Rising Incidents and Apparent Population Growth of *Callithrix* marmosets in São Paulo: Analysing Incidents in São Paulo (2012-2023): Patterns, Seasonal Influences, and Geographic Factors

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Abstract

Urban wildlife may thrive in cities, with urban expansion and greening efforts enhancing opportunities for human-wildlife interactions. This study focuses on identifying trends in 1204 reported incidents involving *Callithrix* marmosets from 2012 to 2023 in São Paulo, Brazil, by analysing both general and specific types of interactions. For this, seasonal patterns were examined to determine the effects of variations in temperature and precipitation, while geographic location, population density, total area, and vegetation cover were explored to understand possible drivers of these interactions. The findings revealed an overall notable increase in *Callithrix* incidents during the study period (from 14 in 2012 to 196 in 2023), with trauma being the most reported incident (accounting for ~55% of reports). Although some seasonal variation in *Callithrix* incidents was observed, no significant correlation was found with weather factors like precipitation or temperature. This suggests that other variables, such as human activities, food availability, or changes in the urban environment, may play a more critical role in shaping seasonal patterns. A strong correlation was found between vegetation cover and *Callithrix* incidents in different regions of the city; however, it is challenging to determine if vegetation cover can be disentangled from other potential drivers, such as total area, geographic location, and proximity to natural habitats. This relationship highlights the importance of green spaces in supporting *Callithrix* populations in urban environments, indicating that vegetation likely plays a crucial role in providing habitat and resources for these primates within city settings. Understanding these dynamics is essential for addressing the challenges of marmoset population growth in urban environments. Effective management strategies must focus on mitigating human-wildlife conflicts while maintaining urban vegetation that is crucial for *Callithrix* survival. This will require balanced urban planning that integrates green spaces with wildlife conservation efforts, ensuring coexistence between humans and wildlife in large cities like São Paulo.

Keywords: Callithrix Marmosets, Urban Wildlife, Human-Wildlife Interaction, Dietary Adaptation, Habitat Fragmentation, Conservation Biology, Electrocution Incidents, Vegetation Dynamics

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1. Introduction

Urban expansion may drive wildlife to seek refuge within cities as their natural habitats diminish. This transition to urban environments may be influenced by several factors, including the availability of food, shelter, reduced predation, and specific adaptations that allow certain species to thrive in urban environments (Dominoni et al. 2016, Raap et al. 2025, Rubene et al. 2023). Also, as many cities work to protect and cultivate green areas within their limits for recreation, biodiversity protection and extreme climate mitigation, opportunities for human-wildlife urban coexistence are likely to increase for some species. This may result in the growth of these urban wildlife populations, and subsequently the potential for more frequent interactions between humans and wildlife. Such encounters can range from being beneficial or neutral to serious human-wildlife conflicts (Soulsbury & White 2015). The increasing presence of *Callithrix* marmosets in São Paulo, Brazil, illustrates how urban environments, particularly urban vegetation cover, can serve as a refuge for theses adaptable monkeys.

One example of increasing interactions between wildlife and human populations results from the colonization (or recolonization) of cities by species that suddenly expand their habitat range and population size within urban limits. This may occur for reasons related to resource distribution, but in many cases the exact cause of sudden urban tolerance and population increases remains unknown. In the city of São Paulo, Brazil, the marmoset genus *Callithrix*—particularly the invasive species *C. jacchus* and *C. penicillata*—has seen a marked rise in reported incidents over the past decade, likely due to a growing monkey population within the city limits. Hybrids between the native *C. aurita* and these invasive species have also been documented, further complicating the city's wildlife dynamics. These marmosets appear to have adapted remarkably well to urban environments by exploiting human resources, utilizing their dietary flexibility, and benefiting from the city's shifting vegetation landscape.

Urbanization often fragments habitats and diminishes natural ecosystems, often forcing wildlife to adapt if they remain in these areas. Species like *Callithrix*, now appear to be thriving in cities due to abundant human food sources, fewer natural predators, and changing vegetation that have likely shaped the growth of the populations in São Paulo. However, the increasing presence of these marmosets in São Paulo has led to a rise in human-wildlife interactions, ranging from harmless encounters to more serious issues like aggression, electrocutions and traffic accidents (Jornal da USP 2024, SciELO 2022). These interactions underscore the complexities of managing wildlife within a densely populated city and highlight the broader impact of urbanization and urban greening on both animals and humans.

Thus, this study looks at local government-collected data on reported incidences of *Callithrix* monkeys within the city limits of São Paulo from 2012-2023. From this I aim to address three primary questions. First, what are the annual patterns in relation to general and specific incident types. Here I am interested in examining evidence for increasing incidents during the past 12 years, and if these differ for incident type (e.g. trauma versus malnutrition). This is to provide proxy evidence for changes in urban *Callithrix* populations, as well as real changes in reported human-*Callithrix* interactions. Second, are there any seasonal patterns of incidents? This is to examine whether seasonal environmental changes may influence these human-wildlife interactions in São Paulo. Finally, I examine whether the frequency of incidents is related to the geographical location in the city, and if this suggests incidence is a function of local human population density, total area or local vegetation cover and type. From this, my aim is to draw some conclusions regarding the growing population of *Callithrix* in São Paulo, and the nature and drivers of human-*Callithrix* interactions.

2. Method

2.1 Species of *Callithrix*

Originally, *C. jacchus* natural geographic range is Northeastern Brazil, while *C. penicillata* originates from the more central parts of the country. Both species have been introduced in the city of São Paulo due to illegal pet trafficking (Malukiewicz et al. 2020). They are largely categorized as different species due to their geographic distribution and not because of the biological species concept (Hershkovitz 1977 p. 489-492). Neither of these species is considered endangered (Valença-Montenegro et al. 2021, Valle et al. 2021, Petter & Desbordes 2013 p. 74, SEMIL 2018). The natural geographic range of *C. aurita* is the montane Atlantic Forest on altitudes over 500m in the southeast of Brazil including the location where the city of São Paulo now resides (Hershkovitz 1977 p. 489-492, Malukiewicz et al. 2020) (Figure 01).

Figure 1. C. jacchus, C. penicillata, C. aurita and their original distribution.

Clockwise starting at the upper left corner: (1) Callithrix jacchus. Burle Marx park, own picture taken 6th august 2024; (2) Callithrix penicillata in Terra Preta, Mairiporã, own picture taken 18th July 2024; (3) Image 03. Callithrix aurita with its very characteristic skull-like face. Por Jack Hynes - CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=25751289*; and (4) Own image* *showing the approximate distribution of marmosets in Brazil. Orange corresponds to C. jacchus, Green to C. penicillata and Red to C. aurita. The other three marmosets C. flaviceps, C. geoffroyi and C. kuhlii are located in the empty area to the east.*

C. aurita is classified as an endangered species by the International Union for Conservation of Nature, with a dwindling population of about 10,000 adults and the spread of the invasive species *C. jacchus* and *C. penicillata*, as well as their hybrids, is a significant factor contributing to the decline in the population of *C. aurita* (de Melo et al. 2015, de Melo et al. 2021).

Another factor is, of course, the long-term destruction of their habitat due to human activity. The taxonomy of platyrrhines, and particularly the subfamily Callitrichinae, which includes the genus *Callithrix*, has been a subject of disagreement and debate regarding the classification of both genera and species. The number of marmoset species in which the genus *Callithrix* pertains ranges between 5 and 21 (Ankel-Simons 2007 p. 113, Mittermeier et al. 1988 p. 13-22, Rosenberger 2011, Rosenberger 2020 p. 15-16, 48) and it was not until recently that *C. aurita* and *C. penicillata* were fully recognized as distinct species; previously, both were considered subspecies of *C. jacchus* (Hershkovitz 1977 p. 489-492, Rímoli et al. 2015, Valença-Montenegro et al. 2015). In contemporary taxonomy, six species are generally recognized within the genus *Callithrix*, largely due to molecular data that has led to the reclassification of the former Amazonian *Callithrix* group into the separate genus *Mico* (Rylands & Mittermeier 2009). This classification serves as the taxonomic structure for *Callithrix* species in this study.

In 1993, São Paulo's first fauna survey was conducted[1] (SVMA 2023), and *Callithrix* was found in 3 of the 115 parks surveyed: Alfredo Volpi, Ecológico Chico Mendes, and Tenente Siqueira Campos Trianon. In 2023, *Callithrix* was recorded in 34 of these parks. However, based on the data I will present in this study, it is highly likely that they are now present in more parks than the official survey suggests.

All *Callithrix* species are small, weighing about 225-450 grams, and are versatile, living in various environments in the middle of South America south of the Amazon. These environments include humid, lush or dry habitats in forests or grasslands with vegetation cover, with a preference for the edges of forests and secondary growth where they can find more food such as fruits and insects. *C. jacchus* originally inhabits forest patches and riverine forests in the arid Northeast Caatinga or thorn scrublands, *C. penicillata* in gallery forests and forest patches on the Brazilian Cerrado or savannah, and *C. aurita* in the more humid and high-altitude Atlantic Forest near the coast in the South and Southeast of Brazil

[1] Inventário da Fauna Silvestre do Município de São Paulo – 2023 can be found as an excel file on this page: https://www.prefeitura.sp.gov.br/cidade/secretarias/meio_ambiente/publicacoes_svma/index.php?p=3351

(Hershkovitz 1977 p. 489-491, Mittermeier et al. 1988 p. 144-146, Rylands & Faria 1993 p. 264).

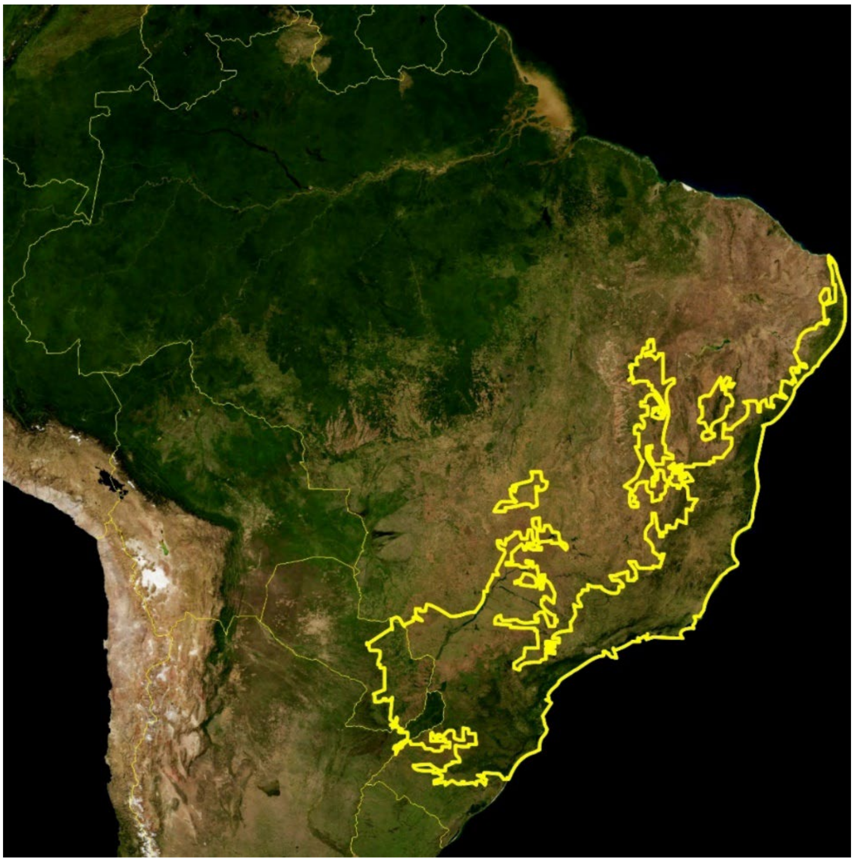
The *Callithrix* is frugivorous and insectivorous, occasionally eating small vertebrates when opportune. They are also specialized gumivores, meaning they consume gum from trees. They gauge and scrape the trees to induce gum flow with their highly specialized chisel-like incisors and canine teeth that are unique to marmosets among primates (Mittermeier et al. 1988 p. 133, 140, 146-147, Rylands & Faria 1993 p. 265). According to Rosenberger (2020 p. 108-109, 140, 147-149), feeding and foraging coevolved to equip them with claws instead of the common primate nails, allowing them to cling to vertical trees that are too large to grasp while scraping the trees and consuming the gum. They have nails only on their hallux, and they are the only primates, aside from humans, where it is not opposable. The mandible, jaw muscles, and cranial morphology allow them to open their mouths widely, enabling them to gouge the wood. This harvesting adaptation is particularly important in drier habitats, providing a significant advantage over other small monkeys, such as the endangered Lion Tamarin species, which occasionally eat gum or sap but only when they come across it already dripping from the tree. The *Callithrix* has the inherent ability to extract gum by chiselling the wood or bark.

