IRL REHABS CNRS, Nelson Mandela University
George, South-Africa

Influence of anthropogenic environments on the activity patterns and vigilance of Chacma Baboons (Papio ursinus) in South Africa

Master 2 internship report

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ABSTRACT

With the continuing expansion of urbanization into primates' natural habitats, it is crucial to understand how species adapt to these anthropogenic changes by observing the distribution of their behaviors. This study examined how the budget activity of three chacma baboon (Papio ursinus) troops varied between two sites with different levels of anthropization: the George campus of Nelson Mandela University, characterized as a peri-urban area (Madiba and North troops), and the Outeniqua Cape Nature Reserve, representing a more rural setting (Outeniqua troop). It also aimed to identify the environmental variables influencing baboon behaviour. In addition, the installation of a baboon monitor on the campus site made it possible to analyze the adaptation of their activity in the face of a direct intervention stimulus. The study, conducted from March to June 2024, accumulated 162.55 hours of observations and recorded 17,991 behaviors. The three troops showed different levels of adaptation to anthropization, with variations in habitat use and behaviors. The Outeniqua troop, considered the most natural, is distinguished by its low consumption of human food, its preference for moving through trees, a higher proportion of self-grooming and heightened vigilance. This suggests that the Madiba and North troops, more in contact with humans, have adjusted their behaviors. Analysis of environmental variables revealed that natural conditions (weather, habitat structure) are major factors influencing baboon activity, and that anthropogenic conditions add extra pressure, pushing them to adapt further. Finally, a comparison of monitor implementation showed that the North troop adjusted its vigilance and grooming behaviours, while the Madiba troop showed little variation. This study highlights the fact that human interventions can significantly alter primate behavior, either positively or negatively.

Key-words: *Chacma baboons*, activity budget, vigilance, anthropization

RESUME

Avec l'expansion continue de l'urbanisation vers les habitats naturels des primates, il est crucial de comprendre comment les espèces s'adaptent à ces changements anthropogéniques en observant la répartition de leurs comportements. Cette étude a examiné comment l'activité budget de trois troupes de babouins chacma (*Papio ursinus*) variait entre deux sites présentant différents niveaux d'anthropisation : le campus de George de l'Université Nelson Mandela, caractérisé comme une zone péri-urbaine (troupes de Madiba et North), et la réserve naturelle d'Outeniqua Cape Nature, représentant un milieu plus rural (troupe d'Outeniqua). Elle visait également à identifier les variables environnementales influençant les comportements des babouins. De plus, l'implantation d'un moniteur de babouins sur le site du campus a permis d'analyser l'adaptation de leur activité face à un stimulus d'intervention direct. L'étude, menée de mars à juin 2024, a cumulé 162,55 heures d'observations et recensé 17 991 comportements. Les trois troupes ont montré des niveaux d'adaptation différents à l'anthropisation, avec des variations dans l'utilisation de l'habitat et les comportements. La troupe d'Outeniqua, considérée comme la plus naturelle, se distingue par sa faible consommation d'aliments humains, sa préférence pour se déplacer dans les arbres, une proportion plus élevée de self-grooming et une vigilance accrue. Cela suggère que les troupes Madiba et North, plus en contact avec les humains, ont ajusté leurs comportements. L'analyse des variables environnementales a révélé que les conditions naturelles (météo, structure de l'habitat) sont des facteurs majeurs influençant l'activité des babouins, et que les conditions anthropiques ajoutent une pression supplémentaire, les poussant à s'adapter davantage. Enfin, la comparaison de l'implantation du moniteur a montré que la troupe North a ajusté ses comportements de vigilance et de grooming, tandis que la troupe Madiba n'a pas montré de grandes variations. Cette étude a permis de souligner que les interventions humaines peuvent significativement altérer le comportement des primates, de manière positive ou négative.

Mot-clés : *Chacma baboon,* activity budget, vigilance, anthropisation

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Preamble

IRL REHABS (International Research Laboratory – Resilient, Emerging, Adaptive, and Built Human-environment Systems) is a joint initiative between the CNRS (National Center for Scientific Research), Nelson Mandela University in South Africa, and the University of Lyon. Launched in 2019 at Nelson Mandela University's George Campus, this lab aims to explore the resilience and adaptation of social-ecological systems in the face of environmental and anthropogenic change. IRL REHABS focuses on interdisciplinary research to understand the complex relationship between humans and natural ecosystems. Research topics include the sustainability of multifunctional landscapes, the integration of biodiversity into livelihoods, and livestock management in harmony with environmental preservation. The project is designed to include not only scientists, but also citizens and local stakeholders, to promote inclusive and sustainable ecological governance.The laboratory also promotes the training and development of young researchers, mainly PhD students and postdoctoral fellows, and provides for research exchanges between France and South Africa. These initiatives contribute to the mutual recognition of PhD degrees between partner institutions and strengthen international collaborations in ecological research and sustainability.

All the data used in the report were collected during the 6-month internship period through 3 months spent in the field. This has made it possible to obtain a very large behavioural database providing a wide range of analyses, the entirety of which we have not been able to present in the report below. Specifically, the age-sex variable could have explained several variations in baboon behaviors as well as a more in-depth analysis of vigilance behaviors. Despite the preparation of the protocols beforehand, the phase of adaptation to the field to match a theoretical protocol to the reality of the field and the constraints we encountered delayed the start of data collection. The presence of the baboon was also a limiting factor, indeed it was sometimes possible not to have contact with them (especially for the Outeniqua troop) for several days or to see them disappear in the dense forest that I could not penetrate. The implementation of the baboon monitor on the campus site was not carried out by the laboratory and was therefore not planned in the time of data collection: this forced us to stop the data collection we had started and to start a new one. What we can note from this internship is that the large field phase carried out as well as the analysis of Boris videos (1 month) filled a very large part of the available time, leaving little time for statistical analysis and writing.

I- Introduction

Human activities expansion stands as the biggest driver of wildlife extinction, primarily through the modification, fragmentation, and loss of natural habitats and natural resources (Cowlishaw and Dunbar 2000; Mulder and Coppolillo 2005; Estrada and al., 2017; Vitousek and al., 1997;Tilman and al., 2017). The worldwide constant growth of anthropic areas is compelling an increasing number of species to adapt to highly anthropic environments (Achard and al., 2001; Muche and al., 2023). This process introduces new challenges requiring species to navigate and survive in habitats increasingly dominated by human activity (Hulme-Beaman and al., 2016). While some species, such as coyotes, raccoons, or mosquitoes, exhibit remarkable adaptability to these altered environments, others are susceptible to habitat fragmentation and natural resource loss, leading to significant population declines and possibly extinction (LaDeau and al., 2013; Murray & St. Clair, 2017; Prange and al., 2004). For example, species such as the African forest elephant (*Loxodonta cyclotis*) and the spotted owl (*Strix occidentalis*) have experienced noticeable population declines due to their reliance on large, contiguous habitats increasingly fragmented by human activities (Dugger and al., 2016; Maisels and al., 2013; Tempel and al., 2014). These species, characterized by slower life histories—longer lifespans, delayed reproduction, fewer offspring, and greater parental investment—are particularly vulnerable to anthropogenic changes. In contrast, generalist species with more rapid evolutionary potential, such as the red fox (*Vulpes vulpes*) and the rock pigeon (*Columba livia*), have successfully exploited new food sources and habitats provided by anthropic landscapes, allowing them to persist and even flourish despite extensive and intensive habitat modification (Bateman and Fleming, 2012; Carlen and al., 2021; Hetmański and al., 2011; Scholz and al., 2020). These generalist species have indeed the ability to survive in a wide range of environmental conditions and possess the genetic and reproductive backgrounds that allow them to adapt quickly to new or changing environments (Charmantier and Gienapp, 2014; Sih and al., 2016). This variability in wildlife responses to anthropization underscores, as global environmental changes continue to accelerate, the importance of gaining insight into the adaptive capacities of species is crucial to preserve biodiversity and ensure the survival of species in increasingly human-dominated landscapes.

