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ECOLOGY AND BEHAVIOR OF COATIS *NASUA NASUA* (LINNAEUS, 1766) IN AN URBAN PARK IN SOUTHERN BRAZIL

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Abstract: The Atlantic Forest has important environmental heterogeneity and biodiversity, thus it is recognized as one of the most critical global ecological regions. Coatis *Nasua nasua* are found in urban forest fragments and urbanized areas and use available green spaces and human-provided resources and so are a good model to study the influence of anthropogenic environments. The aim of this study was to investigate the effects of urbanization and forest fragmentation on the ecology and behavior of coatis (*Nasua nasua*) in Arthur Thomas Municipal Park, Londrina, Paraná, Brazil. Ecology and behavior include population size, daily activity patterns and habitat use obtained through active search and direct visualization of individuals and their tracks. Population density was estimated at 36.1 individuals per km^2 and is greater than estimates in natural areas, probably due to anthropogenic food sources and the absence of top predators. Coati activity was greatest between 08:00 and 13:00 h when they tend to be terrestrial. Forested habitat was the most used, followed by secondary vegetation, and coatis used different the areas of the park in different ways during the dry and rainy periods, with a wide use of anthropogenic areas in all periods, closely related to the contribution of food of anthropic origin.

Keywords: Coatis; Behavioral ecology; Anthropogenic influences; Habitat use.

INTRODUCTION

The impact of anthropogenic influences on landscapes has been observed to manifest in ways that are both unpredictable and profound, with notable effects on the diversity, abundance, habitat use, and behavior of wildlife (Haddad, 2015; Dirzo, *et al.* 2014) and habitat fragmentation has long been considered a major cause of global biodiversity loss (Wu, 2013; Fahirg, 2003). More than 75% of the land surface of the Earth has experienced some form of anthropogenic disturbance (Ellis and Ramankutt, 2008). Among the most abrupt changes is urban growth (McCleery, 2010). The urban environment is characterized by high human population densities, impermeable surfaces, buildings, reduced vegetation, pollution, and wastewater, along with increased available of waste foods in garbage (Adams *et al.* 2006), and is a mosaic of man-made structures interspersed with green spaces (Breuste *et al*. 2008).

These factors can be observed in different regions of the Atlantic Rainforest. This region has a high degree of environmental heterogeneity and includes different climatic zones with tropical to subtropical vegetation formations (Tabarelli *et al.* 2005). The Atlantic Rainforest, due to its great biodiversity, is among the most important ecological regions in the world and a biodiversity hotspot (Myers *et al.* 2000). This biome is the second-largest forest in Brazil, currently with only a quarter of its original formation, equivalent to 30 million hectares (Rezende *et al.* 2018; Rosa *et al*. 2021). Over the last century, 88% of the Atlantic Forest has been destroyed, and the remaining vegetation patches are usually small, isolated and suffer from anthropogenic disturbances (Ribeiro *et al*. 2009).

The responses of mammals present in urban perimeters depend on the gradient into which the species is inserted. Species in urban centers use garbage as a food source and buildings and culverts for shelter, whereas species in adjacent areas with more green space use the vegetation for food and shelter (McCleery, 2010). Mammals that succeed in colonizing urban environments often have greater population densities due to a combination of factors, such as reduced dispersal, high fecundity, absence of predators, high food availability, and high heterogeneity of the urban environment (Cypher & Frost, 1999; Gaston *et al.* 2005; McCleery, 2010). Successful colonization of urban environments has been reported primarily in small mammals and mesocarnivores, which tend to exhibit high trophic and behavioral plasticity (Crooks 2002; McCleery, 2015; Bateman & Fleming 2012). These species are known as urban exploiters (McKinney, 2006) and are characterized by their ability to exploit both natural and anthropogenic resources present in the habitat and may have denser populations in urban habitats compared to natural habitats (Fedriani *et al.* 2001; Bateman & Fleming, 2012).

The ring-tailed coati (*Nasua nasua*, Linneaus, 1766) is a medium-sized mammal (3 - 6 kg), gregarious, and widespread in neotropical rainforest from Venezuela to Colombia and from northern Uruguay to Argentina (Gompper & Decker, 1998), where they are usually the more abundant mesopredator (Family: Procyonidae, Order: Carnivora; Gompper & Decker 1998). From Venezuela to Colombia and from northern Uruguay to Argentina (Gompper & Decker, 1998) they are among the few carnivores that are not threatened or endangered (Helgen & Emmons, 2016).