2.2 Study location and the history of the local forest habitat

The study was undertaken within the city limits of São Paulo, Brazil. Although a focus of this study is to examine whether changes in incidents over time is related to changing vegetation cover, understanding whether vegetation cover in the city of São Paulo is increasing or not is challenging due to conflicting data and the extremely complex urban landscape. Historically, São Paulo's original Atlantic Forest has been severely degraded, with the figures being complicated by differences in methodology, definitions of vegetation, and the types of land included in these assessments. Some urbanized areas have seen an increase in green spaces, but this growth is unevenly distributed, often favouring wealthier neighbourhoods and leaving poorer areas with minimal green cover. The overall picture of the dynamics of the vegetation cover remains unclear to accurately assess the true state of vegetation in the city of São Paulo.

The Atlantic Forest, originally spanning from northern Argentina and Paraguay along Brazil's Atlantic coast, once covered 15% of Brazil's land (Figure 2). However, since the arrival of the Portuguese in 1500, Brazil's economic activities, such as wood and gold extraction, sugar cane and coffee production, have led to extensive deforestation and unfortunately making it into one of the world’s most devastated woodlands (INPE 2019, MMA 2024, Thomas et al. 1998, Warren 1996). Today, estimates are that between 8-15% of the original forest remains mature and healthy (Rosenberger 2020 p. 286, SOS Mata Atlântica 2023). In São Paulo state, the vegetation cover has drastically decreased from 81.8% before European arrival to just 13.7% by 1990, much due to the expansion of coffee plantations in the 19th century (Kupper 1999). SEMIL (2022 p. 18-21) reported that native vegetation cover in São Paulo state increased from 13.4% in 1990 to 22.9% in 2020. However, the enhanced spatial resolution achieved with improved satellite technology in the 2020 study allowed for the detection of previously unidentified forest patches. According to Painel Verde (2024) 22.85% of the state's total area had native vegetation cover as of May 2024. From 1985 to 2021, declines in pasture and agricultural areas were offset by increases in silviculture (Mapbiomas 2022). Since 2006, the entire Atlantic Forest is protected under federal law (Planalto 2006, IBGE 2008).

Figure 2. Extent of the Atlantic Forest.



The yellow line encloses the ecoregion of the Atlantic Forest. You can also see the Cerrado Savannah (Brownish area) that lies between the Atlantic Forest and the Amazon Rainforest (Northwest). The north part of the Cerrado is the Caatinga. By NASA and Miguelrangeljr - Public Domain, *https://commons.wikimedia.org/w/index.php?curid=20391424*.

The expansion of the city of São Paulo also came at the expense of the Atlantic Forest. The city's population grew from around 8,000 in the late 18th century to approximately 240,000 by the early 20th century. As São Paulo became Brazil's coffee hub and economic powerhouse in the 19th century, the surrounding forest was further depleted. By 1940, São Paulo had 1.3 million inhabitants, doubling to over 2 million by 1950. In the 1980s, the population surpassed 8 million, making it one of the world's largest cities. By 1990, the population reached over 9.5 million, crossing the 10 million mark before the end of the millennium (de Souza 2020, Governo do Estado 2024, SMUL 2023 p. 1-2). São Paulo's urban planning struggled to keep pace with the rapid population growth, leading to uncontrolled city expansion. The Atlantic Forest suffered significantly, as did the water systems, with much of the city's sewage flowing untreated into the rivers. Despite various initiatives to address the lack of urban planning and mitigate environmental impacts, success has been mixed. Today's guidelines for the strategic overview of green urban planning in the city of São Paulo, PMMA, PMSA, PMAU and PLANPAVEL[2], determines to make the city carbon dioxide neutral by 2050. Greenhouse gas emissions must be reduced, climate impact solutions reformed, and a fair distribution of parks and nature for the population implemented.

In 1911, Swiss botanist Alfred Usteri conducted the first systematic study of São Paulo's flora, describing a landscape dominated by forests, fields, and wetlands. By that time, most primary forests had already been destroyed due to agricultural expansion and widespread burning, leaving mainly secondary growth on abandoned coffee plantations in the city's northern and southern extremes. These secondary forests are still there today. As the city rapidly expanded in the latter half of the 20th century, urbanization increased, and large favelas emerged. The current vegetation cover consists mainly of fragmented secondary growth that has resisted urban expansion, primarily in the far south and north, with smaller patches in parks, squares, and along roads (da Silva Filho 2005 p. 27-46, Prefeitura de São Paulo 2002 p. 6-15, Usteri 1911 p. 28-59).

In 2016, 30% of the city of São Paulo's territory was covered by forest, with 74.7% being Tropical Rainforest (port. Mata Ombrófila Densa). The remaining areas were classified as Heterogeneous Forest, Mixed High Altitude Montane Rainforest, Fields, Floodplain, Aquatic Vegetation, and Floodplain Forest (Diário Oficial da Cidade de São Paulo 2017). The distribution of the city's forest is regularly updated and available on the city hall's website at a 1:10,000 scale (PMMA 2024). A landmark report published in 1988 by SEMPLA, SMA, and São Paulo's State Government, titled "Vegetação Significativa do Município de

[2] PMMA – Plano Municipal de Conservação e Recuperação da Mata Atlântica (eng. Municipal Plan for Conservation and Recovery of the Atlantic Forest); PMSA – Plano de Conservação e Recuperação de Áreas Prestadoras de Serviços Ambientais (eng. Conservation and Recovery Plan for Areas Providing Environmental Services); PMAU – Plano Municipal de Arborização Urbana (eng. Municipal Urban Afforestation Plan); and PLANPAVEL – Plano Municipal de Áreas Protegidas, Áreas Verdes e Espaços Livres (eng. Municipal Plan of Protected Areas, Green Areas and Open Spaces).

São Paulo” (Significant Vegetation in the Municipality of São Paulo), identified key tree-covered areas in the city, which were then protected as environmental heritage by State Decree nº 30.443/1989, later amended by Decree nº 39.743/1994. These protected areas covered 32.1% of the city's total area. A 2020 survey updated the protected areas to 44.4%, increasing from 490 km^2 in 1988 to 678 km² which led to the Municipal Bill 17.794/2022, which added more areas of permanent preservation such as those of exceptional scenic, scientific or historical value (SVMA 2020b p. 14-15, SVMA 2023b). Hence, this increase in protected areas does not necessarily reflect an increase in vegetation, but rather improved conservation efforts compared to 1988. The city’s vegetation cover was identified to 736 km^2, or 48.2% in 2020 while considered to be only 33.6% in the report from 1988. This large increase is to be treated more as a reference considering the methodological, technological and cartographic limitations in 1988 and does therefore not mean that there has been a net increase in vegetation cover. The largest isolated areas of vegetation are concentrated in the south, east and north edges of the city (Figure 3).

Figure 3. The municipal limits of São Paulo.

Observe the large green areas containing Atlantic Forest particularly in the south region (Mata de Parelheiros e Marsilac) but also in the north region (Serra da Cantareira) and in the east region (Parque do Carmo and Matas de Cidade Tiradentes/Iguatemi).

In 2020 the rural areas represented 31.8% of the city´s total territory but had a 79.4% vegetation cover while the urban areas which represented 68.2% of the city´s total territory only had a 33.7% vegetation cover. The Southern zone of the city possessed 460.3 km^2 of vegetation cover out of a total area of 740.6 km^2, the Northern zone 151.6 km^2 out of 299.9 km^2, the Western zone 39.2 km^2 out of 129.0 km^2, the Eastern zone 80.5 km^2 out of 331.6 km^2 and the Central zone 4.4 km^2 out of 26.7 km^2 (SVMA 2020b p. 48-50, 55, 70, SVMA 2020c). These numbers illustrate clearly the imbalance of green areas in the city. The distribution of trees accompanying roads and avenues is uneven and reflects the income concentration. Neighbourhoods with more trees are in regions inhabited by the upper-middle class where subdivisions are more expensive. The least favoured areas are found in poorer parts where too narrow sidewalks often difficult afforestation (Prefeitura de São Paulo 2002 p. 14-15).

The green areas per capita in São Paulo increased from 11.7 m^2 per citizen in 2008 to 16.6 m^2 in 2017 (RNSP 2024). However, wealthier neighbourhoods have significantly more green spaces, while poorer areas have almost none (Figure 4).

Figure 4. Aerial photograph of Morumbi area.

Aerial photograph (2008) of the favela Paraisópolis with its scarcity of vegetation cover surrounded by the much richer areas of Morumbi with considerably more green areas. Fernando Stankuns, CC BY-NC-SA 2.0: https://www.flickr.com/photos/stankuns/3202990747.

For example, Alto de Pinheiros, an upper-middle-class district, has 852,000 m² of park area for 43,000 residents, whereas the less privileged Sacomã district, with 248,000 residents, has no park area at all. This lack of green spaces in poorer districts makes them more vulnerable to heat, pollution, and flooding while limiting opportunities for leisure and physical activity. Critics argue that São Paulo should focus on intelligent and qualitative afforestation, rather than simply increasing the number of trees in areas that already have good environmental indices. It's also noted that many lower-income communities in the far north and south of the city, which lie near or within forested areas, have the best environmental indices regarding vegetation cover. However, this inequality between higher and lower-income areas primarily considers urbanized areas, not rural ones (Arantes et al. 2021, Jornal da USP 2023, Quirino 2024, Vejasp 2020).

The overall green area in the municipality, including non-vegetation like green rooftops and artificial grass, increased from 52.35% in 2017 to 54.13% in March 2023 (Prefeitura de São Paulo 2023). A final report on green areas was expected in June 2023 but has not been published to this day (Prefeitura de São Paulo 2023b).

The Municipal Department of Urban Planning and Licensing (SMUL 2023) assessed São Paulo's urban and non-urban areas using Local Climate Zones (LCZ) (Stewart & Oke 2012) to measure urban heat. The report highlighted the growth of "sparse" (port. esparsas) areas—regions with isolated constructions and high soil permeability, located between urban and rural zones. These areas expanded significantly between 2002 and 2022, primarily in rural regions with critical ecosystems that need preservation for the city's sustainability. In 2002, São Paulo's urbanized area covered 56%, non-urbanized 36%, sparse occupation 5%, and water 3% of the total area. By 2022, urbanized areas increased slightly to 57%, non-urbanized areas decreased to 31%, and sparse occupation grew to 9%. The report indicates that this growth is due more to densification in existing areas rather than new expansions, most of them in the South zone of the city (SMUL 2023 p. 7-9, 24-25). This trend may explain why some environmental laws from the late 20th century might be considered less effective, despite a slowdown in urbanized area expansion (da Silva Filho 2005 p. 45-46, SMUL 2023 p. 24-25).