Among wildlife species, non-human primates (NHPs) constitute a compelling case for studying how species adapt to anthropic environments due to their close evolutionary relationship with humans and their increasing presence in urban and peri-urban areas (Bersacola and al., 2023; McLennan and al., 2017, 2020). While the exploitation of human environment by NHPs offers certain advantages, such as highly nutritious and easily accessible food resources and reduced risk of predation, it also applies significant pressures that alter their natural behaviors. These pressures include shifts in dietary habits, with NHPs increasingly seeking out packaged or processed foods, as well as changes in exploratory behavior and activity budgets (Corrêa and al., 2018; Dhananjaya and al., 2022; Fehlmann and al., 2017; Kaplan and al., 2011.; Katlam and al., 2018; Kennedy Overton and al., 2024; Saj and al., 2001). Typically, Japanese macaques (*Macaca fuscata*) in Japan and chacma baboons (*Papio ursinus*) in South Africa have shifted their diets to include substantial amounts of human-provided food, such as processed items, bread and sweets (Hoffman and O'Riain, 2012; Kennedy Overton and al., 2024; Oi and al., 2021). In Bali, Indonesia, long-tailed macaques (*Macaca fascicularis*) have adapted to urban settings by actively exploring for food among tourists, including searching through bags and entering buildings (Riley and Fuentes, 2011). Similarly, olive baboons (*Papio anubis*) in Kenya, Barbary macaques (*Macaca sylvanus*) in Morocco, Vervet monkeys (*Chlorocebus pygerythrus*) in Uganda, and Bonnet macaques (*Macaca radiata*) in southern India have all exhibited shifts in their activity budgets. These primates spend more time near human settlements or agricultural areas, exploiting predictable food sources provided by humans, which reduces the time available for social interactions, grooming, and resting (Kumara and al., 2009; Novak and and., 2014; Sha and Hanya, 2013; Thatcher and al., 2020). Overall, these behavioral adaptations underline the profound impact of urbanization on primate ecology, and the growing need for shared territories between humans and wildlife. It therefore becomes essential to understand the possible negative consequences of anthropization on NHPs for their conservation (Almeida-Rocha and al., 2017).

Across sub-Saharan Africa, *Papio* is among the most successful and widely distributed primate genera, inhabiting a diverse range of habitats, climates, and latitudes (Henzi and Barrett, 2003). This extensive habitat occupancy is largely attributed to their remarkable adaptability, which includes a highly flexible omnivorous diet, complex and variable social organization, a high degree of behavioral plasticity, diverse mating systems, and both terrestrial and arboreal locomotory abilities (Alberts and Altmann, 2006; Else, 1991; Henzi and Barrett, 2003; Whiten and al., 1987; Whiten and al., 1991). Among the six species of the *Papio* genus, the chacma baboon, *Papio ursinus*, is found in a mosaic of natural and anthropogenic landscapes across southern Africa, showing its remarkable behavioral and ecological flexibility (Henzi and Barrett, 2003; Kansky and Gaynor, 2000; Whiten and al., 1987). On South Africa's west coast, these adaptive traits have enabled the chacma baboon's successful colonization of human-transformed environments. However, this adaptation to urban and peri-urban areas has become a significant source of conflict with local populations, as baboons increasingly include human-derived foods in their diet, such as agricultural produce, human food waste, or items looted from homes, farms, or picnic sites(Chowdhury and al., 2020; Hill, 2000.; Kennedy Overton and al., 2024). Although chacma baboons are legally protected by legislation

(Western Cape Nature Conservation 2000), the shift in their diet has led to increasingly negative interactions with humans, often resulting in serious injuries and fatalities due to poisoning or shooting in anthropic areas (Beamish and O'Riain, 2014). Several studies on chacma baboons have documented their exploitation of new food resources and alterations in the social organization within anthropogenic environments (S. P. Henzi and al., 2011; Lewis and O'Riain, 2017; Mazué and al., 2023; Pebsworth and al., 2012.). However, there has been limited research on the impact of anthropogenic environments on the activity budgets of different baboon troops across a gradient of habitat modification. This gap in the literature may be due to the logistical challenges of simultaneously tracking and observing several troops living in diverse environments. Understanding how chacma baboons and the Papio genus adapt their ecology and behavior in anthropized habitats is essential for fostering mutually beneficial coexistence.

This study seeks to address this gap by conducting a detailed analysis of the activity budget behaviors of chacma baboons across different anthropized environments. To achieve this, we employed scan sampling at 5-minute intervals over three months in George, a city located in the Garden Route region, South Africa, focusing on three distinct baboon troops: (i) the Outeniqua troop, residing in a predominantly natural, rural environment, (ii) the Madiba troop, situated on a peri-urban campus, and (iii) the North troop, inhabiting an environment that lies between rural and peri-urban settings (Fig. 1). This methodology allows for a detailed assessment of how these baboons allocate their time to key activities such as foraging, resting, movement, and social interactions. Due to frequent conflicts between baboons and humans on the campus that occurred during the present study, monitors were introduced after the first month of data collection in areas where the Madiba and North troops reside. These monitors employed non-lethal deterrents, including following the baboons on foot or bike and using sticks or paintball guns to discourage their presence near human dwellings. This setup enabled us to conduct a dual behavioral analysis of these two troops, comparing their activity budget before and after the presence of monitors. The primary objective of this study is to understand how the activity budgets of three groups of chacma baboons vary across environments with differing levels of human influence, to assess their behavioral responses to the presence of monitors, and our second objective is to evaluate their vigilance in these contexts. By addressing these questions, this research will enhance our understanding of the behavioral ecology of non-human primates in anthropogenic landscapes and contribute valuable insights for the development of effective conservation and conflict management strategies.