Coatis play a significant role within the mammal community and contribute to forest dynamics. They are part of the diet of large felids, and fluctuations in their populations indicate a decline in the populations of top predators (Wright *et al*. 1994). Fluctuations in the population of the coati can also have an adverse impact on the regeneration of forests, as they play an important role in the dispersal of seeds (Alves-Costa, 1998; Alves-Costa & Eterovick, 2007). Given their capacity to establish themselves in environments that have been disturbed by humans, the coati is regarded as an important seed disperser in such areas (Alves-Costa & Eterovick, 2007).

High rates of predation by mesopredators can cause changes in the population dynamics of their prey, which can lead to their extinction (Courchamp *et al.* 1999). In addition to ecosystem damage, the release of mesopredators can cause public health damage, as many species that are reservoirs of zoonotic diseases use anthropogenic resources available at the edge of fragments (Gibb *et al.* 2020). Coatis are good models for understanding the population dynamics and ecological patterns of mesopredators, and studying and understanding the ecology of this group is essential to avoid potential damage to the ecosystem and to public health. The aim of this study was to examine how coatis (*N. nasua*) use an urbanized and fragmented forest. We estimate population density and size, daily activity patterns and habitat use, including preference for areas and type of vegetation and analyzed seasonal variation in behavior and habitat use. We then suggest how coati behaviors are influenced by the consequences of anthropogenic activities.

MATERIAL AND METHODS

Study area

The study was conducted in the Arthur Thomas Municipal Park (PMAT, 85 ha, 23º 15' - 23º 30' S and 51º 15' - 51º 00' W, near Londrina, Paraná). A total of 67 ha comprises remnants of seasonal semideciduous forest (Cotarelli *et al.* 2008). The park is surrounded by an urban matrix, with a neighborhood at the northern end where residents pass through at some points in the park, at the southwestern end there is a large amount of garbage and food from anthropogenic sources left on the sidewalk, and at the eastern end the PMAT merges with a privately owned forest reserve and has an altitude ranging from 520 to 620 m above sea level (Campos *et al.* 2005). The climate of the city of Londrina-PR is classified as humid subtropical with an average temperature of 22ºC and a rainfall of 1500 mm to 1600 mm per year (Nitsche, 2019).

Figure 1. Map of the Arthur Thomas Municipal Park, in the municipality of Londrina, Paraná, showing the trails followed during the study.

Characterization of the trails

Nine trails in the park were used to record the presence of animals. The trails vary in size from 200 to 1000 m (Table 1).

Table 1. Characterization of the trails covered during this study in the Arthur Thomas Municipal Park, Londrina, Paraná. SEMA = Municipal Environmental Department.

Trails	**Extension (m)**	**Characterization**
1	600	Artificial substrate, anthropic activity (SEMA), canopy 20-25 m
2	800	Artificial substrate, anthropogenic activity (tourism), canopy 20-25 m
3	800	Artificial substrate, anthropogenic activity (tourism), canopy 20-25 m
4	300	Artificial substrate, anthropogenic activity (urban), canopy 10 m
5	270	Terrestrial substrate, anthropogenic activity (reduced), canopy 10 m
6	250	Terrestrial substrate, anthropogenic activity (reduced), canopy 15 m
7	560	Terrestrial substrate, anthropogenic activity (reduced), canopy 20 m
8	650	Terrestrial substrate, anthropogenic activity (reduced), canopy 20-25 m
9	1200	Terrestrial substrate, anthropogenic activity (tourism), canopy absent
TOTAL	5430	

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Search and habituation for coatis

The study was partially conducted during the SARS-CoV-2 pandemic. The researchers involved in the study followed WHO recommendations by wearing N95 masks and keeping a minimum distance of 3 m from the animals studied, considering that coatis are susceptible to Covid-19 (Stoffella-Dutra *et al.* 2023).

The study area was observed for a total of 776 hours between 18 June 2021 and 26 May 2022, with monitoring conducted for eight hours per day, three days per week. A portion of the study was conducted during the period of the global pandemic caused by the SARS-CoV-2 virus, during which time the PMAT was closed to visitors. During this period, active searches were conducted to locate individuals from the coati population and/or their tracks (Prist *et al*. 2020). The data collection began simultaneously with the animal habituation phase. At the outset of the study, a minimum of one field campaign per week was conducted to facilitate habituation. Four criteria were examined during this period: 1) the emission of alarm vocalizations in the presence of the observer, 2) the display of defensive behavior (immobilization), 3) foraging in the presence of the researcher and 4) the return of individuals to their resting places in the presence of the researcher. The behavioral observations were conducted in accordance with the methodology established by Beisiegel & Mantovani (2006).

