for scientists but also for various social actors, including birdwatchers and animal protection groups. In this sense, further research and careful assessment of the factors that influence

the impact of marmoset predation on avifauna are necessary. This could also help develop more effective management and conservation strategies that consider the complexity of ecosystems and species interactions in different socioenvironmental contexts.

CONSERVATION AND MANAGEMENT

Straddling the boundary between forests and cities, the marmoset environment in Rio de Janeiro is composed of different types of buildings and artifacts, such as the urban power grid through which they move, as well as food available in gardens and parks. To address the conservation and management of wildlife, in this scenario, it is necessary to consider the relationships that are established in everyday urban life between marmosets and humans, particularly with residents living on the edge of the forest or park goers.

In protected areas that are open to receiving tourism visitation, there are frequent signs with the instructions "do not feed wild animals" or restricted areas released for visitors to feed, but sometimes visitors insist on feeding the animals. Conservation efforts in those areas, when possible, include awareness and environmental education to teach the lay public that feeding wild animals can be harmful to both animals and humans because of potential attacks and the transmission of diseases. In addition, industrialized foods, especially those containing sugar, are harmful to the health of wild animals.

Ecological problems unfold in urban environments in multiple discussions, and scientific or technical issues are, in this case, implicated in social and subjective issues that often escape the specialized fields in which they are formulated. Human-wildlife interactions evoke ethical issues that need to be remembered, linked to the fact that marmosets are not biological automata but rather living primates that are making a new environment habitable. In both the natural sciences and the humanities, functionalism may not always be the best guide, and it is important to pay attention to the complexity of the relationships between humans and other species, as well as to the importance of an interdisciplinary approach capable of describing those relationships.

Notably, invasive alien species, such as marmosets, which are charismatic species, have an effect on human well-being. However, this issue can generate conflicts and is one of the main challenges in eradicating these species from invaded sites, controlling them, and managing them (Blackburn *et al.* 2011). A proper approach to these conflicts requires social learning and trust among national, federal, and state agencies, controlling of invasive species, communicating with society and the lay public and informing and sensitizing people to increase awareness of the impacts of invasive species on ecosystems (Blackburn *et al.* 2011). A legal instrument for the eradication and control of invasive species is very important, especially for preventing the expansion of these species and prioritizing sensitive and pristine areas (Blackburn *et al.* 2011, Zaluar *et al.* 2021). These areas include: i) inside protected areas; ii) ecosystems outside protected areas; iii) buffer zones of protected areas; iv) ecological corridors and iv) areas undergoing ecological restoration (Blackburn *et al.* 2011).

ECOLOGICAL PROCESSES

For a deeper comprehension of the ongoing ecological processes, it is imperative to acknowledge that the invasion of marmosets primarily occurs within the Atlantic Forest, Cerrado, and Caatinga biomes. It is noteworthy that the Atlantic Forest is known for its rich biodiversity and high rate of endemism of plants and animals (Myers *et al.* 2000, Marques & Grelle 2021). This biome occupies, according to data from the Ministry of the Environment, approximately 15% of the Brazilian territory and comprises more than 60% of the country's population, in addition to a large part of its urban and industrial structure (Arbilla & Silva 2018). It is estimated that the Atlantic Forest remnants comprise around 23% of forest vegetation only, 36% of other natural vegetation cover, and 97% of the vegetation fragments are small (<50 ha) (Vancine *et al.* 2024). Approximately 7 to 8% of protected forests are in good conservation status in this biome (Arbilla & Silva 2018). The Brazilian Atlantic Forest is known to be susceptible to the impacts caused by invasive species (Oliveira & Grelle 2012, Bruno & Bard 2016), particularly because these species are generalists with a life history associated with humans (Delariva & Agostinho 1999). The issue of biological invasion thus represents a major challenge for the conservation of the biome (Bruno

& Bard 2016).

Regarding wildlife management, in technical terms, there are different strategies to address the proliferation of invasive species that are considered threats to ecosystems. Among them, as we previously mentioned, the capture and return of the animals to their places of origin, or the sterilization of individuals of the species in question are important. However, if legislation prevents release in invaded areas, other control measures should be taken. In extreme cases, however, there is the possibility of promoting actions to eradicate invasive species in the invaded area, which is particularly important in cases where the native species are under threat (*e.g.* the antbird *F. s. littoralis*). Measures such as those predicted by law, however, are rarely applied, both because of the cost and logistics aspects and because of issues that escape the *strict sensor* field of management practices (Bruno & Bard 2016). A drastic measure such as the extermination of a primate population would imply basic ethical issues related to the care of animal life and issues related to the impact it would have on public opinion.