II- Materials and methods

1. Study area description

The present study was conducted in the Western Cape, South Africa, especially across the Garden Route Biosphere Reserve, an area of 2000km² between the cities of George and Knysna. The reserve, recognized by UNESCO's World Network of Biosphere Reserves (Pool-Stanvliet and Coetzer, 2020), is known for its rich biodiversity, including Afro-temperate forests, fynbos, wetlands, mountains, and coastal ecosystems. The region experiences a mean annual rainfall ranging from 800 to 1100 mm, with mild temperatures typically between 18 and 25 °C (Vromans, 2013). Despite its ecological significance, the landscape has been extensively altered by human activities, including agriculture, forestry, tourism, and urban development, particularly in urban areas like Mossel Bay, George, and Knysna (Socio-Economic Profile: Garden Route District Municipality, 2021). To safeguard this biodiversity hotspot, the Garden Route Biosphere Reserve was established, with the Garden Route National Park (GRNP) serving as its core, protecting vital natural areas that support biodiversity conservation. However, the landscape's complexity, featuring a mosaic of agriculture, logging, urban zones, and natural vegetation, has resulted in a highly fragmented and patchy IUCN Category II protected area (Mormile and Hill, 2017; Slater and al., 2018).

In this study, behavioral data on chacma baboons were collected across three locations, to compare different degrees of anthropization:(i) a peri-urban area within the George Campus of Nelson Mandela University, (ii) an intermediate area between the peri-urban Campus of Nelson Mandela University and agricultural zones, and (iii) a predominantly rural environment in Outeniqua Nature Reserve. These locations correspond hereafter to the Madiba, North, and Outeniqua troops. The Madiba troop inhabits mainly the George Campus of Nelson Mandela University (-33.96061, 22.53384) (Fig. 1a, red square), an area covering approximately 400 hectares, which includes a mix of natural and developed spaces, such as student housing, academic buildings, cafeterias, roads, lawns, and surrounding natural forest, fynbos and pine plantations (Fig. 1a, orange and red symbol). The North troop also occupies parts of the George Campus but extends its range into adjacent agricultural lands, reflecting a gradient between urban and rural environments (Fig. 1a, light and dark blue symbol). The Outeniqua troop is located in the Outeniqua Nature Reserve (-33.94097, 22.42499) (Fig. 1a, purple square), covering about 38,000 hectares. This rural area is characterized by expansive fynbos, large tracts of native forests and pine plantations, with minimal human infrastructure, limited to occasional buildings such as accommodation and park facilities (Fig. 1a, purple symbol).

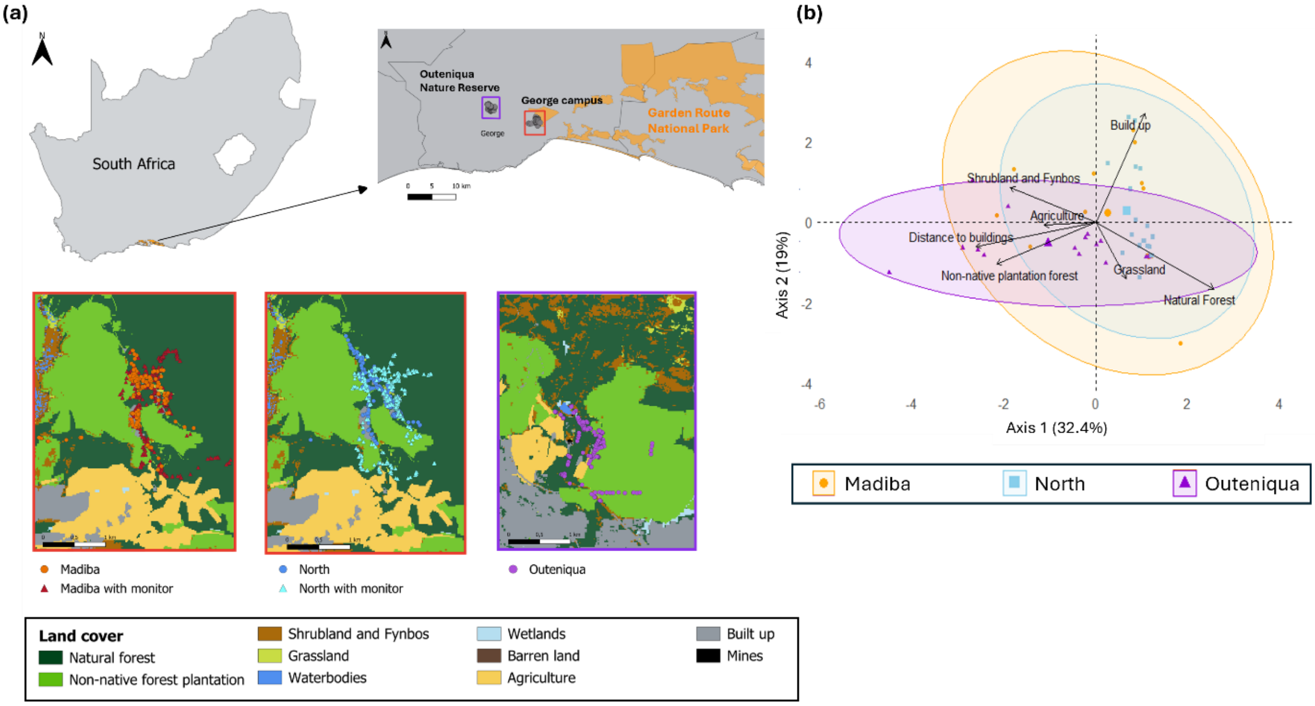

Figure 1. (a) Study area and scan records in the Garden Route, Western Cape, South Africa. The top left map displays the study site within the Garden Route region of South Africa. The top right map highlights the specific locations within the Outeniqua Nature Reserve and the George Campus of Nelson Mandela University. Enlarged views of each location show the landscape composition and the GPS points where all scans were recorded during the study for the three baboon troops monitored (Madiba in orange, Madiba with monitors in red, North in dark blue, North with monitors in light blue and Outeniqua in purple). Source: SANLC, 2020 - EPSG 32734. **(b) Principal component analysis (PCA) of land cover variables for each chacma baboon troop.** The PCA plot (PC1 vs. PC2) illustrates the distribution of land cover variables with GPS points recorded per half-day for the three troops, Madiba (orange points), North (blue points), and Outeniqua (purple points).

2. *Landscape characterization of each study site*

To characterize the landscape in the area used by the baboons, an estimation of each group's home range size was made using GPS points recorded during each scan of the groups. The approximate home range area was estimated during each study period using the furthest points that the group traveled to in all directions. During this study, the home range of the Madiba troop was 155.9 ha and that of North troop 162.3 ha, rising to 236.1 ha for the M-Madiba troop and 221.3 ha for the M-North troop after the baboon monitor implementation, finally the one of the Outeniqua troop was 164.5 ha, The study area represented using QGIS (3.34.11), under a WGS 84 – UTM 34S projection, was characterized according to the land cover metric and the distance to building, following (Kennedy

Overton and al., 2024). To characterize the land cover within the study area, we utilized a raster layer obtained from the South African National Land Cover Datasets (2018), available through the Department of Forestry, Fisheries, and the Environment (DEFE, 2021). The original dataset included 73 distinct land cover classes, which were subsequently consolidated into 10 broader categories for analysis: natural forest, non-native forest plantations (i.e. often large pine plantation), shrubland, grassland, waterbodies, wetlands, barren land, cultivated land (i.e. any land used for growing crops, whether it's monoculture or mixed), built-up areas, and mines. The building layer specific to the study area was generated through geoprocessing techniques using QGIS software (Rosas-Chavoya and al., 2022). Within the study area, land cover percentages, as well as the closest distance from a GPS point to a building, were calculated for each sample buffer using the zonal statistics plugin in QGIS. To reduce multicollinearity, variables with a correlation coefficient greater than 0.8 were excluded from the analysis. Subsequently, a principal component analysis (PCA) based on the habitats in which each GPS point was located, has been conducted to visualize the distribution of the three troops and their land use to identify similarities and differences between them (Fig. 1b).