The Urban Afforestation Division (DAU) aims to increase São Paulo's vegetation cover and biodiversity, with the number of planted tree seedlings rising from 12,869 in 2016 to 61,680 in 2023 (SVMA 2024). This effort focuses on incremental planting to expand green areas, not on replacing old or sick trees. However, some tree plantings by private individuals and non-governmental entities are not recorded in the official system. Additionally, some regional governmental entities have inaccurately reported isolated incremental plantings as replacement actions (PMAU 2020 p. 106-108).

The Biosampa (2023 p. 28) Index Report includes 23 indicators, such as native biodiversity, ecosystem services, and governance and emphasizing the importance of urban biodiversity in mitigating climate change and enhancing local ecosystems. In 2022 it reached a record score of 70 points out of 92 possible, this is an increase from previous years: 2019 with 63 points; 2020 with 64 points and 2021 with 62 points. The category Native Biodiversity saw significant improvement, positive trajectory was also seen in Governance and Education. However, in 2019 five of the indicators in the Native Biodiversity category was classified with n/a (not applicable) and therefore lost 20 points, meaning that with applicable data 2019 could have surpassed 2022.

2.3 Data

São Paulo's Wildlife Division (Divisão da Fauna Silvestre da SVMA[3]) plays a crucial role in protecting and conserving the city's wild fauna. They perform vital work, receiving injured, orphaned, and confiscated wild animals daily, whether seized by environmental police or handed over by the public. For this study they provided detailed records of all incidents involving the genus *Callithrix* between 2012 and 2023. The record consists of 1,350 incidents over the 12 years covered.

The dataset provided by São Paulo's Wildlife Division, used in this study, is organized in an Excel sheet that records incidents involving *Callithrix* species in São Paulo from 2012 to 2023. The data is structured across 14 columns, originally labelled in Portuguese, which I have translated into English and bolded with capital letters in the following section.

The **Incident ID** column assigns a unique identification number to each incident, enabling precise tracking and reference throughout the study. Temporal data is captured in the **Date**, **Month**, and **Year** columns, which record the exact date, month, and year of each incident, respectively. This temporal information is crucial for examining trends over time, including seasonal variations and annual changes in incident frequency. Species identification is provided in the **Species** column, where the specific *Callithrix* species involved in each incident is noted. This allows for species-specific analyses, contributing to a better understanding of the distribution and behaviour of different *Callithrix* species in an urban environment. The **Immature** column indicates whether the individuals involved were juveniles, offering insights into the age distribution of affected populations. Meanwhile, the **Harm** column details the type of harm or aggravation associated with each incident, such as trauma or conflict, providing context for the nature of the interactions between *Callithrix* and their urban surroundings. The **Trauma** column specifies whether trauma was involved in the incident and detailing the nature of the injury, such as electrocution or physical harm. The **Additional**

[3] https://capital.sp.gov.br/web/meio_ambiente/w/servicos/fauna/3391

Details column provides supplementary information that complements the columns Harm and Trauma. Incident locations are captured in the **Location** and **Address** columns, which specify the general location and exact address of each event. The **Park** column further identifies whether the incident occurred within a park, highlighting the role of natural and semi-natural areas in the urban ecosystem. Outcome data is recorded in the **Outcome** and **Resolution Date** columns. The Outcome column describes the resolution of each incident—whether the animal was placed in captivity, died, or received other forms of intervention—while the Resolution Date column notes the date of resolution. The structured and detailed organization of the dataset facilitates the exploration of both temporal and spatial patterns in *Callithrix* incidents, enabling a comprehensive analysis of the factors that influence the distribution, behaviour, and outcomes of these primates within São Paulo's urban landscape.

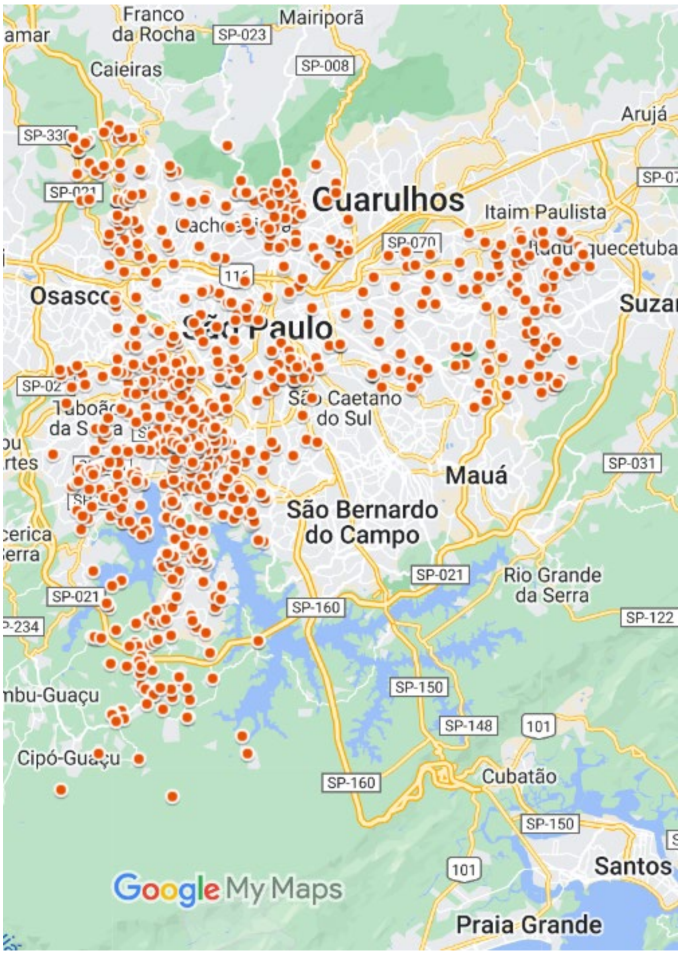
The quality of a dataset is key to making sure its analyses are accurate and reliable, and this study on *Callithrix* incidents is no different. A review of the dataset reveals a clear difference in data completeness between the earlier years (2012–2021) and the more recent year (2023). During the first decade of data collection (2012–2021), the dataset maintains a low level of missing data, with most columns showing only minimal gaps. This consistency suggests that data collection practices were robust during this period, enabling a comprehensive analysis of trends, species behaviour, and outcomes of *Callithrix* interactions within the urban environment. However, the data from 2023 presents a quite significant contrast, with a marked increase in blank entries, particularly in six columns: (1) Additional Details 30.1%, (2) Resolution Date 28.6%, (3) Harm 28.6%, (4) Trauma 28.6%, (5) Immature 28.1%, and (6) Location 27.6%. The last quarter of 2023 (October to December) is the most affected, with 30 out of 46 entries missing in these columns, accounting for 65.2% of the data. The lack of data in the three columns for the year 2023 limits the extent of the analysis that can be performed.

In 2016, there is a noticeable drop in the number of incidents, with only 5 recorded incidents (in the municipal area) compared to the increasing trend observed in previous years. This is a significant anomaly in the dataset, as the number of incidents before and after 2016 is much higher. It could indicate an unusual event or factor that temporarily reduced incidents that year, such as changes in reporting, wildlife behaviour, or environmental factors. Further investigation would be needed to understand the reasons behind this sharp decline in 2016.

2.4 Analysis

São Paulo, a city with a population of approximately 11.5 million people (IBGE 2023), has expanded over time to merge with several neighbouring cities, forming a metropolitan region that now encompasses 22 million residents (IBGE 2021). Initially, the dataset included 1,350 incidents, some of which occurred in the broader São Paulo metropolitan area, outside the actual city limits. To ensure that the analysis focused exclusively on incidents within the city, the dataset was filtered to 1,204 incidents. Incidents near the city's boundary, where the exact location was difficult to determine, were retained if they appeared to fall within the city limits. Additionally, a small number of addresses with minor misspellings were corrected and included, provided they were within the city limits. These 1,204 incidents represent the sample used to study the population of *Callithrix* within São Paulo's city limits, with their locations plotted on Google My Maps[4] (Figure 05).

Figure 5. Locations of incidents plotted on Google My Maps.



2.4.1 Temporal annual patterns in relation to incidence type

To address the research question, a comprehensive descriptive quantitative analysis was conducted using data from São Paulo's Wildlife Division, focusing on trends in *Callithrix* incidents from 2012 to 2023. The study aimed to identify

[4] https://www.google.com/maps/d/edit?mid=1_25HAOpEeLJLwW-VI1CEOLYeR6lmNaw&ll

yearly fluctuations and analyse incident percentages across nine categories: Total Incidents, Roads, Residences, Parks, No Information, Trauma, Conflict, Electrocution, and Immature.

Incidents listed under the "Location" column as Residences, Condominiums, Schools, and Universities were combined into a single category labelled "RESIDENCE." This consolidation was done due to the similar patterns observed in these settings and to increase the sample size for these incidents. Similarly, incidents categorized as Others, Government Agency, and Supermarket were grouped together under the label "OTHERS" because these were relatively few, less significant for the study, and did not closely align with other items in the column.

To visualize possible trends, two multi-line graphs (Figure 6 and 9) were created, illustrating the distribution of incidents across the nine categories over the years studied. Each line represents a different category, allowing for a clear comparison of how the frequency of incidents in each category has evolved over time, highlighting significant changes and patterns that may inform future strategies.

To assess the trend in *Callithrix* incidents over the years 2012 to 2023, I employed a simple linear regression analysis using Python to compute p-values. The null hypothesis (H_0) posits that there is no significant trend in incident frequency over time, while the alternative hypothesis (H_1) suggests that a significant trend exists. The computed p-values indicate whether the observed trend is statistically significant, thereby helping to determine if changes in incident frequency over the years are more than just random fluctuations. The results were rounded to three decimal places.

Further, five additional multi-line graphs (Figure 7, 8, 10, 11, 12) were created to detail the percentage distribution of incidents across seven categories: Roads, Residences, Parks, Trauma, Conflict, Electrocution, and Immature. These graphs provide a visual comparison of how the relative frequency of incidents in each category has changed year by year, offering insights into the dynamics of incident occurrences.

2.4.2 Temporal seasonal patterns of incidents

Additionally, the study examined and compared climate data for three key variables—Temperature, Precipitation, and Incidents—throughout the year. This data was organized and displayed using a multi-line and bar chart (Figure 13), which facilitated a clear visual comparison of trends across different months and helped identify potential correlations. This method provided a deeper understanding of how monthly variations in temperature and precipitation might relate to the frequency of incidents, uncovering patterns that could guide future research on the impact of climate factors on incident occurrences.

To quantify the relationship between precipitation, temperature, and the frequency of *Callithrix* incidents, I utilized Python to perform a statistical analysis using Pearson's correlation coefficient and p-value. This coefficient measures the strength and direction of the linear relationship between two continuous variables. The p-values obtained from this analysis indicate whether the observed correlations are statistically significant. The result was rounded to three decimal places.

2.4.3 Vegetational patterns in relation to incidence

To explore the relationship between São Paulo's vegetation cover and the distribution of *Callithrix* incidents, I conducted an analysis combining data on vegetation, human population, total area and incident reports across the city's different zones—North, West, South, East, and Centre. The goal was to identify patterns that might explain how these factors influence the distribution of incidents. Additionally, I created a map plotting the incidents across the city to visually identify areas with particularly high occurrences. This spatial mapping highlighted regions of concentrated activity and revealed potential connections between urban ecological features and the frequency of *Callithrix* incidents.

To visually represent this data, I created a multi-line and bar chart (Figure 14), which details the distribution of incidents, total area, vegetation cover, and human population across the five zones. This chart provides a clear visual comparison of how these variables and the frequency of *Callithrix* incidents interact within the city. The design helps to identify patterns and correlations between these variables, offering valuable insights into the dynamics of human-wildlife interactions in São Paulo's complex urban landscape.