Population size and density

To estimate population size, the nine trails were each walked at approximately 1 km h^{-1} for 40 minutes, and the trails were visited at random. Population abundance and density were estimated using repeated counts and hierarchical N-mixture models in the R software using the Unmarked package. This model is capable of estimating abundance from imperfect counts and detections (Royle, 2004). It is necessary to replicate counts at sampling sites (Kéry *et al.* 2009).

Detectability was estimated using occupancy models with the R software and the "Unmarked" package, which estimates the probability of detecting at least one individual from the studied population.

Period of daily activity

To establish the activity patterns of the individuals, sightings of solitary individuals and/or groups were estimated for each one-hour sampling period during the park's opening hours. The term 'active' was used to describe animals that were observed to be moving, foraging, vocalizing or performing maintenance. Conversely, individuals that were resting or sleeping were classified as inactive.

Habitat use and seasonal variation

Geographical locations were measured using Global Positioning System (GPS) for all group records and for solitary individuals, and core density maps were created using Q-GIS software (QGIS Development Team, 2023). To account for seasonal variation, the year was divided into two seasons: a dry season (April to September) and a rainy season (October to March). The frequency of sightings on the trails was calculated as the proportion of sightings per unit of distance travelled, taking into account the fact that the trails have different lengths and therefore different probabilities of encounter. In order to facilitate comparisons between trails, each replicate value is representative of the proportion of sightings per trail in each season, resulting in four replicates per trail. The initial plan was to test for differences between trails using ANOVA. However, after testing the residuals for normality with the Shapiro-Wilk test ($W = 0.86537$, $p = 0.0004388$), it was identified that the data exhibited a non-normal distribution. Consequently, the non-parametric Kruskal-Wallis test was applied, followed by the Wilcoxon post-hoc test to assess the differences between the trails.

RESULTS

Abundance and density

A total of 88 encounters (69 groups, 19 solitary males, of 753 individuals sighted) were observed. Groups were found on all trails, with a detectability of 7%. Solitary males were seen on only five trails, both in the west portion of the PMAT, with a detectability of 4%. When group and solitary male data were combined for presence and absence, coatis were observed on all trails with 11% detectability.

We estimated that 31 individuals were present for an estimated population density of was 36.1 individuals km^2 for the park

Period of daily activity

During the sampling period, coatis had a higher encounter rate in the morning with 37 encounters, representing 56% of the total group encounters. The greatest encounter rates were from 10:00 – 11:00 and 11:00 – 12:00 h with 10 encounters each, while the 8:00, 9:00 and 12:00 periods had 9, 8, and 3 records, respectively. In the afternoon, the coati group was encountered 29 times. The period with the highest encounter rate was 13:00 h with 13 encounters, followed by 14:00, 15:00, 16:00 h with 6, 5, and 2 encounters, respectively.

Encounters with solitary males peaked in the morning, representing 62% of the sightings. The time period with the highest number of sightings was 10:00 h, with 4 records, followed by 11:00 h, 08:00 h, and 09:00 h, with 3, 2, and 1 record, respectively. The afternoon period accounted for 37.5% of encounters and had the highest encounter rate at 14:00 h with 3 records, followed by 15:00, 13:00, and 16:00 h, with 2, 1, and 0 records, respectively (Figure 2), with a significant difference between groups, $p < 0.001$ ($t = -6.06$, $df = 7$, $p < 0.001$). No cases of inactivity of the coatis were recorded during the study.

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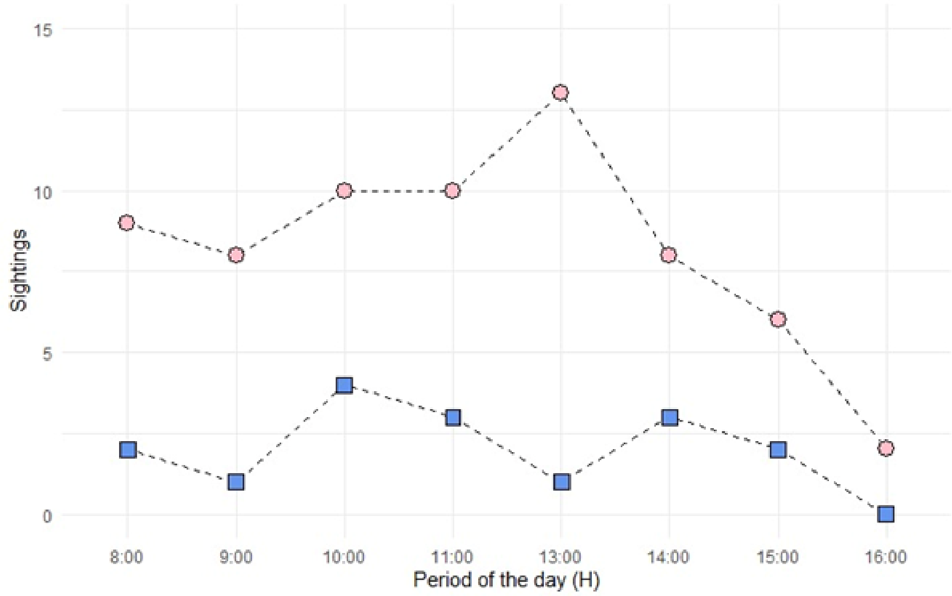