3. ***Baboon troops description***

The identification of individuals by age and sex followed the classification criteria outlined by (Wallace and Hill, 2012). Baboons were categorized into four groups: adult males and adult females, identified by their full species-specific and sex-specific size; subadults, which are not fully grown but have surpassed infant development, frequently exhibiting independent behavior (sex not determined); and juveniles, characterized by their smaller size, dependency on adults, and proximity to them (sex not determined). The Outeniqua troop comprises 20 individuals, including 12 adult females, 1 subadult, and 7 juveniles, with no adult males present. The North troop consists of 22 individuals, including 3 adult males, 6 adult females, 5 subadults, and 8 juveniles. Lastly, the Madiba troop, the smallest of the three, includes 13 individuals: 1 adult male, 3 adult females, 2 subadults, and 7 juveniles. Detailed demographic information for each of the studied troops is provided in Table 1.

Table 1. Demographics of the chacma baboons by habitat. The numbers could vary due to immigration, emigrations, births, and deaths during observation. All individuals observed for the study are included in this table.

Age-sex class	Outeniqua	Madiba	North
Adult male	0	1	3
Adult female	12	3	6
Subadult	1	2	5
Juvenile	7	7	8
Total	20	13	22

4. Behavioral sampling methodology for activty budget

The behavioral observations of chacma baboons were conducted daily, following the ethical guidelines for the treatment of animals in behavioral research and teaching (Guidelines for the Use of Animals, 2012). Data collection occurred from March 25th to June 26th, 2024, covering 47 days. Observations were carried out from 8:00 am-12:00 am and 13:00-17:00 each day, with each troop observed for an average of 16 days. The minimum time of observation per half-day with any given troop was 5 minutes, and the maximum was extended to 4 hours. Behavioral data were collected using scan sampling methods as described by (J. Altmann, 1974). The baboons were observed on foot ensuring minimal disturbance to their natural behavior. The troops being followed were already accustomed to it.

Every 5 minutes, we conducted video scans using a Canon camera (Canon SX70 powershot HS) during which we noted various parameters: their GPS location (using Map Marker 3.9.0_723), the distance of the observer to the nearest baboon (measured with a Voyager laser rangefinder), the habitat structure (categorized as open or closed), the weather (sunny, cloudy), and the presence of humans or cars within a 50m radius of the baboon. We also noted the structural configuration of the group at each scan, categorizing them as "grouped" (all individuals within 5 meters of each other), "subgroup" (individuals within 5 meters of each other in the same subgroup but distant by more than 5 meters from another subgroup), or "dispersed" (all individuals more than 5 meters apart). The video scans were randomly performed on all visible individuals, with each scan lasting approximately 1.30 minutes.

5. *Study period*

At the beginning of the study, the two baboon troops located on campus (Madiba and North) were not subject to any management interventions for four weeks (March 25th to April 26th). This initial phase allowed for the observation of natural baboon behavior without external influences. However, due to increasing conflicts between baboons and humans on campus, including incidents of baboons breaking into housing and stealing food from students, management measures were subsequently implemented. Monitors were employed to mitigate these conflicts by following the chacma baboons on foot or by bike and using non-lethal deterrents, such as sticks or paintball guns, to keep the baboons away from the campus and residential areas. For this reason, during the study, behavioral data were collected in two distinct phases for the Madiba and North troops: the first month without any management intervention and the subsequent period with active monitoring (April 29th to June 26th). This design enabled the comparison of baboon behavior in the absence and presence of monitors. For the purposes of this study, data collected from the Madiba and North troops during the unmanaged phase are referred to as Madiba (M) and North (N), respectively. Data collected during the managed phase, with monitors present, are designated as M-Madiba (M.mnt) and M-North (N.mnt). This classification facilitates a comparative analysis of baboon behavior under different management conditions. The Outeniqua troop (O), which was located in a more rural setting, remained unmanaged throughout the study period and is consistently referred to as the Outeniqua troop (O) in all analyses.

6. *Behavioral video records analysis*

Following data collection, all recorded scans were manually reviewed and analyzed using the BORIS software program (Friard and Gamba, 2016). This analysis was based on an ethogram specifically developed for this study, which categorizes behaviors into seven distinct groups: "affiliation" (i.e., positive social interactions including grooming, playing, lipsmacking or geckering), "agonistic" (i.e., any form of aggressive physical contact, gesture or vocalization), "feeding" (i.e., foraging, manipulating, or ingestion of food, with the type of the food resource as natural or human-modified), "locomotion" (i.e., all forms of movement, including walking, running, and flight responses), "resting" (i.e., when remaining in one location, inactive, lying down or asleep), "sexual" (i.e., anogenital presentation and mounting) and "vigilance" (i.e., distributed according to four levels of vigilance, Vig0: slow glance with a passive position and routine scan; Vig1: repeated glances with a passive position and intense scanning; Vig2: individual on these four legs with an active position and routine scan; Vig3: individual on these two hind legs achieving a quick glance from both sides with an active and intense stance). We then created subcategories from these categories to provide more details on general behaviors, such as the type of food ingested for feeding, the type of locomotion performed, walking, running, fleeing, or the type of vigilance exhibited. The comprehensive ethogram used for this analysis is provided in Supplementary Table S1.

7. *Statistical analysis to characterize chacma baboon's activity*

Data normality and homoscedasticity were assessed using the Shapiro-Wilk and Levene tests, respectively. The Shapiro-Wilk test was used to evaluate the normality of the data, while the Levene test was employed to assess the equality of variances (homoscedasticity). Both tests were conducted in RStudio (version 4.1.2) using the shapiro.test and leveneTest functions from the stats and car packages, respectively (Fox, 2007). A significance level of $p \leq 0.05$ was applied to determine statistical significance. Given that the data did not meet the assumptions for parametric tests, non-parametric Kruskal-Wallis tests were performed to compare behaviors of chacma baboons. The kruskal.test function in R was used for this purpose. The Kruskal-Wallis test is a rank-based non-parametric test that allows for the comparison of more than two groups. The relative frequency of each behavior was calculated by dividing the total frequency by the total number of observed behaviors within the relevant category. First, a Kruskal-Wallis test was conducted to compare the overall distribution of behaviors across the three baboon troops (Outeniqua, Madiba, and North). This analysis provided a global perspective on behavioral differences across the troops. Then separate Kruskal-Wallis tests were conducted to compare the distribution of behaviors during the morning and afternoon periods. This analysis aimed to identify any temporal variations in behaviors. Finally, for each specific behavior, a Kruskal-Wallis test was performed to compare how that behavior differed between the three troops. This analysis was used to highlight troop-specific behavioral patterns. To get a clear visual representation of the distribution of behaviors in the dataset, histograms were generated. These histograms were generated to visualize the percentage of records for each behavior across the three troops, between day periods (morning and afternoon) and between troops.