To quantify the relationship between incidents and three variables: (1) vegetation cover; (2) human population; and (3) total area of the five zones and the frequency of *Callithrix* incidents, I used Python to perform a statistical analysis using Pearson's correlation coefficient and p-value.

All charts were carefully designed with colourblind-friendly palettes, ensuring that the data is accessible and easily interpretable by a broad audience.

3. Results

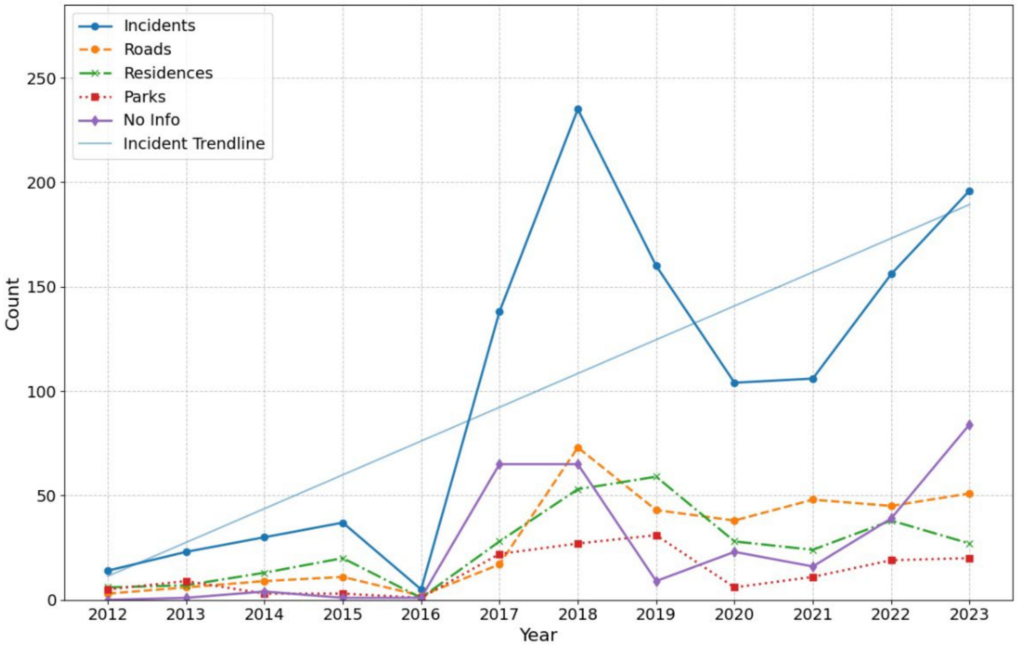
3.1 Temporal annual patterns in relation to incidence type

Over the period from 2012 to 2023, the total number of incidents with *Callithrix* in the city of São Paulo experienced significant growth. In 2012, the number of incidents was relatively low, with only 14 reported cases. This number gradually increased over the next few years, reaching 37 incidents by 2015. However, in 2016, there was a sharp drop to just 5 incidents. Following this, a notable spike occurred in 2017, with incidents rising to 138, and then nearly doubling to 235 in 2018. Although the number of incidents decreased slightly in the following years, they remained consistently higher than in the early years, with 196 incidents reported in 2023. Overall, this pattern reflects a substantial increase of 1300% in the frequency of incidents over the 12-year period, highlighting a significant upward trend (Table 01) (Figure 6).

Table 1. Annual Progression and Location of Callithrix incidents in São Paulo.

Year	Incidents	Roads	Residence	Parks	Others	No info
2012	14	3	6	5		
2013	23	6	7	9	1	
2014	30	9	13	3		4
2015	37	11	20	3	1	1
2016	5	2	1	1		1
2017	138	17	28	22	4	65
2018	235	73	53	27	4	65
2019	160	43	59	31	7	9
2020	104	38	28	6	6	23
2021	106	48	24	11	6	16
2022	156	45	38	19	7	39
2023	196	51	27	20	4	84
Total	**1204**	**346**	**304**	**157**	**40**	**307**

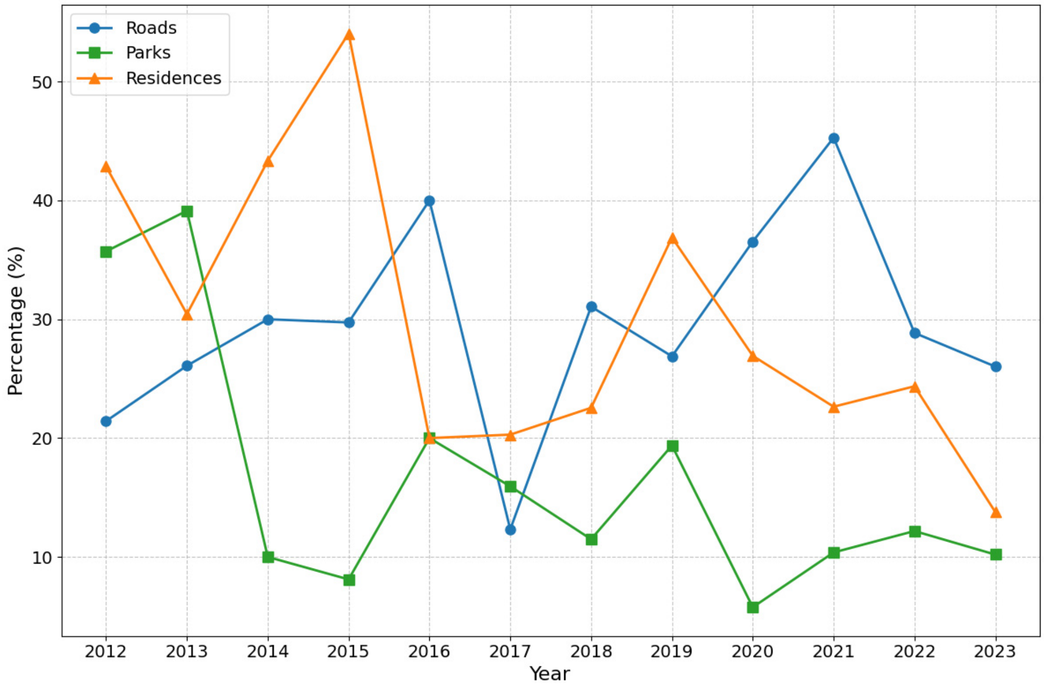
Figure 6. Distribution of Callithrix Incidents and Contributing Factors by Year.



In analysing the trend in Callithrix incidents from 2012 to 2023, a simple linear regression analysis was conducted in Python to assess whether there is a significant trend in the data. The resulting p-value of **0.005** indicates that the null hypothesis (H_0) can be rejected at conventional significance levels (p-value: 0.05), supporting the presence of a statistically significant trend in incident frequency over the analysed period. This finding implies that the increase in incidents is not due to random chance but rather reflects a real underlying trend.

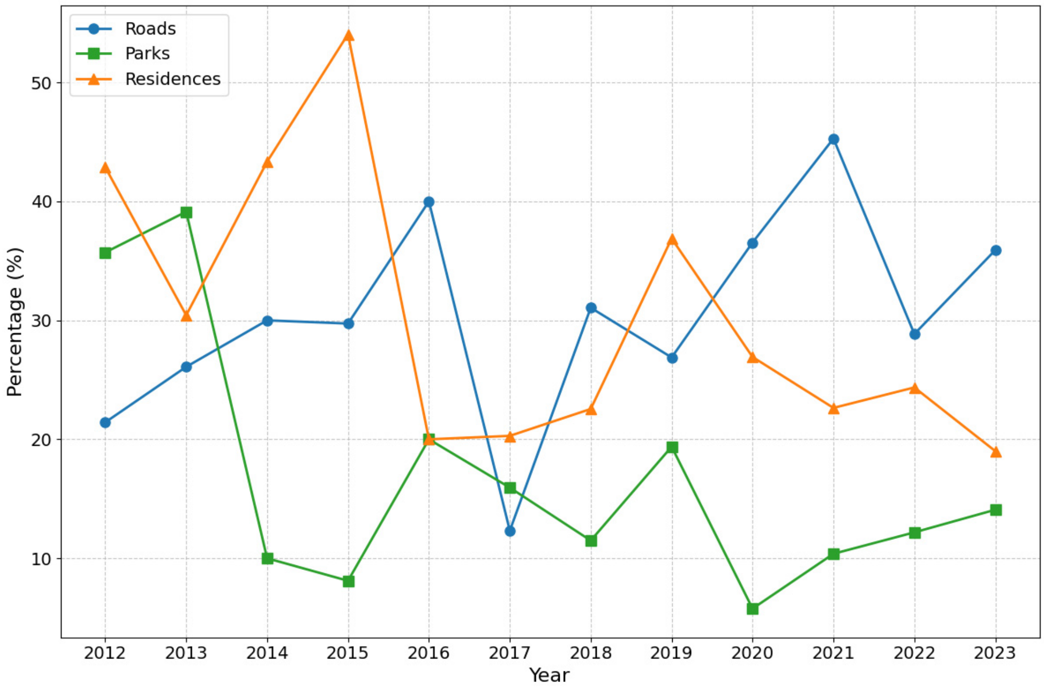
The most frequent locations of these incidents were roads and residential areas. There are no discernible obvious trends indicating a significant increase or decrease in the incidence of these events at any specific period over the years. There appears to be a slight shift in the trend, with a minor percentage decrease in incidents occurring in residential areas, parks and schools, accompanied by a corresponding percentage increase in road-related incidents when considering each year (Figure 7).

Figure 7. Distribution of Callithrix Incidents by Category (Percentage).



Notably, in 2023, there are 54 blank entries in the location column compared to only 5 blank entries across all the other years combined. If these 54 blank incidents from 2023 are excluded, recalculating the percentage based on 142 incidents instead of 196, the trend is clearer (Figure 8).

Figure 8. Distribution of Callithrix Incidents by Category without blank entries (Percentage).

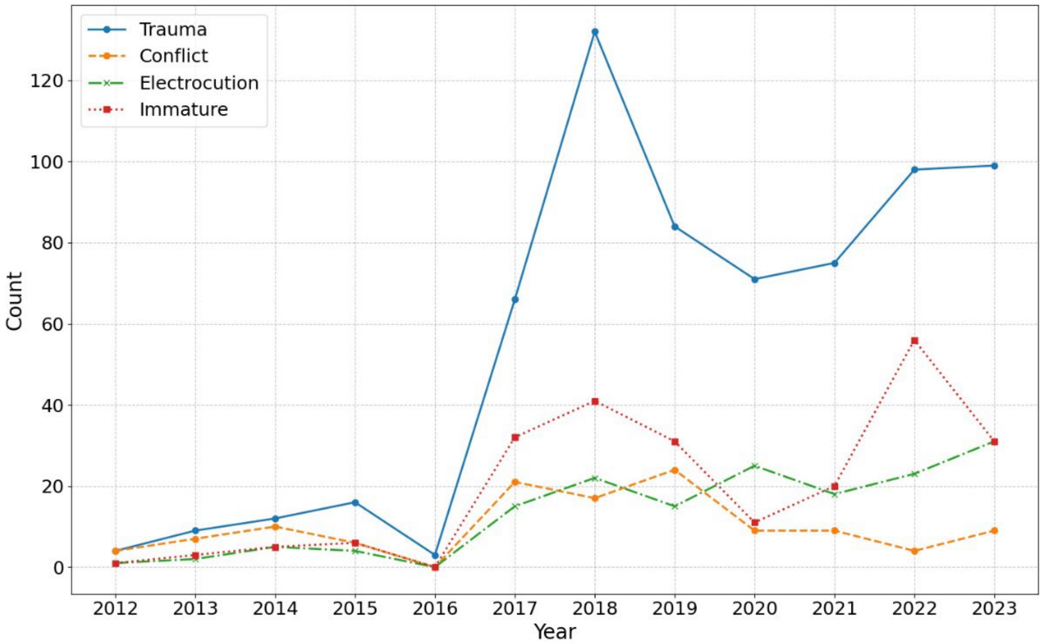


More than half of the incidents were classified as trauma, totalling 669 cases. This was followed by immature incidents, which accounted for 237 cases. Electrocution-related incidents numbered 161, and conflict-related incidents amounted to 120 (Tabel 02) (Figure 9).