Figure 2. Daily encounter pattern of *Nasua nasua* coatis in Arthur Thomas Municipal Park, Londrina, Paraná, during the study. Each time point represents the sum of encounters during the next hour. Pink circle: Group. Blue squares: Solitary males.

Habitat uses

Coatis tended to be observed on the ground, with 64 records (74%), in comparison to 12 records (14%) in trees. Some individuals were in both simultaneously (11 times, 13%) (Figure 3). There were no records of solitary males on arboreal substrates, 100% of the records were on terrestrial substrates.

During the wet season, coatis were more often found on the ground (73%) than in the trees (16%) or both (11%) while in the dry season 80% were on the ground, 16% in trees and both 4% (Figure 4).

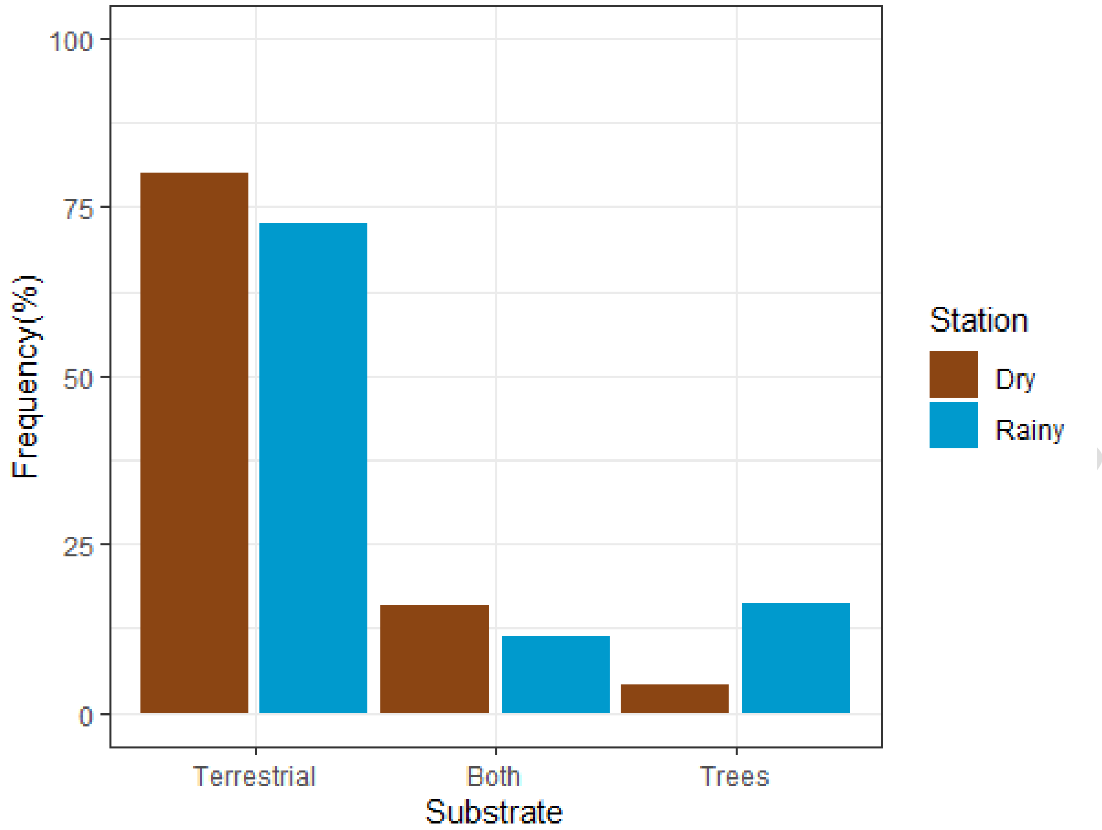

Figure 3. Frequency of substrate use by *Nasua nasua* coatis in Arthur Thomas Municipal Park, Londrina, Paraná, during dry (March, April, May, June, July and August, N = 43) and rainy (September, October, November, December, January and February, N = 45) seasons.