8. *Modeling the impact of environmental factors on chacma baboon's activity*

To get a comprehensive assessment of the relationship between environmental factors and baboon activities, we use a combination of several approaches, a multinomial logistic regression, a residual analysis, and p-value visualization. First, a multinomial logistic regression analysis was performed to investigate the impact of environmental variables (Habitat, Weather, and Cars) on various baboon activities. The analysis was conducted using the "nnet" package in R (Ripley, 2016), specifically utilizing the multinom function to model the categorical outcome variable representing baboon activities, which included categories such as Affiliation, Agonistic, Feeding, Locomotion, Resting, Sexual, and Vigilance. Initially, a baseline model was fitted without interaction terms, including the predictors Habitat, Weather, Cars, and Troup (representing different baboon troops). To capture potential interaction effects, a second model was developed incorporating specific interaction terms between Weather and Habitat, and Weather and Cars. The Akaike Information Criterion (AIC) was used to compare model performance, with lower AIC values indicating a better balance between model fit and complexity (Akaike, 1974). Then the residuals from the multinomial logistic regression model were analyzed to assess the model's goodness-of-fit. Residuals were extracted using the residuals function, and their distribution was visualized in boxplots to examine the residuals by activity category. These analyses were performed to identify any systematic patterns or outliers that might indicate model misspecification or areas where the model's predictive accuracy could be improved. Given the nature of multinomial logistic regression, the model inherently compares each behavior to a chosen reference category. To obtain a comprehensive understanding of the influence of the predictors across all behaviors, we systematically re-ran the model, changing the reference category in each iteration. This approach allowed us to derive p-values for all behaviors relative to each other, ensuring a complete analysis. The p-values obtained from each iteration were compiled to provide a complete set of p-values for each behavior relative to all others. This method ensured that the significance of all behaviors could be assessed comprehensively. Using a method like Fisher's or Stouffer's, we combined the individual p-values obtained from the different reference models into a single p-value for each behavior. Finally, a dot plot was generated to visualize the p-values of the predictors (Habitat, Weather and Cars) across the different baboon activities. The plot was created using the ggplot2 package in R, with p-values plotted on the y-axis and predictors on the x-axis. The geom_point function was used to represent each activity by color-coded points, and a red dashed line was added at $p = 0.05$ to indicate the significance threshold.

9. *Statistical analysis comparing chacma baboon's activity with and without monitors*

We followed the same method as explained in the point 7, for statistical testing of global activity for the verification of normality and homoscedasticity of the data. As assumptions were not verified, we performed the non-parametric Kruskal-Wallis test for the following comparisons. The method to obtain the relative frequency was also identical, this time considering the Madiba and North troops with and without baboon monitor. These tests will allow us to have a view on the possible behavioral differences of the baboons following the implementation of a baboon monitor.

10. *Ethics*

This study exclusively employed non-invasive methods, ensuring that we always maintained a minimum distance of 50 meters from the chacma baboons. The research was conducted with full ethical approval from the Animal Ethics Committee of Nelson Mandela University (permit 0544) and Cape Nature (permit CN44-87-28483). Furthermore, the study adhered to the International Primatological Society's Code of Best Practices for Field Primatology, ensuring the highest standards of animal welfare and ethical research.

III- Results

1. Landscape and anthropization level characterization of each troop

The analysis reveals distinct patterns in habitat use among the three baboon troops (Fig. 1a.). The Madiba troop is primarily concentrated in "build-up" and "shrubland and fynbos", with some spread towards the natural forest, indicating a diverse range of habitat uses. In contrast, the North troop predominantly occupies grassland and natural forest habitats, with some use of build-up areas, reflecting a balance between anthropized and natural environments. The Outeniqua troop shows a strong association with plantation forests and cultivated habitats, maintaining a greater distance from built-up habitats, although its home range remains broad. The results obtained in the PCA showed that the Madiba troop is closest to anthropized structures, followed by the North troop, while the Outeniqua troop has the greatest average distance from buildings. (Fig. 1b). This spatial distribution underscores the differing levels of habitat anthropization, and preferences among the troops: the Madiba troop favors proximity to buildings, the North troop shows intermediate use of both anthropized and natural habitats, and the Outeniqua troop largely avoids built-up areas, favoring more natural and cultivated habitats, that are less disturbed environments.

2. Behavioral scans collected

During the study period, a total of 162.55 hours of observation were conducted, yielding 17,991 behavioral scans across all troops. Specifically, we recorded 23.40 hours for the Madiba troop, 26.30 hours for the North troop, 31.45 hours for the Outeniqua troop, 41.05 hours for the M-Madiba troop, and 39.55 hours for the M-North troop (Table 2). The detailed breakdown of behavioral scans recorded during morning and afternoon observation periods across the different troops is provided in Table 2. The implementation of baboon monitors is associated with an increase in the observation hours and subsequent scan counts for both the M-Madiba and M-North troops, with scan totals of 3,999 and 4,509, respectively. These scans allowed for a more detailed analysis of the behavioral adaptations of these troops to human presence and deterrence measures.

Table 2. ***Number of behavioral scans recorded during morning and afternoon observation periods for each troop, through the 47 days of this study.*** Data collected during the managed phase, with monitors present, are designated as M-Madiba and M-North.

Troops	Outeniqua	Madiba	North	M-Madiba	M-North
Morning	1,491	7,20	1,377	2,231	1,940
Afternoon	2,926	1,367	1,601	1,768	2,569
Total	4,417	2,087	2,978	3,999	4,509

3. *Activity budget patterns of chacma baboons troops*

3.1. Activity budgets of chacma baboons: global, per day period and per troop

Results showed that the behavioral data were not following a normal distribution (statistic W=0.9653; p=5.24^{-05}), so Kruskal-Wallis tests were performed for all the following analysis. From a global perspective, across the three main troops (Madiba, North, and Outeniqua), results did not show any significant differences between behaviors of chacma baboons, except for the feeding who is significantly more important than the resting (feeding-resting: z=3.1056, p=0.0199). Despite such a result between the other global activities, some tendencies are observable: feeding emerged as the most dominant activity, accounting for 28.8% of the recorded behaviors (n = 2.732). This was followed by vigilance (20.5%, n = 1.940), affiliative interactions (17.7%, n = 1.676), locomotion (17.2%, n = 1.630), and resting (14.8%, n = 1.408). Sexual (0.8%, n = 73) and agonistic (0.2%, n = 23) behaviors were observed less frequently (Fig. 2.a).