Table 2. Annual Progression of harm, trauma and immature incidents of Callithrix in São Paulo.

Year	Trauma	Conflict	Electrocution	Immature
2012	4	4	1	1
2013	9	7	2	3
2014	12	10	5	5
2015	16	6	4	6
2016	3			
2017	66	21	15	32
2018	132	17	22	41
2019	84	24	15	31
2020	71	9	25	11
2021	75	9	18	20
2022	98	4	23	56
2023	99	9	31	31
Total	**669**	**120**	**161**	**237**

Figure 9. Distribution of Callithrix Incident Types by Year.

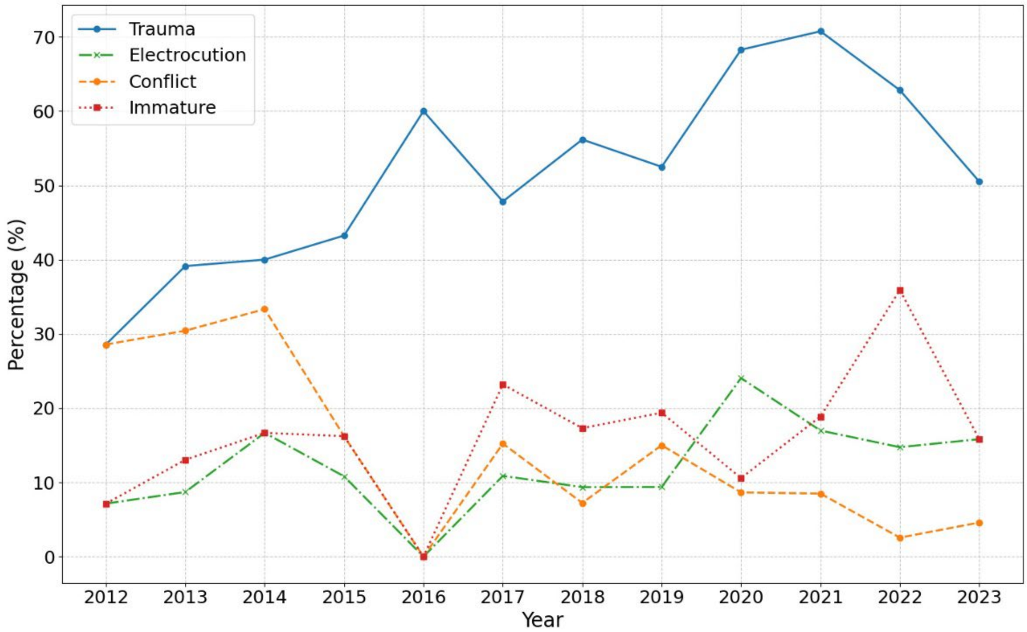


Additionally, there were 226 incidents classified as indeterminate or without information. Among other categories, both metabolic and captivity-related incidents each accounted for 43 cases. Orphans were involved in 40 incidents, infectious issues were noted in 33 cases, and nutritional aggravations were related to 18 incidents. Furthermore, 12 incidents were classified as suggestive, parasitic, neoplastic, or due to intoxication.

The data indicate a significant upward trend in trauma-related incidents, culminating in a peak of 132 cases in 2018. Electrocution incidents displayed variability over the years, with the highest occurrence recorded at 31 cases in 2023. Conflict-related incidents remained relatively consistent, peaking between 2017 and 2019. Additionally, incidents involving immature individuals shows an increasing trend over the years with a peak in 2022, reaching 56 cases. These trends are largely attributable to the overall increase in the total number of reported incidents.

When analysing the leading aggravation, trauma, which accounted for 669 incidents, there appears to be a consistent percentage increase over the years from 2012 to 2023. The proportion of trauma-related incidents rose from 28.6% in 2012 to 50.5% in 2023 (Figure 10). The resulting p-value of **0.003**, indicates that the null hypothesis can be rejected at conventional significance levels (p-value: 0.05). This supports the presence of a statistically significant trend in the proportion of trauma incidents over the analysed period.

Figure 10. Distribution of Callithrix incidents by Category (Percentage).



In 2023, there are notably 56 blank entries in the harm column, while only 4 blank entries are recorded across all other years combined. By excluding these 56 blank incidents from 2023 and recalculating percentages based on 140 incidents rather than 196, the trend becomes more apparent (Figure 8). This adjustment also increases the trauma-related percentage to 70.7% (Figures 11 and 12), further clarifying the observed trend and enhancing statistical significance, with the p-value now < **0.001**.

Figure 11. Distribution of Callithrix incidents by Category without blank entries (Percentage).

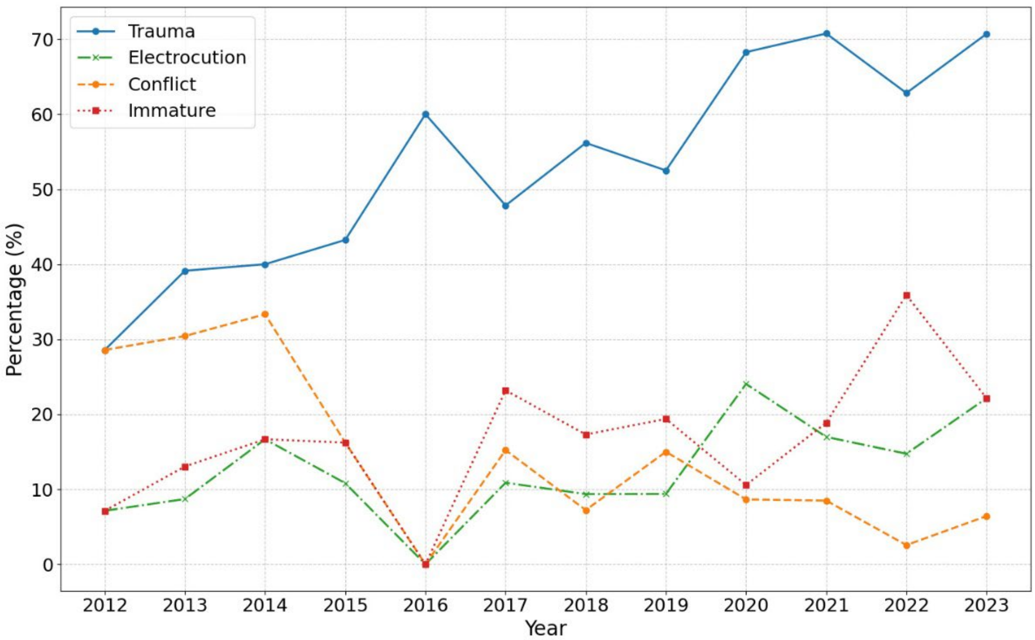
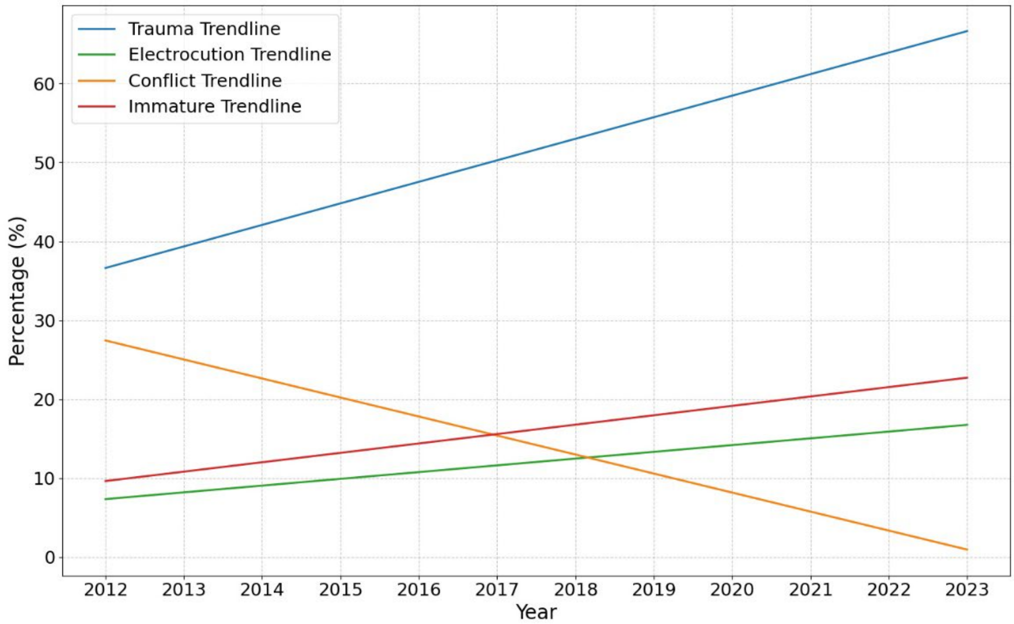


Figure 12. Trendlines of Callithrix incidents by Category without blank entries.



The frequency of conflict-related incidents stabilized at a lower level between 2017 to 2023 compared to the initial years. Between 2012 and 2014, conflicts accounted for approximately 30% of incidents, but this figure dropped to around 7% from 2017 to 2023. The resulting p-value of **0.003**, supports the presence of a statistically significant decreasing trend in the proportion of conflict incidents over the analysed period. If the 56 blank incidents from 2023 are excluded the p-value increases to **0.004** but is still statistically significant.

The Harm related to metabolic issues, captivity, and orphanhood do not appear to follow any discernible trend, and the number of such incidents is relatively low, making precise analysis difficult. This observation also applies to the rest of the entries in the Harm and Trauma columns with even fewer incidents.

Of the 669 recorded trauma incidents, 161 were due to electrocutions, showing an apparent increasing trend in the percentage of electrocutions each year, rising from 7.1% in 2012 to 15.8% in 2023. The p-value for this trend is **0.093**, indicating that it is not statistically significant. However, after adjusting for the 56 blank incidents from 2023, the percentage of electrocutions increases to 22.1%, making the upward trend more pronounced, with a statistically significant p-value of **0.043**. It is worth noting that in São Paulo, most of the electric grid and telephone lines are overground rather than subterranean, and it is rather common to see *Callithrix* balancing on these wires to move from one location to another (own observation).

Incidents involving immature *Callithrix* totalled 237 during the observed period. The data reveal an upward and relatively consistent trend in the percentage of incidents involving immature individuals for each year. The p-value for this trend is **0.105**, indicating that it is not statistically significant. However, after adjusting for the 56 blank incidents from 2023, the percentage of immature incidents increases to 22.1%, making the upward trend more pronounced, with a statistically significant p-value of **0.048**.