Habitat use and seasonal variation

Coatis were found more frequently on Trail 4 (26%, n = 194), followed by Trail 8 (22%, n = 167), Trail 1 with 17% (n = 125), Trail 3 with 12% (n = 94), Trail 2 with 10.49% (n = 79), Trail 5 with 5.44% (n = 41), Trail 7 with 3.18% (n = 24), Trail 6 with 2.78% (n = 21), and Trail 9 with 1.06% (n = 8). The Kruskal-Wallis test indicated a significant difference between the frequency of sightings across different trails (p = 0.006). Post-hoc Dunn's test revealed that Trail 4 differed significantly from Trail 7 (p = 0.001, adjusted p = 0.042) and Trail 9 (p = 0.0006, adjusted p = 0.020). While initial comparisons suggested that Trail 4 also differed from Trail 6 (p = 0.004) and Trail 5 (p = 0.046), these differences were not statistically significant after Bonferroni correction (adjusted p > 0.145). Furthermore, the difference between Trail 7 and Trail 8 (p = 0.033) did not remain significant after adjustment (adjusted p = 1.000). These results show that although several initial comparisons suggested differences, only the differences between Trail 4 and Trails 7 and 9 retained significance after adjusting for multiple comparisons (Figure 4).

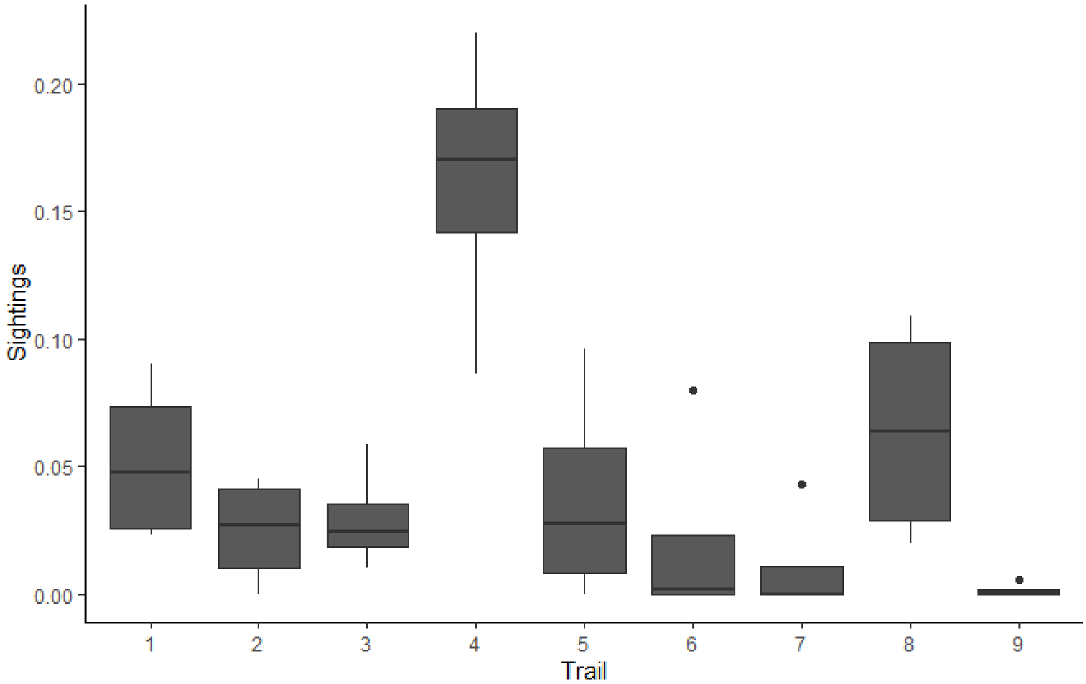

Figure 4. A comparative analysis of the frequency of sightings per trail utilized by *Nasua nasua* in the Arthur Thomas Municipal Park, Londrina, Paraná. The values were standardized by the length of the trails, resulting in sightings per unit of distance traveled. Each boxplot represents the distribution of these proportions for each trail.

The highest percentage of encounters with coatis occurred during the rainy season, representing 51.13% (n = 45) of sightings, while the dry season accounted for 48.87% (n = 43). However, no significant difference was found between the number of sightings in the two seasons ($p > 0.05$), indicating that the encounter rates were effectively the same across seasons. The Kernel density maps indicate variations in habitat use during the seasons. During the rainy season, a wider range of habitat used can be observed, with a lower occurrence in anthropogenic habitats (number of records = 45, total number of individuals counted = 326). In the dry season, coatis used anthropogenic areas more frequently, using Trail 4 most frequently (number of records = 43, total number of individuals counted = 339) (Figure 5).