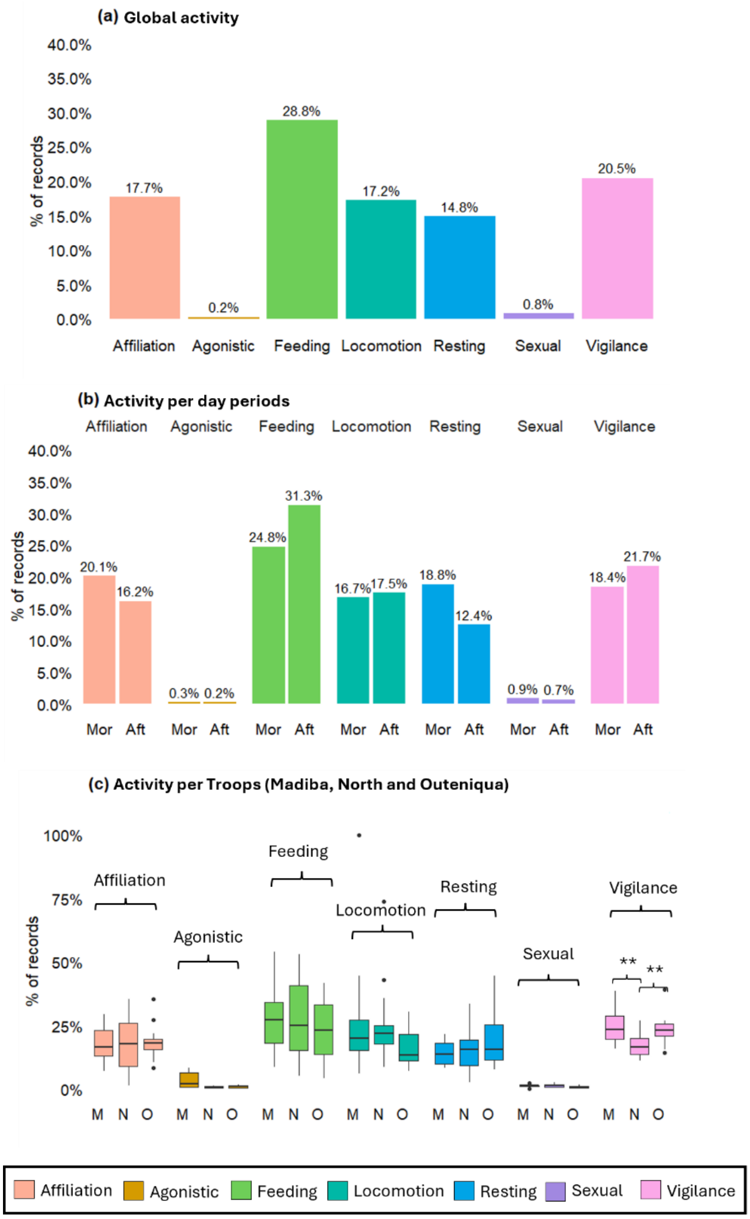

Figure 2. Proportions of behavioral categories in the global activity budgets of three chacma baboon troops. Madiba (M), North (N), Outeniqua (O). (a) The figure displays the percentage distribution of different behavioral categories across the activity budgets of the three troops; (b) The percentage distribution of different behavioral categories across the activity budgets of the three troops within day periods, morning (Mor) and afternoon (Aft) respectively. (c) The percentage distribution of different behavioral categories between the three troops: boxes represent the interquartile ranges; horizontal lines within the boxes represent the medians; whiskers indicate the minimum and maximum values. Significant Kruskal-Wallis followed by Dunn's tests significant are represented by "**"; $p \leq 0.05$.

As the data used in the following tests do not follow a normal distribution (statistic W=0.9041, p= 5.17^{-12}), we also performed Kruskal-Wallis tests for the comparison of each activity category between the three troops. The analysis revealed no significant differences in most behavioral activities between the troops. However, significant differences were observed in vigilance behavior among the troops. Madiba and North troops exhibited higher levels of locomotion (M: 18%, N: 21.9%; O: 13.7%) compared to the Outeniqua troop. Conversely, the Outeniqua and Madiba troops were engaged in more affiliative interactions (M: 18.8%; N: 15.5%; O: 18.7%) than the North troop. The activities with the lowest recorded levels across all troops were agonistic (M: 0.6%; N: 0.2%; O: 0.1%) and sexual behaviors (M: 0.8%; N: 0.8%; O: 0.7%). However, no significant differences were found among the three groups in terms of feeding ($H = 0.6566$; $df = 2$; $p = 0.7202$), resting ($H = 0.7665$; $df = 2$; $p = 0.6816$), affiliation ($H = 0.8651$; $df = 2$; $p = 0.6488$), agonistic behaviors ($H = 1.6538$; $df = 2$; $p = 0.4374$), locomotion ($H = 5.5994$; $df = 2$; $p = 0.0608$), or sexual behaviors ($H = 2.5636$; $df = 2$; $p = 0.2775$). The only significant difference observed was in vigilance behavior, with the Madiba and Outeniqua troops showing significantly higher vigilance than the North troop (M: 20.7%; N: 17.1%; O: 22.5%) (M-N: $z = 3.3818$; $p = 0.0010$; N-O: $z = -2.7756$; $p = 0.0082$; M-O: $z = 0.5804$; $p = 0.8424$) (Fig 2c).

3.2. Variation in activity budgets between each behavioral sub-category and each troop

Differences in activity budgets among the three baboon troops were observed across various behavioral sub-categories, with the Outeniqua troop showing significant differences with one of the Madiba or North troops or with both depending on the behavioral subcategory considered. The Outeniqua troop appears to rely significantly less on human-derived food compared to the Madiba troop (M-O: $z = 2.4602$, $p = 0.0282$) (Fig. 3a). Regarding modes of travel, the Outeniqua troop engages significantly in more climbing compared to the Madiba troop (M-O: $z = -2.1822$, $p = 0.0436$)

(Fig. 3b) and uses running significantly less frequently as a mode of travel compared to both the Madiba (M-O: $z = 3.4772$, $p = 0.007$) and North troops (N-O: $z = 2.5947$, $p = 0.0142$) (Fig. 3c). Additionally, the Outeniqua troop demonstrates a significantly higher level of self-grooming than the North troop (N-O: $z = -2.7081$, $p = 0.0101$) (Fig. 3d). The Outeniqua and Madiba troops exhibit similar proportions of the third level of vigilance (active posture and intense vigilance), with the Outeniqua troop showing a significantly higher engagement in this behavior compared to the North troop (M-O: $z = 3.3690$, $p = 0.0011$; N-O: $z = 2.3789$, $p = 0.0260$) (Fig. 3e). No significant differences were detected in the proportion of natural food usage among the three troops ($H = 0.6161$, $df = 2$, $p = 0.7349$), nor in any sub-category of affiliative interactions (e.g., grooming, social play, lips-making).