3.2 Temporal seasonal patterns of incidents

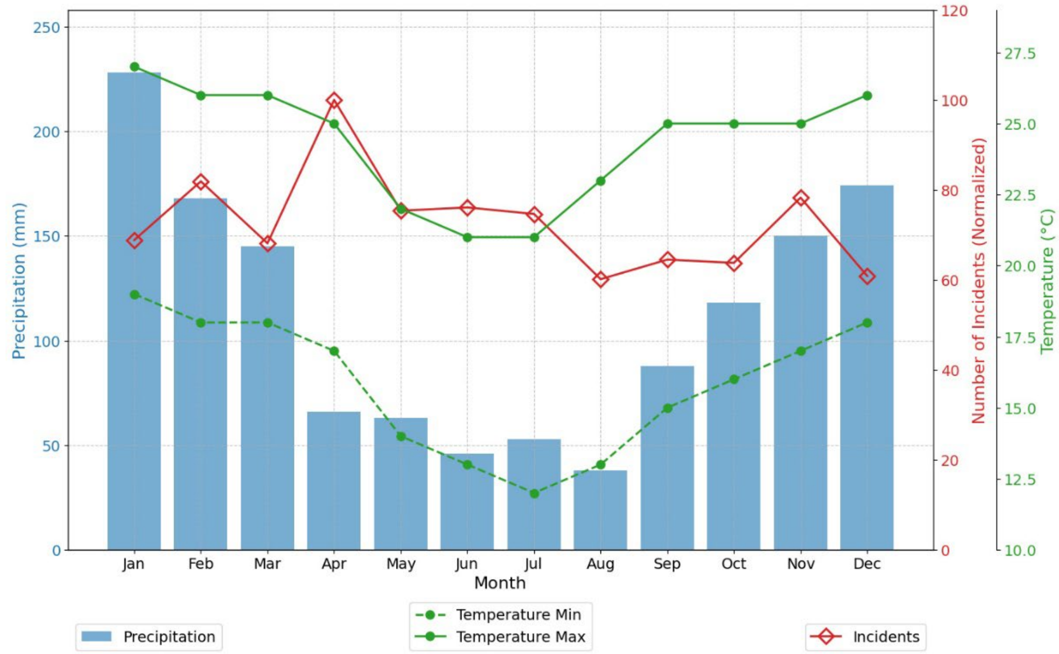
To examine seasonal variations in *Callithrix* incidents, the data reveals that the peak number of incidents occurred in April with 138 recorded, while the lowest number was in August with 83 incidents. The distribution of incidents throughout the year in São Paulo demonstrates seasonal fluctuations. A trimester analysis highlights these variations, showing a peak in incidents from April to June, totalling 347 incidents. Conversely, the period from August to October, with 260 incidents, represents a decrease in activity. The most pronounced variation is observed between two six-month periods: February to July, which recorded 657 incidents, and August to January, which recorded 547 incidents. The February-July period, spanning from late summer to early winter, appears to be a time of heightened activity, while the August-January period, covering late winter to early summer, shows reduced activity (Table 03) (Figure 13).

Table 3. Monthly Incidents, Minimum and Maximum Temperatures, and Precipitation.

Month	Incidents	Temperature min/max (ºC)	Precipitation (mm)
January	95	19-27	228
February	113	18-26	168
March	94	18-26	145
April	138	17-25	66
May	104	14-22	63
June	105	13-21	46
July	103	12-21	53
August	83	13-23	38
September	89	15-25	88
October	88	16-25	118
November	108	17-25	150
December	84	18-26	174
Average	**100.33**	**15.8-24.3**	**111.42**

Temperatures and precipitation were collected at Climatempo (2024).

Figure 13. Monthly Callithrix Incidents, Temperature, and Precipitation.



The number of incidents has been normalized to a percentage of its maximum value to fit within the chart and allow comparison with precipitation and temperature data.

The analysis of precipitation and its impact on incident frequencies reveals no significant correlation. The Pearson correlation coefficient for precipitation and incidents shows a slight negative relationship **-0.167**, with a p-value of **0.603**, suggesting it is likely due to random chance rather than a true underlying effect.

These results suggest that variation in rainfall has minimal influence on the frequency of incidents recorded during the study period in the city of São Paulo. Despite changes in precipitation levels across seasons, no clear pattern emerges between rainfall and incident counts. For instance, during the five driest months from April to August, which have an average precipitation of 53.2 mm compared to the annual average of 111.4 mm, incident levels show only a slight increase, averaging 106.6 incidents per month versus the annual average of 100.3 incidents. This indicates that other factors, beyond precipitation, are likely influencing *Callithrix* incident variations.

Similarly, the relationship between midpoint temperatures and incidents shows almost no correlation, with a Pearson correlation coefficient of **0.019**, and a p-value of **0.952**. The results clearly suggest that temperature alone does not adequately explain variations in *Callithrix* incidents in the city of São Paulo. Thus, it is likely that other factors are playing a more significant role, necessitating further investigation into additional variables affecting incident rates.

It is important to recognize that the absence of data from the final months of 2023 constitutes a limitation to this study. This data gap may undermine the accuracy and completeness of the analysis, possibly resulting in biased outcomes or incomplete conclusions. Particular caution should be applied when interpreting the findings, especially regarding trends that could be influenced by seasonal variations or other time-sensitive factors. However, excluding the 2023 data from the analysis does not influence the overall results.

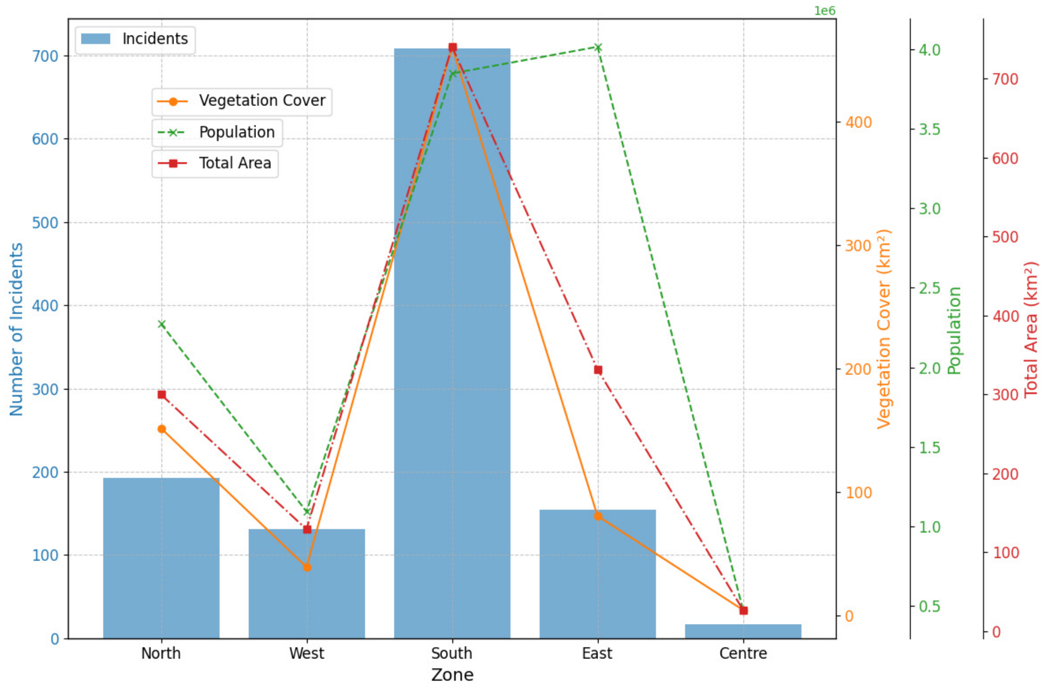
3.3 Local and regional geographic patterns in relation to incidence

The incident data for *Callithrix* in São Paulos five zones during the years 2012 and 2023 were: North 193 (16.0%); West 131 (10.9%); South 709 (58.9%); East 154 (12.8%); and Centre 17 (1.4%). The associated data on human population, vegetation cover and total area separated in the five zones are found in Table 04 and visually showed in Figure 14.

Table 4. Incidents, Human Population, Vegetation Cover and Total Area by Zone in São Paulo: North, West, South, East, and Centre.

Zone	Incidents	Human Population	Vegetation Cover (km^2)	Total Area (km^2)
North	193	2,274,466	151.59	299.87
West	131	1,093,021	39.18	128.97
South	709	3,847,746	460.29	740.61
East	154	4,015,583	80.53	331.58
Centre	17	473,798	4.39	26.67
Total	**1,204**	**11,704,614**	**735.98**	**1527.7**

Figure 14. Distribution of Callithrix Incidents, Vegetation Cover, Population, and Total Area by Zone.



The analysis of *Callithrix* incidents across São Paulo's five zones from 2012 to 2023 reveals a significant correlation between vegetation cover and the frequency of incidents reported. Specifically, the South zone, which has the highest vegetation cover at 460.29 km² and recorded 709 incidents (58.9% of the total), demonstrates a robust association between extensive greenery and a higher incidence rate. Similarly, the North zone, with 151.59 km² of vegetation and 193 incidents (16.0% of the total), supports this correlation, indicating that substantial vegetation may contribute to an increased number of incidents. The East zone, despite having a relatively large total area, possesses a moderate vegetation cover of 80.53 km² and reported 154 incidents, accounting for 12.8% of the total. This incident rate aligns with expectations, suggesting a correlation between vegetation cover and incident frequency. Similar correlations appear in both the West and Centre zones, where incident rates also correspond to the levels of vegetation cover, further supporting the relationship between these variables across different zones. The correlation between vegetation cover and *Callithrix* incident frequencies has a correlation coefficient of **0.990** and a p-value of **0.001**.

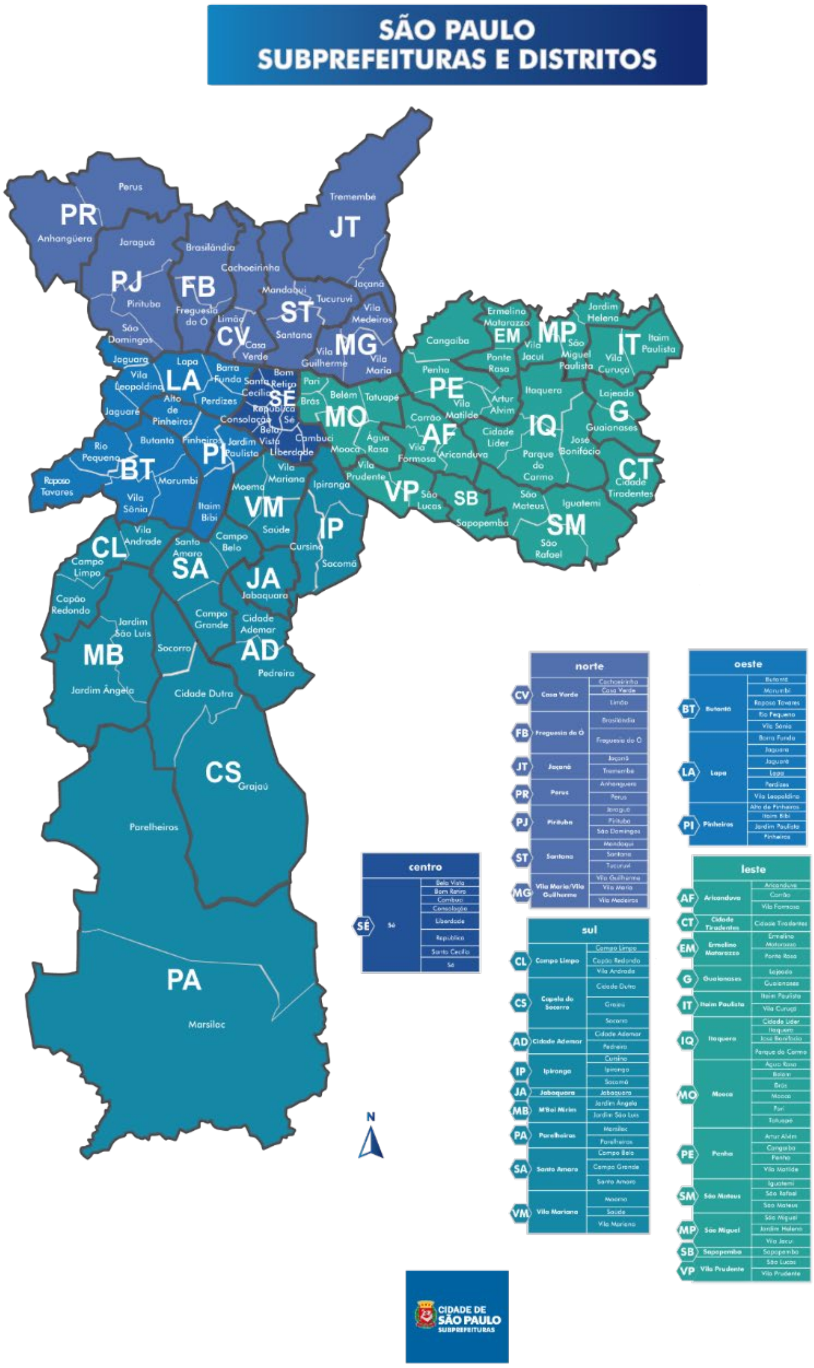
Although the Pearson correlation between *Callithrix* incidents and human population size in each area is **0.651**, however, the p-value of **0.234** indicates that the relationship is not statistically significant at conventional levels which could indicate that human population is not an important factor, or it could be an effect of the small sample size. The East zone, with its notably large population, stands out as a clear example. Despite the high population, the relatively low number of incidents suggests that population size does not strongly correlate with the frequency of *Callithrix* incidents in this zone.