Despite all the concerns of the scientific community about invasion, few studies have investigated the ecological roles these species play in places where they have been introduced and established populations. The invasive marmosets were introduced to invaded areas a long time ago, and the population of the invading marmosets at invaded sites is large, making management and control complex to evaluate in terms of their effectiveness. Therefore, we suggest that further studies should be carried out to investigate, through modelling, the best form of management for controlling invasive marmosets. The association between bioinvasion and the decline and extinction of native species is based on limited observations, and there are studies that suggest more efforts to determine which sites native species are likely to be threatened by invasive species and to identify which invaders are more likely to cause extinctions (Gurevitch & Padillla 2004) such as the case of the antbirds *F. s. littoralis* and *T. ambiguus* (Ballarini *et al.* 2021).

In this context, studies that address the current conditions of defaunated forests are increasingly common (Seddon *et al.* 2014, Genes *et al.* 2017, Iacona *et al.* 2017). A recent study carried out in Tijuca National Park, which is surrounded by the metropolis of Rio de Janeiro, revealed that invasive marmosets are potential seed dispersers, can contribute to the reestablishment of vegetation, and favour forest restoration and the connectivity of urban forest fragments (Silva *et al.* 2017). In this case, their presence would play an important ecological role in the restoration of degraded areas, with implications for both biodiversity conservation and ecosystem maintenance.

Debates concerning the harmful effects of invasive species are very important for biodiversity conservation. To deepen these studies, however, it is necessary to consider a number of other factors, including the relationships between humans and animals in their broader dimension. We must remember that we are addressing here the conservation of a threatened biome such as the Atlantic Forest, and the management of fauna in the Atlantic Forest involves complex dilemmas, especially in areas of degraded and fragmented forests. It is important to consider, in this context, that we are dealing with invasive species that have been integrated into these ecosystems for decades, which presents challenges in their management due to both the difficulty of population control and their role in the trophic balance. To exemplify this complexity, the city of Rio de Janeiro, with its urban forest fragments, faces the dilemma of balancing the conservation and management of invasive species, such as marmosets, as they can negatively impact native biodiversity but also, in some cases, aid in the restoration of urban forests. Furthermore, economic and social issues complicate the control of invasive species.

FINAL CONSIDERATIONS

In the field of environmental humanities, controversies such as this one involving marmosets have been described in recent interdisciplinary efforts, such as those formed around extinction studies (Rose *et al.* 2017) and multispecies studies (Kirksey & Helmreich 2010, Dooren *et al.* 2016, Süssekind 2018). A cooperative research program has been inventorying and reflecting on the unintended ecological effects triggered by human activities and infrastructures, including processes of invasion, hybridization, and proliferation of exotic species, defining terms “feral effects” or “feral ecologies” (Tsing 2019, Tsing *et al.* 2021). Regarding the case

of urban fragments of the Atlantic Forest, it is also worth noting that the study of ecological invasions and anthropogenic transformations has made important bridges between social and natural sciences in the realm of environmental history and historical ecology (Solórzano *et al*. 2017, Arbilla & Silva 2018, Sales & Guedes-Bruni 2018).

In addition, the introduction of exotic and invasive species has potentially altered global ecosystems, modifying evolutionary processes and impacting biodiversity at invaded sites, sometimes leading to the extinction of native species (Mack *et al.* 2000). Biological invasions have a negative impact on a global scale and, together with climate change and alterations in land use and cover, cause major environmental damage (Zenni *et al*. 2016). In a time marked by the increasing devastation of tropical vegetation, which is linked to the global expansion of agriculture, extractive systems, and urbanization, the study of ecological processes triggered by human disturbances has become increasingly urgent. This urgency is even more pronounced in a context where ecological restoration and reforestation are recognized as important tools in local policies aimed at mitigating climate change. In this sense, we understand that the case of marmosets of the genus *Callithrix* can contribute to the debate on invasive species and hybridization by contextualizing them within broader processes of human disturbances and forest regeneration.

In conclusion, to make progress in conserving biodiversity in the current context of forests affected by human action, whether in urban or natural environments, environmental issues cannot be dissociated from the socio-political issues in which they are implicated.

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