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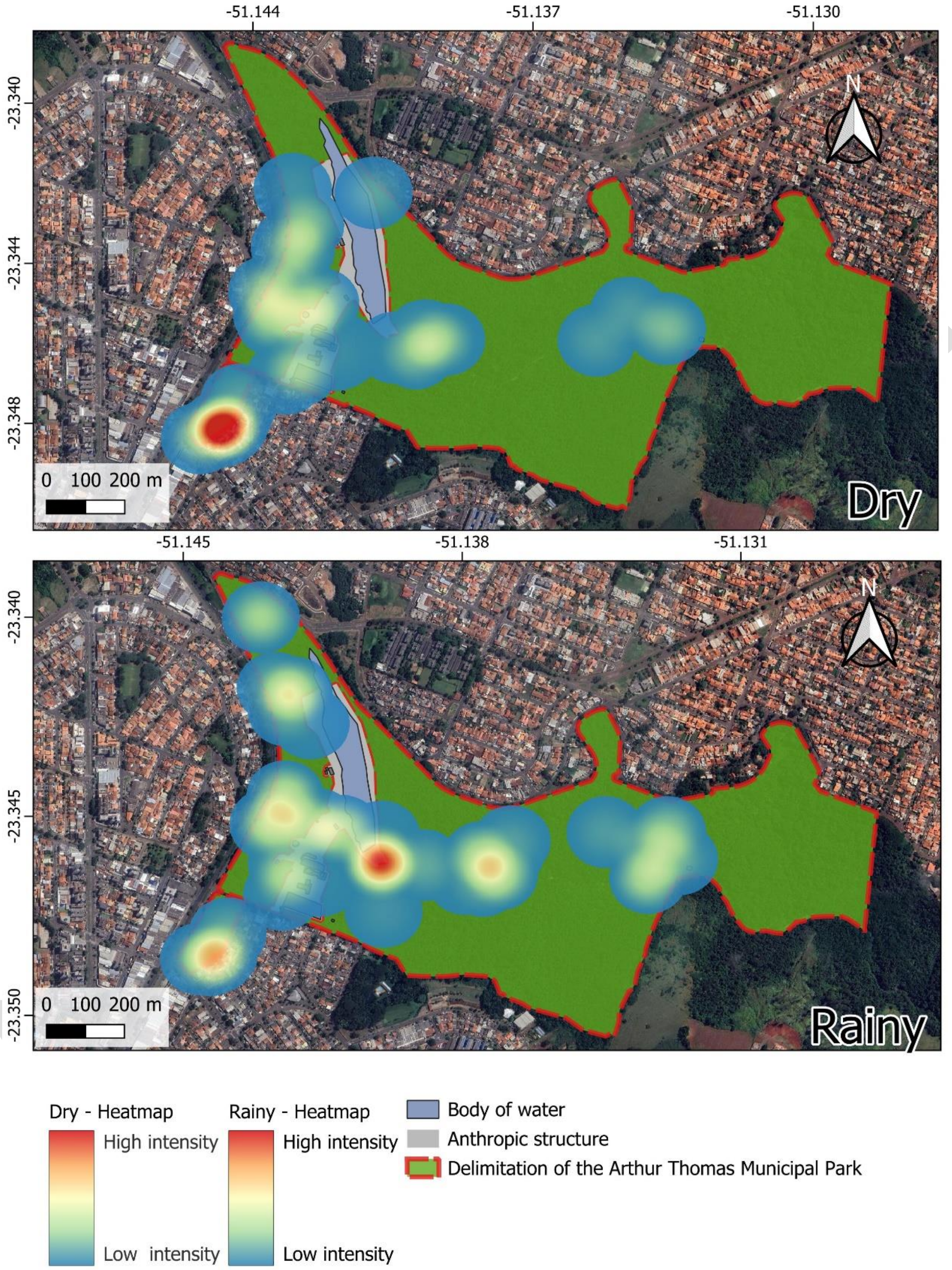

Figure 5. Map of intensity of area use by *Nasua nasua* coatis in Arthur Thomas Municipal Park, Londrina, Paraná in the dry (September, October, November, December, January and February) and rainy (September, October, November, December, January and February) season.

DISCUSSION

The density of coatis (*Nasua nasua*) in Arthur Thomas Municipal Park (PMAT) was estimated at 36 individuals per km², similar to other studies, such as in Mata dos Godoy (D = 36 individuals per km²). However, different values were observed in Vila Rica do Espírito Santo State Park (Fênix municipality), where densities reached 129 individuals per km² (Ruim, 2014). The density of coatis at PMAT is still higher than the average of 10.7 individuals per km² typically found in non-anthropized habitats (Hemetrio, 2007), suggesting that anthropogenic influences may be contributing to the population increase in the PMAT.