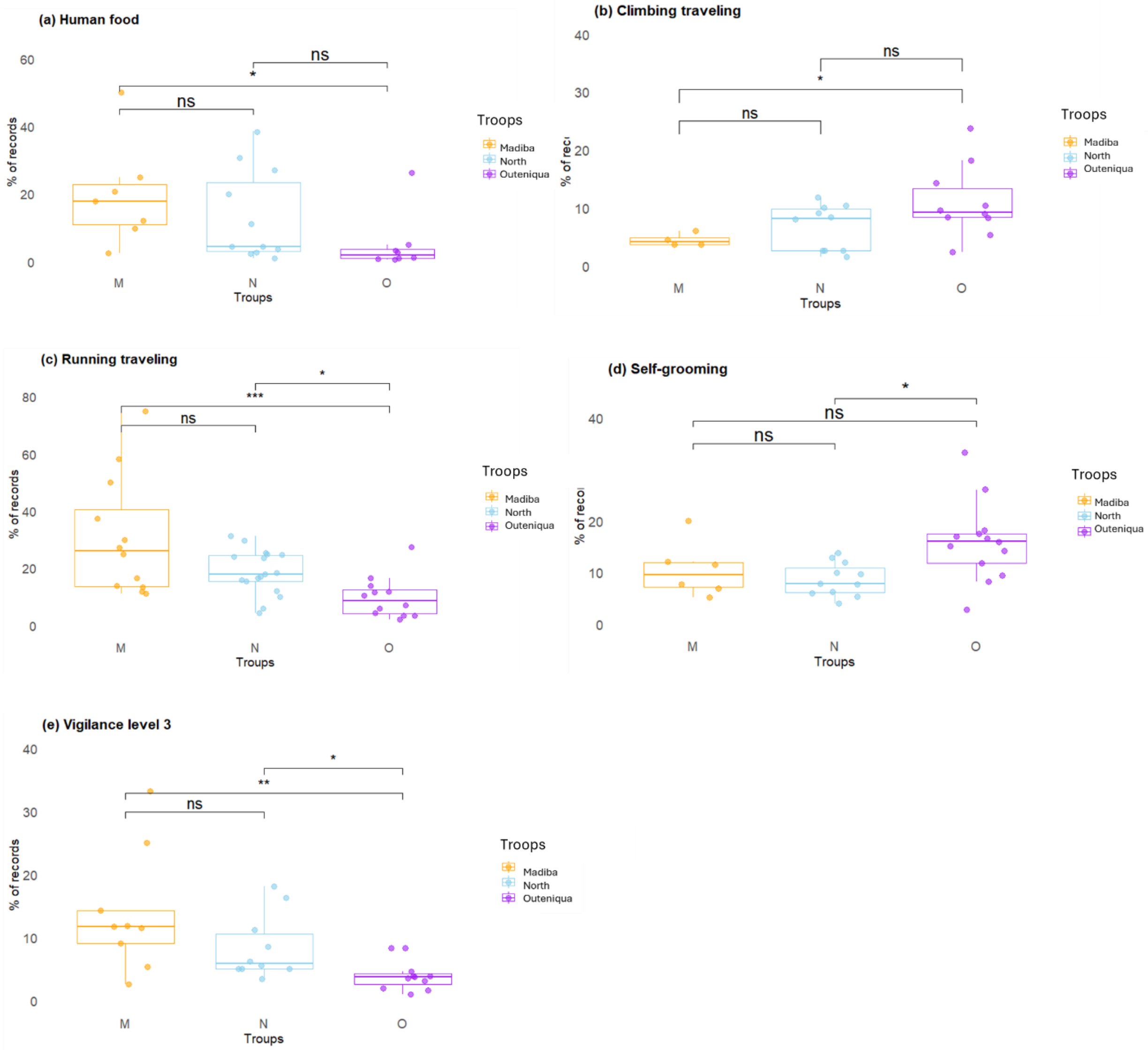

Figure 3. Proportions of records (in percentage) of each behavioral subcategory in the activity budget of the three troops of chacma baboons. Boxes represent the interquartile ranges; horizontal lines within the boxes represent the medians; whiskers indicate minimum and maximum values. Significant results from the Kruskal-Wallis test followed by the Dunn test are indicated by the significance stars; $p<0{,}005$. (M) Madiba troop, (N) North troop and (O) Outeniqua troop. Proportions concerned records per half-day: (a) Human food; (b) Climbing locomotion; (c) Running locomotion; (d) self-grooming; (e) Third level of vigilance.

3.3. Habitat, weather cars and humans as drivers of activity budgets of chacma baboons in different anthropic environments

We selected weather, habitat structure (open or closed), the presence of cars and finally the presence of humans as variables to characterize the study site environment. The correlation between variables was first tested for the categorical variables “weather” and “habitat structure” using the Chi² test, which showed no correlation between these two variables ($x^2=1.103$, df=1, $p=0.2936$). Secondly, we tested the correlation between the binary variables “car” and “human” using the Phi test, which revealed a positive correlation between these two variables ($\Phi=0.73$). Given this result, we decided to consider only the “car” variable for further analysis. In addition, agonistic and sexual behaviors were extracted from the model because they were too low in number of occurrences compared to other behaviors (Affiliation: n=1676; Agonistic: n=23; Feeding: n=2732; Locomotion: n=1630; Resting: n=1408; Sexual: n=73; Vigilance: n=1940).

From the visual analysis of the following behaviors, we note a slight difference in affiliation (Open=17.4%, Close=20.6%), locomotion (Open=16.9%, Close=20.1%) and resting (Open=14.2%, Close=21.7%), which seem to be performed more in closed environments, with, conversely, more feeding (Open=29.7%, Close=19.5%) and vigilance (Open=20.8%, Close=17.2%) behaviors in open environments (Fig 4a). With regard to the other two variables, i.e. weather and the presence of cars, we did not observe a large visual variation in the activity budget at first sight (Fig 4b and 4c).