When analysing the total area of the zones in relation to the number of incidents, a strong positive correlation is observed, as indicated by a Pearson coefficient of **0.961** and a p-value of **0.009**. This suggests that larger areas are generally associated with a higher number of incidents. While vegetation cover may be an important factor, many variables probably influence the incident rate. This suggests that various factors, including vegetation cover, area size, geographic location, and possible collinearity between these variables, influence the frequency of *Callithrix* incidents.

It is important to note that the vegetation cover data used in this analysis was calculated in 2020 and does not correspond to each specific year. While changes in vegetation cover have undoubtedly occurred, the use of different methodologies in various studies has led to inconsistencies such as methodology. Therefore, I have chosen to rely solely on the 2020 data, which is the best study to date and should reasonably correspond to the other years as well.

The zone's areas are presented in Figure 15.

Figure 15. The five zones of São Paulo with their corresponding regions.



North zone in purple, West zone in blue, South zone in dark green, East zone in light green and Centre in dark blue (Prefeitura de São Paulo 2024).

4. Discussion

4.1 Temporal increase in incidents during the study period

The 1300% increase in *Callithrix* incidents in São Paulo between 2012 and 2023 indicates a significant rise in the urban population of these primates. According to SVMA (2020), there were 1,714 *Callithrix* incidents from November 1991 to November 2020. If accurate and using the same methodology for collection as the data used in this study, this implies 873 incidents occurred from 1991 to 2011, based on a total of 1,350 incidents reported for the metropolitan area, not discounting those incidents that happened outside the city limits. This averages to approximately 43.5 incidents per year over ~20 years (241 months) prior to the study period. This figure is higher than the 29.6 incidents per year averaged from 2012 to 2016 in the metropolitan area but significantly lower than the 112.5 incidents per year from 2012 to 2023, also calculated using data from the metropolitan area. For the years 2017-2023, the estimated average rises to 171.7 incidents annually. Although detailed data from SVMA (2020) for these years is not available, it is important to mention because it suggests there may have been previous peaks in incidents, though likely not as high as those observed between 2017 and 2023. This inclusion underscores that the increase in incidents during the study period is probably the highest since at least 1991.

The linear regression analysis of incidents in this study does not suggest that the increase or decrease in general or specific incidents will continue indefinitely. External factors, such as reaching critical population limits, urbanization, wildlife management interventions, disease outbreaks and deforestation, are likely to impact the future trajectory. Additionally, infrastructure development (e.g., roads and power lines) and changes in public awareness or behaviour may further influence incident trends. While these factors may cause trends to shift, predicting such changes based solely on the current data remains uncertain.

Outliers, such as the unusually low number in 2016 and the spike in incidents in 2018, can significantly affect the regression results. Excluding these years may provide a clearer view of the overall trend. Investigating these outliers is crucial to determine whether they are anomalies or part of a larger pattern.

Despite these concerns, the analysis shows a somewhat steady increase in incidents over the 12-year period, without any clear cyclical patterns. Given the limited data points, detecting complex trends beyond a linear increase is challenging, which supports the use of simple linear regression in this study. A larger dataset, such as incorporating SVMA (2020) data dating back to 1991, would be necessary to reveal potential non-linear trends or fluctuations in incident frequency. For now, the linear model provides the best fit given the short timeframe and available data.

The observed rise in incidents during this study requires a nuanced interpretation, considering both ecological and social factors affecting *Callithrix* populations and their interactions with urban environments. This increase may be attributed to either a larger overall monkey population or demographic pressures that compel the monkeys to seek refuge in more hazardous areas with inadequate vegetation cover. Thus, the reasons for observed increases may be multifaceted and complex. One possible explanation is a change in vegetation cover within the city. It is conceivable that the vegetation cover has increased or become more suitable for *Callithrix* species. However, the dynamics of vegetation change in São Paulo are intricate, with certain areas appearing to have benefited more from conservation efforts than others. For instance, the dense forest in the South region may be experiencing an expansion of sparse areas which forces the monkeys to enter the more urban areas (SMUL 2023, pp. 10, 24-25). Alternatively, the increase in reported incidents might be due to a greater willingness among the public to report encounters to São Paulo's Wildlife Division or an enhancement in the division's operational resources. However, this latter explanation seems less plausible, given that the São Paulo Wildlife Division has reported being overburdened with incident reports (SVMA 2020). Several additional factors could contribute to the observed increase in *Callithrix* populations in São Paulo.

The urban environment itself may have become more hazardous or favourable for these monkeys in recent years. Urban areas can offer abundant food sources, such as waste and fruit-bearing plants, which support larger populations. A study conducted in an urban area of Olinda, in the state of Pernambuco, showed that 52% of the monkeys' food consumption was human based (Albuquerque & Borstelmann de Oliveira 2020). Another study in Ilhéus, in the state of Bahia, found that they frequently ventured into orchards (Rodrigues & Martinez 2014 p. 16). This behaviour shows their adaptability and the increasing reliance on anthropogenic food sources. Reduced predation in these environments may also boost survival rates. Habitat fragmentation and urbanization likely create new ecological niches that they exploit. Species like *C. jacchus* and *C. penicillata* are highly adaptable and can thrive in these modified environments and are also apparently easier to keep in captivity (Mittermeier et al. 1988 p. 141, 145).

Of the total 1,204 incidents involving the genus *Callithrix* in São Paulo between 2012 and 2023, only 13 were identified at the species level: 4 incidents involving *C. aurita*, 6 involving *C. penicillata*, and 3 involving *C. jacchus*. The remaining 1,191 incidents were identified only to the genus level, leaving no data in the São Paulo Wildlife Division’s records to determine the extent of representation for each species. Due to the lack of species-specific data from São Paulo's wildlife division, it is impossible to determine the exact proportion of each

Callithrix species residing within the city. However, it is likely that most *Callithrix* in the city of São Paulo are *C. jacchus*, *C. penicillata*, and their hybrids. Pure *C. aurita*, the original species, is likely extinct in the city, except perhaps in captivity, with only hybrids remaining in the urban environment. Even though the specific species are not mentioned to any great extent in the São Paulo Wildlife Division's data, it is highly likely that it concerns primarily *C. jacchus* and *C. penicillata* and their hybrids. I base this conclusion on reports, official observations (Estado de São Paulo 2023, G1 2020, OECO 2022, SVMA 2020, UOL 2023), and my own observations. Having lived in the South zone of the city for more than 25 years, I have observed numerous *C. jacchus* as well as occasional *C. penicillata* and their hybrids. However, I have never encountered a true *C. aurita* within the city. It is likely that incidents involving *C. aurita* have been sporadic, probably not many more than the four cases recorded by São Paulo's Wildlife Division.

This underscores the critical importance of providing comprehensive reports that include all available data. One likely reason for the lack of species-specific identification is that the São Paulo Wildlife Division is overburdened, likely due to some extent to the growing population of marmosets. As Juliana Summa, the Division's director, stated in late 2020 regarding the marmoset population, "No Wildlife Animal Rehabilitation Centre in Brazil is able to handle such a high demand for rescues" (my translation) (SVMA 2020). Another reason might be that it is challenging to identify them to the species level because of interbreeding which may remove most of the species' characteristic phenotypes (Cezar et al. 2017). Anyway, it is time consuming to make species specific evaluations.

The dietary flexibility due to their gum extraction from trees enables them to cultivate feeding sites as desired, often selecting one or a few trees to gouge, translating into a smaller home range with less foraging for food, resulting in lower energy expenditure and fewer hazards. Up to 70% of a *Callithrix*'s dietary intake has been documented to consist of gum. This peculiar adaptation enables the marmosets to occupy environments characterized by resource limitations and pronounced seasonality because gum is available all year round (Mittermeier et al. 1988 p. 159-161). They have home ranges of around 1-5 ha compared to the similarly sized tamarin *Saguinus fuscicollis*, which has a home range of about 30 ha. *C. jacchus* in dry scrub habitats in northeast Brazil has been recorded to have home ranges of 0.3 to 2.4 ha. *C. jacchus* and *C. penicillata* have smaller home ranges than *C. aurita* (Ankel-Simons 2007 p. 114, Lamoglia 2015, Malukiewicz et al. 2020, Mittermeier et al. 1988 p. 162, 174, Rosenberger 2020 p. 24-25, 48-49, 126-129, Rylands & Faria 1993 p. 268-269, Smith 2010, Valença-Montenegro 2021). Primates with smaller home ranges and less reliance on frugivory tend to fare better in fragmented forest environments, and those species with ecological and behavioural flexibility are often better equipped to adapt to changing environments (Anderson et al. 2007, Schwitzer et al. 2011). *C. aurita* has a larger estimated home range, requiring an area of up to 40 ha. Although its diet is like other *Callithrix* species, it is less specialized in gnawing on tree trunks to extract gum, relying on a more opportunistic behaviour to acquire the resource (MMA 2019). *C. jacchus* also has adapted chewing muscles capable of producing large tree-gouging gapes, though the study does not compare this directly with other *Callithrix* species (Taylor & Vinyard 2004). According to Natori (1986), the dentition of *C. aurita* is less specialized for tree-gouging compared to *C. jacchus* and *C. penicillata*, as *C. aurita* has slightly more developed first molars and slightly smaller lower incisors relative to the other two species. Gum extraction primarily relies on the lower incisors rather than on molar trituration.

Both *C. jacchus* and *C. penicillata*, however, seem to have excelled at tree-gouging to be able to reach the gum. The use of gum, which is available year-round, appears to be inversely related to the availability of fruit as a resource. These two species can therefore occupy the most unfavourable habitats while also achieving the highest population densities due to small home ranges (Mittermeier et al. 1988 p. 162, 165, Rylands & Faria 1993 p. 265-269). The gum eating is probably one plausible explanation why the *Callithrix* can survive and thrive in urban environments with only patches of trees where protection, physical space and food is scarce. On the other hand, in a study by Martins and Setz (2000), *C. aurita* spent 50.5% of their feeding time consuming gums, primarily feeding opportunistically on gum that was already exuding due to natural causes, such as wind breakage. The species often failed to pierce holes in the wood themselves.

Several indications from the data analysis suggest that the growing *Callithrix* population in São Paulo is facing increasingly hazardous living conditions. First and foremost, the data indicate that incidents involving trauma, electrocutions, and immatures appear to be increasing. One plausible explanation is that the city becomes more dangerous for the monkeys when they adventure themselves further away from the larger and more protective forests that are surrounding the city, especially in the South, North and East extremities. The city itself is probably not more dangerous today than it was in 2012; however, the increasing demographic pressure on the *Callithrix* population likely compels them to take greater risks as they are forced to become more urbanized.