Other studies conducted in different biomes and phytophysiognomies, such as the Cerrado and Atlantic Forest have also yielded disturbing results. Hemetrio (2007) observed that the coati density was 53 individuals per km^2 (estimated by mark and recapture) in Mangabeiras State Park (236 ha), in the municipality of Belo Horizonte, in the state of Minas Gerais. The Mangabeiras State Park also has an urban matrix similar to that of the present study. Another study in the same location in 2011 measured 30.3 individuals per km^2 using observation methodology. In the Prosa State Park, in the city of Campo Grande, Mato Grosso do Sul, Costa *et al*. (2009) measured 33.7 individuals per km^2. That park covers 134 ha and is surrounded by an urban matrix, as found in PMAT.

While the estimated density of the coati (*Nasua nasua*) is not considered high in PMAT compared to most other studies, it may be influenced by the availability of anthropogenic resources. During the study period, both the group and the solitary male were observed extensively using food left behind by residents near the PMAT. These resources included garbage, food scraps, pet food, ground corn, bread, biscuits, and rice discarded on pavements surrounding the park or provided through direct interactions with citizens.

Some mesopredator species are indeed affected by anthropogenic pressures but are able to adapt and persist in altered environments, including the red fox (*Vulpes vulpes*), the white-nosed coati (*Nasua narica*), and the common raccoon (*Procyon lotor*), which have expanded their range in North America in recent years (Prugh *et al*. 2010). While these species face significant behavioral and demographic shifts, such as changes in movement patterns, diet, and social structure, their omnivorous diet, medium size, high reproductive potential, and behavioral plasticity (Michalski & Peres, 2005; Alves-Costa & Eterovick, 2007; Lyra-Jorge *et al*. 2009) enable them to survive. In the Neotropics, other mesopredator species, like the tayra (*Eira barbara*) and the crab-eating raccoon (*Procyon cancrivorus*) (Bernardo & Melo, 2013), exhibit similar adaptability. These traits allow them to exploit the abundant resources in urban environments (Crooks & Soulé, 1999), although their behaviors in these anthropogenic habitats differ significantly from those in undisturbed environments. Species capable of using urban resources often become dominant in smaller anthropized fragments (Reis *et al*. 2003; Pardini, 2004), especially in light of the decline of species that would otherwise compete for these resources, such as deer, tapirs, and anteaters, which have experienced significant population reductions (Dirzo *et al*. 2014; Bogoni *et al*. 2018; Gonçalves *et al*. 2018).

Another factor influencing the density of coatis (*Nasua nasua)* found at PMAT is the absence of top predators and other potential competitors (Silva, 2007). Mammalian communities are strongly influenced by predation (Aberhan *et al*. 2006, Terborgh & Estes 2010), and the decline or absence of top predators is closely related to mesopredator release (Terborgh, 1988; Crooks & Soulé, 1999; Prugh *et al*. 2009), a phenomenon to which most of the remaining 96% of Atlantic Forest fragments are susceptible (Jorge *et al*. 2013). The recurrent presence of mesopredators in the biome raises concerns, as it can lead to irreversible damage to the ecosystem, such as the extinction of their prey, and pose risks to public health through the spread of zoonotic diseases (Prugh *et al*. 2009; Gibb *et al*. 2020).

The results of this study indicate a longer period of daily activity for coatis in the morning and early afternoon. These results partially confirm those found in the literature. Bonnati (2006), on the island of Campeche in Florianópolis-SC, also observed, by direct visualization, a greater activity of the coatis in the early hours of the morning and a decrease in the early hours of the afternoon, which did not occur in the present study, considering that a high rate of encounter with the group was observed in the early hours of the afternoon, this being due to the contribution of food of anthropic origin made by the inhabitants of the surroundings of the PMAT.

In this study, greater daily activity was recorded for solitary males during the 10:00-11:00 h. sampling periods, while Pinheiro (2015) at the Água Limpa Ecological Station, a 70.66-hectare conservation unit, and Bonnati (2006) in a 50-hectare-island setting found greater recordings in the early morning hours.

Coatis are predominantly terrestrial (Emmons and Feer, 1996; Gompper and Decker 1998), even though in some places they may be more arboreal (Carlos Botelho State Park, Beisiegel (2001) and Beisigel and Mantovani (2005). Here, in PMAT, coatis are essentially terrestrial (Barros and Frendozo 2010). This may be due to the small number of bromeliads in the PMAT. According to the last floristic survey carried out in the study area, PMAT does not have any bromeliad or epiphyte species (Cotarelli 2008), in which coatis are known to forage on mollusks, amphibians, annelids and coleopterans (Alves-Costa *et al*. 2004; Beisiegel & Mantovani 2006). Other factors also contribute to the increased use of terrestrial substrates. During the study, it was observed that the food left on the ground substrate by visitors and residents of the park may influence their behavior, and the absence of predators may also negatively influence the use of the tree platform by coatis (Beisiegel & Mantovani 2006), where the animals feel more protected (Beisiegel, 2001). The findings of this study suggest that coatis utilize a range of habitats within the PMAT, with a higher prevalence in forested regions. While the majority of coatis inhabit forest ecosystems, they demonstrate the capacity to inhabit diverse habitat types. During the course of the study, we observed a diminished utilization of non-forested areas, such as the peripheries of the lake, indicating a proclivity for forested environments. In this study, coatis were found using the urban perimeter in all seasons, but a greater number of occurrences in winter while in summer and spring there was a more uniform use of the habitat by coatis, with a lower intensity in the urban perimeter compared to the other seasons, as indicated by the kernel intensity map. The greater use of habitat in spring and summer may be due to the decentralization of resources available in the park, but for better conclusions, we recommend studies on the phenology of the trees present in PMAT.

The results of this study corroborate other studies, Bonnati (2006) also found a higher use of secondary vegetation in all seasons, and as in this study, environments with anthropogenic formation were widely used, but the coatis still prefer secondary vegetation. It is expected that the changes observed in habitat selection during the seasons are related to the availability and distribution of food resources present in the park, as observed in other studies where the species showed variations in its diet influenced by seasonality (Alves-Costa *et al.* 2004).

During the collection period, some difficulties were encountered: during most of the studies, the trails were not maintained, which may have affected the detectability. Another important point to emphasize is the proximity of the park to the urban perimeter, since during the study residents were seen passing through the park, which could also interfere with the studies and endanger the physical integrity of the researchers as well as their material goods that were with them in the field. The study was conducted during the COVID-19 pandemic, so PMAT was closed to visitors, which may have also influenced the results.

The Arthur Thomas Municipal Park is a fully protected conservation unit and, according to the Brazilian National System of Nature Conservation Units - SNUC (Brazil 2000), can be used for recreation, tourism and scientific research. Areas such as this are of great importance because they are refuges for wildlife, while playing an important role in the well-being of human life (Araújo, 2007; Lederman & Araújo, 2012). Protected areas have a high demand for scientific studies, which often do not provide answers that can help in the management of these areas (Luz & Elias, 2014). The development of research in protected areas is extremely important because it is this research that supports the short-, medium- and long-term management plans for protected areas (Ferreira *et al.* 2021). In this study, we demonstrated the need to update and implement the actions foreseen in the Arthur Thomas Municipal Park Management Plan, since it was published in 2004 and already anticipated problems with overabundant populations of *Nasua nasua*.

CONCLUSION

With the results obtained in this study, we can affirm that the coati's population has a high density, probably because it receives energy inputs from anthropogenic actions and the absence of top predators. It is important to note that much of the study was carried out during the COVID-19 pandemic and, consequently, PMAT was closed to visitors. Subsequent studies should be conducted in the presence of visitors, as researchers have reported coatis foraging in garbage cans and interacting with visitors, when the park reopened doors. It is also recommended that garbage cans with lids be installed to prevent the fauna present from using garbage as a resource. In areas adjacent to the park, there are signs indicating the prohibition of feeding the fauna present in the park, but it is recommended that this be reinforced and implemented more actively, with direct communication with visitors and residents.

Although the habits of the coatis have been influenced by the anthropogenic matrix, they still follow the pattern expected for the species in natural habitats. To draw better conclusions on the habitat, use and seasonality of the coatis, it is recommended to update the floristic inventory of the PMAT and the phenology of the plant species present. Birth, mortality and dispersal studies are strongly recommended to better monitor the population. It is also necessary to update the management plan and, consequently, the survey of the mammalian fauna present in the park.

New studies using different methodologies could provide more complete data on the ecological aspects of the *Nasua nasua* population present in the PMAT. It is recommended that active capture methods such as tagging and recapture with retention traps that can be used to obtain parameters such as sex ratio and age classification. The increase in the coati population may affect other species of fauna and flora in the park, competing for resources and/or preying on other species, so it is recommended that studies be carried out on the ecological and population dynamics of the other species present in the park.

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