The peak in incidents starting in 2017 and ending with a top in 2018, is likely attributable to the yellow fever epidemic that occurred in Brazil in 2017 and 2018 (Estado de São Paulo 2024). Estimates suggest that around 5,000 monkeys died due to yellow fever in the state of São Paulo in 2017, with many howler monkey groups being decimated or rendered locally extinct. The situation was exacerbated by the spread of misinformation, sensationalized news, and public ignorance, leading some individuals to mistakenly believe that monkeys, rather than mosquitoes, were the vectors for yellow fever. This fear, coupled with misinformation, prompted residents in several regions to attempt to eradicate non-human primates from nearby forests, often through poisoning. The genera *Aotus* (owl monkey), *Saguinus* (tamarins), *Alouatta* (howler monkey) and *Callithrix* are likely more sensitive to the disease than the other platyrrhini and far more sensitive than human beings (Bicca-Marques & de Freitas 2010, Estado de São Paulo 2024, Fapesp 2018, Fiocruz 2017). It is easy to imagine the stress of the combined human aggression and sickness suffered by the monkeys. Incidents involving infection is noteworthy, as most of those cases occurred between 2017 and 2019, coinciding with the yellow fever epidemic in São Paulo state during 2017-2018, with 22 out of 33 incidents occurring during this period.

4.2 Temporal seasonal patterns of incidents

The analysis of *Callithrix* incidents in São Paulo reveals some seasonal variations in incident rates, with certain months showing higher frequencies. While precipitation and temperature show weak correlations with incident rates, other factors likely play a more significant role in these fluctuations. The decrease in incidents during certain seasons could be due to less favourable environmental conditions which may reduce *Callithrix* activity. Martins and Setz (2000) demonstrated that gum feeding increased during the dry season, which may suggest less activity outside the home range but that goes against the slight negative correlation with precipitation and incidents.

One possible explanation for the observed patterns is variations in food availability. *Callithrix* species are known to rely on fruit and other resources that may fluctuate seasonally (Mittermeier et al. 1988 p. 147-153). Changes in the abundance or accessibility of these resources could lead to increased movement or foraging activity, resulting in a higher number of incidents during certain periods. Another potential factor is human activity. Urban areas experience variations in human activities throughout the year, such as public events, festivals, or construction projects. However, the peak in April is not easily explained with the famous Brazilian Carnival that normally occurs between mid-February to early March.

These activities might disrupt *Callithrix* habitats or increase interactions between humans and other primates, contributing to higher incident rates. Habitat alterations and fragmentation could also influence incident patterns. Seasonal changes in vegetation cover or habitat quality might affect *Callithrix* behaviour and movement patterns, leading to variations in incident frequencies. For instance, during certain times of the year, *Callithrix* populations might be forced into more urbanized areas due to changes in their natural habitat, increasing the likelihood of incidents.

Additionally, social dynamics within *Callithrix* groups could play a role. Changes in group composition, reproductive cycles, or territorial behaviour might influence how frequently these primates encounter human environments. In summary, while precipitation and temperature have minimal direct impact on incident rates in the city of São Paulo, other factors such as food availability, human activity, habitat conditions, and social dynamics likely contribute to the observed seasonal variations in *Callithrix* incidents. Further research is needed to explore these variables in greater detail to fully understand the drivers behind the fluctuations in incident rates.

The increase in missing data for 2023 presents a challenge for drawing reliable conclusions, particularly when analysing recent trends and seasonality if we include this year's data. The observed inconsistency between earlier and later years of the study suggests that findings based on the most recent data should be approached with caution. Potential causes for this data gap might include disruptions in data collection processes, changes in reporting practices, or resource constraints within São Paulo's Wildlife Division. To mitigate the effects of these missing data, future analyses could benefit from methods such as data imputation or focusing on the more complete sections of the dataset. Enhancing data collection practices in future studies will be important to reduce missing data and ensure the continued reliability of the dataset for ongoing research into *Callithrix* interactions in urban São Paulo.

4.3 Local and regional geographic patterns in relation to incidence

All marmosets rely on trees for sleeping, protection, and as a source of food, making it likely that *Callithrix* survival is influenced by changes in vegetation, whether through an increase or alterations in the types of vegetation available. *Callithrix* is very selective in choosing sleeping trees, probably due to predation, and they chose high trees with high first branches where they sleep on large branches with lots of vegetation cover or in the crown of palm trees (Duarte & Young 2011). In the city of São Paulo, vegetation cover that enhances the survival of *Callithrix* may have increased in recent years through maturing of recovering vegetation. Unfortunately, as we have seen, studies on vegetation cover and green areas are often contradictory, frequently employing different methodologies, which makes them difficult to compare and does not necessarily imply a net increase in overall vegetation cover. This discrepancy sometimes becomes apparent when comparing governmental reports with those conducted by private organizations and environmental groups (MMA 2015 p. 37-38). While governmental studies may sometimes present a more optimistic view highlighting positive trends and indicating improvements in urban greenery, reports from private entities and environmental organizations often point to the ongoing challenges posed by urban expansion and infrastructure development. These differing perspectives make it challenging to reach a consensus on the true state of urban vegetation, underscoring the need for objective and rigorous research.

The data presents a challenge in understanding the individual influence of each variable due to potential collinearity among the independent factors such as population size, vegetation cover, total area, variations in urban infrastructure, levels of human-wildlife interaction, and the effectiveness of local wildlife management strategies and proximity to nearby *Callithrix* habitats. Collinearity occurs when two or more predictor variables in a model are highly correlated, making it difficult to determine the distinct effect of each variable on the outcome—in this case, the frequency of *Callithrix* incidents. For example, larger zones tend to have higher vegetation cover and often a larger population, as seen in the South zone, which makes it challenging to separate the unique impact of vegetation from that of area or population. The size of the area might lead to a greater number of incidents simply because there is more space for *Callithrix* to inhabit, however, the anomaly in the East zone, where the number of *Callithrix* incidents is relatively low despite its large total area, demonstrates that total area alone is not a perfect indicator for predicting incident rates. Higher population density could increase the frequency of human-wildlife interactions. Similarly, vegetation cover provides suitable habitat and resources, which can lead to higher *Callithrix* populations and, therefore, more incidents, but could also attract the animals closer to more urban areas. Additionally, the proximity of a zone to natural *Callithrix* habitats may lead to more frequent spillover incidents as animals move between their natural environment and urban areas in search of food or shelter, further complicating the analysis. This interconnectedness makes it difficult to ascertain whether the number of incidents is directly influenced by vegetation cover, population density, total area, or proximity to natural habitats. Addressing this issue of collinearity would require more advanced statistical techniques, such as multivariate regression analysis or variance inflation factor (VIF) analysis, to effectively disentangle the overlapping effects of these predictors. The inherent uncertainty in statistical inference also means that while strong correlations may be observed, they do not necessarily imply direct causation, underscoring the need for cautious interpretation.

Also, the p-values and Pearson correlation obtained for incidents compared to human population, total area and vegetation cover are based on a relatively small sample size (five zones), which limits the reliability of the conclusions. To gain more accurate insights, future studies should conduct a comparative analysis of incidents across the 32 subprefectures of São Paulo. This would provide a more detailed perspective on how vegetation cover and incident rates vary within each subprefecture, helping to assess whether the significant p-values hold with a larger sample and offering a clearer understanding of incident distribution in urban settings.

In SVMA (2020b p. 28-40), vegetation cover is classified into 15 categories. Categories 1 through 5 pertain to various types of tropical forests; category 6 includes high-altitude grasslands; category 7 encompasses herbaceous-shrub vegetation in floodplains; category 8 covers floating aquatic vegetation; categories 9 and 10 refer to heterogeneous and homogeneous forest masses; category 11 denotes areas with minimal tree cover, including tree-shrub or tree-like elements typically found in herbaceous environments where tree canopies or palm crowns do not connect; category 12 is designated for agricultural land; category 13 describes vegetation with medium to high tree cover, including interlocking canopies, shrubs, and tree-like plants situated in green spaces associated with road systems, public squares, tree-lined sidewalks, landscaped areas, parks, and private properties; category 14 refers to herbaceous-shrub vegetation; and category 15 represents mixed vegetation.

For the purposes of this study, categories 11 and 13 are of particular importance. Real forests, classified under categories 1-5, are only present in the North zone (61.44 km², representing 20.5% of the total area), South zone (233.47 km², or 31.5% of the total area), and East zone (9.05 km², or 2.7% of the total area). Neither the Centre nor the West zone contains any vegetation classified under categories 1-5 (SVMA 2020b p. 55). Despite the absence of these forest categories, *Callithrix* species are present, suggesting that forests may not be essential for their survival. Categories 11 and 13, however, are found to a significant extent across all zones, indicating that these types of vegetation are likely sufficient for the *Callithrix* to thrive. A notable example is the district of Santo Amaro with a total area of 37.76 km^2 in the South zone, which, having a high number of *Callithrix* incidents, contains 1.43 km² of category 11 and 8.63 km² of category 13 vegetation, totalling approximately 90.7% of the area's vegetation[5] (SVMA 2020b p. 62). Almost all remaining area, 0.92 km², is category 14 herbaceous-shrub vegetation, which lacks trees and is likely unsuitable for the monkeys.

Therefore, categories 11 and 13 appear to provide adequate habitat for species such as *C. jacchus* and *C. penicillata*, which have likely adapted to the more challenging, drier environments found in central and northern Brazil. Future studies could focus on a more specific analysis by examining each of the 32 subprefectures within the city of São Paulo and their individual distribution of vegetation cover and incident rates. By exploring localized patterns, researchers could gain deeper insights into how factors such as subprefecture-level urban infrastructure, microhabitats, and human activities influence *Callithrix* incidents. This approach would allow for a more precise understanding of the relationship between vegetation, total area, and other contributing factors, potentially revealing details that are not apparent when analysing broader zones.

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[5] https://www.google.com/maps/d/edit?mid=1_25HAOpEeLJLwW-VI1CEOLYeR6lmNaw&ll

5. Conclusion

The rise in *Callithrix* incidents, particularly *C. jacchus* and *C. penicillata*, signals a notable shift in São Paulo's urban wildlife dynamics, possibly linked to change in vegetation cover. However, to fully grasp these variations, factors like urban planning, human behaviour, and conservation strategies must be considered, underscoring the need for a multifaceted wildlife management approach.

Although the rate of deforestation has slowed, safeguarding the remaining areas of the Atlantic Forest is crucial for maintaining biodiversity and ecological balance. Initiatives such as habitat preservation, the creation of green corridors to connect fragmented areas, and environmental education programs are essential strategies. These efforts help mitigate habitat fragmentation, ensure the survival of *Callithrix* species, and promote peaceful coexistence between humans and wildlife. By enhancing public awareness and improving habitat connectivity, these measures aim to protect the forest and its species from further degradation.

Interestingly, an increasing *Callithrix* population may reflect a healthier urban environment due to enhanced tree coverage, but this also elevates the risks of human-wildlife conflict, including zoonotic disease transmission and resource competition. Cases like reported rabies (Favoretto et al. 2001) exemplify these risks.

Furthermore, the intrusion of *C. jacchus* and *C. penicillata* threatens the genetic integrity of *C. aurita* through hybridization. While removing invasive species might seem logical, it raises ethical concerns, particularly given the limitations of rehabilitation centres in handling non-threatened species (Malukiewicz et al. 2015, Malukiewicz et al. 2020).

Despite some positive trends, such as improved environmental education and tree-planting initiatives, urbanization continues to pose challenges. The perceived increase in vegetation cover could result from improved data collection rather than actual growth. Furthermore, without clear evidence of ongoing deforestation or recovery, attributing the rise in *Callithrix* populations solely to changes in vegetation remains uncertain, as other factors like urban dynamics and human interactions might play significant roles in shaping these population trends.

This complex understanding highlights the need for an integrative approach to managing both urban expansion and wildlife conservation in São Paulo.

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