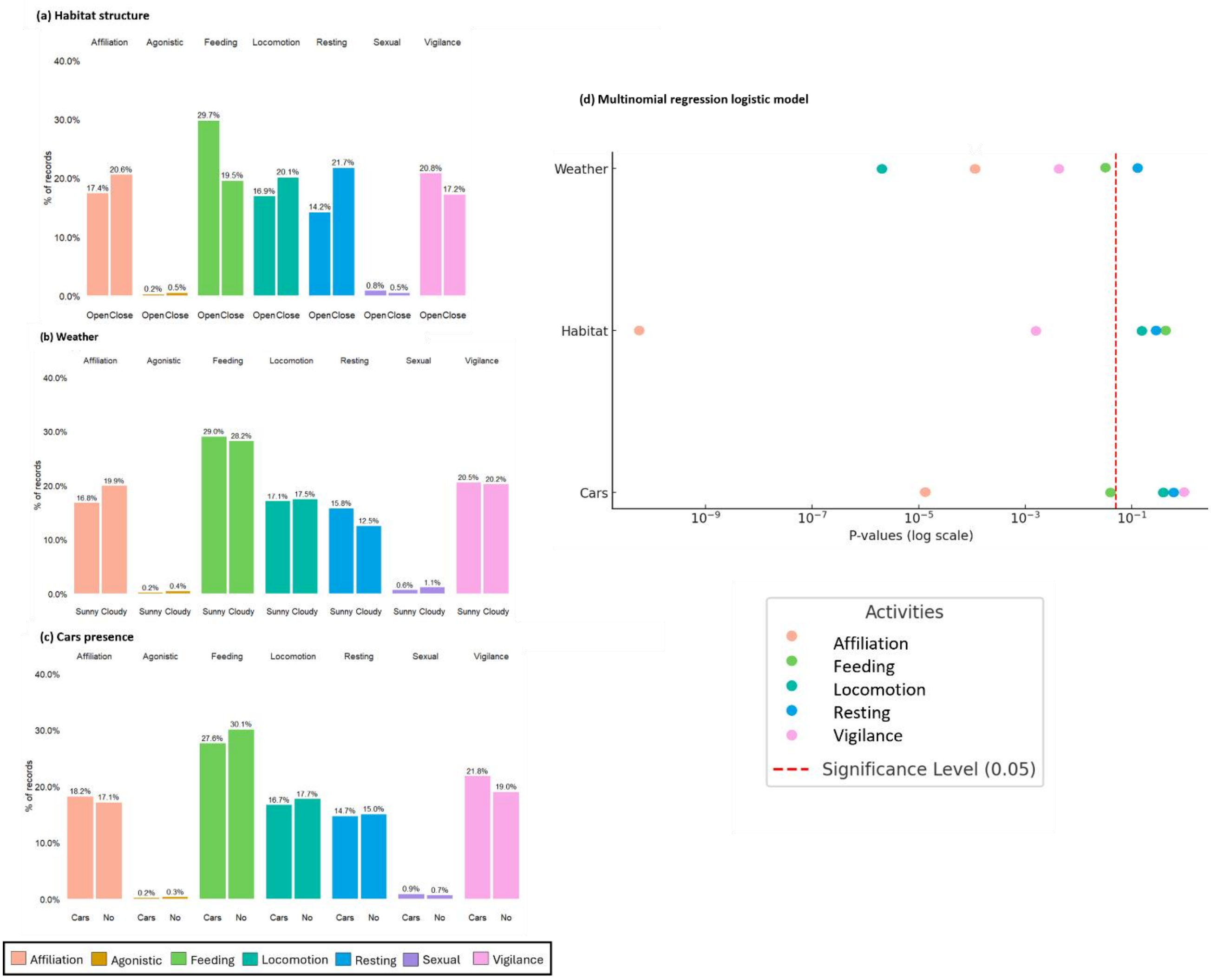

Figure 4. Proportions of behavioral categories in the global activity budgets of three chacma baboon troops according to environmental variables (Weather, Habitat and Cars). Madiba (M), North (N), Outeniqua (O). Activity budget distributed by (a) Habitat structure: Open /Close. (b) Meteorological conditions: Sunny/Cloudy. (c) Presence of cars; ***(d) Graphical representation of the multinomial regression logistic model with the five respective activities: Affiliation, Feeding, Locomotion, Resting and Vigilance.*** Significant level p<0.005 is indicated with the red line.

The performance of the multinomial logistic regression made it possible to identify a significant effect of environmental variables on the different categories of baboon behaviors. Social behaviors such as affiliative interactions seem to be the first to be impacted by the three environmental variables, suggesting that this will be the first behavior that baboons will tend to adapt during a change in environmental conditions (Fig 4d). The opening or closing of the habitat seems to play a crucial role in determining the behaviors of affiliation (coeff= 0.7769, p=5.72e-11) and vigilance (coeff= 0.3933, p=0.0015), indicating that baboons adapt their social interactions and vigilance in relation to the structure of their environment. The presence of cars mainly affects affiliative (coeff= -0.2854, p=1.3908) and feeding (coeff= -0.1505, p=0.0423) behaviors, highlighting the real impact that human presence can have on the activity budget of baboons living near urban areas. Weather seems to play role in most baboon behavior patterns, particularly locomotion (coeff= 0.3935, p=1.9734e-06) and vigilance (coeff= 0.2107, p=0.0042), suggesting that weather conditions are very important in determining how baboons allocate their time and energy (Table 3). The assessment of the quality of the model's fit was verified using the residue study (Supplementary Table S2). The model residuals have a median close to zero, suggesting that the model's predictions are accurate on average. The low dispersion of residues in the box (IQR) indicates that the majority of residues are close to the median, reflecting a good overall fit of the model. Although whiskers cover most of the residue, some outliers are present. The Akaike Information Criterion (AIC) for the multinomial logistic regression model is approximately 30767.74.

Table 3. Results of the multinomial logistic regression model of baboon activity budget according to the three environmental variables (Habitat, Cars and Weather). The green characters indicate a significant pvalue<0.005.

Behavior	**Predictor**	**Coefficient**	**Std. Error**	**z-value**	**P-value**
Affiliation	Habitat	0.77695737	0.11806017	6.5507194	5.73E-11
Affiliation	Cars	-0.28542633	0.06585829	-4.3435034	1.39E-05
Affiliation	Weather	0.24366133	0.0649874	3.8580755	0.00011495
Feeding	Habitat	0.09939575	0.10276975	0.9672383	0.40784699
Feeding	Cars	-0.15056416	0.07416289	-2.0297956	0.04237724
Feeding	Weather	0.16068243	0.07660237	2.1660675	0.03046249
Moving	Habitat	-0.17050738	0.10255274	-1.4172217	0.15677559
Moving	Cars	-0.06265856	0.07709296	-0.8124415	0.42115994
Moving	Weather	0.39267694	0.08247637	4.7561522	1.38E-06
Resting	Habitat	0.5496452	0.10413117	5.2782971	1.29824466
Resting	Cars	0.14585835	0.25345652	0.5741054	0.56569011
Resting	Weather	-0.33487566	0.07461287	-4.4877415	7.24E-06
Vigilance	Habitat	0.39238559	0.13505478	2.9062524	0.00367192
Vigilance	Cars	-0.00582135	0.01704458	-0.15611675	0.90179453
Vigilance	Weather	0.21070965	0.07361589	2.8622834	0.00462096

4. Evolution in activity budgets of troops facing monitoring

The introduction of the baboon monitor has led to significant behavioral changes in the North troop, particularly an increase in overall vigilance (N-N.mnt: $z = -4.6614$; $p = 9.42 \times 10^{-6}$) (Fig. 5b). In contrast, no significant behavioral shifts were detected in the Madiba troop (Fig. 5a). Further analysis of behavioral subcategories revealed distinct changes within each troop.

The North troop exhibited a significant increase in self-grooming activity (N-N.mnt: $z = -2.5372$; $p = 0.0335$) (Fig. 5c), while the Madiba troop showed a significant rise in fleeing from humans (M-M.mnt: $z = -2.4960$; $p = 0.0376$) (Fig. 5d) when the monitor was present. The analysis of the vigilance levels (Vig0, Vig1, Vig2, and Vig3) revealed nuanced shifts within the North troop. There was a notable increase in the first level of vigilance (N-N.mnt: $z = -2.8919$; $p = 0.0114$) and a corresponding decrease in the third level of vigilance (N-N.mnt: $z = 3.0264$; $p = 0.0074$) (Fig. 5e). Conversely, the Madiba troop displayed a significant decrease in the second level of vigilance (M-M.mnt: $z = 2.4180$; $p = 0.0466$) (Fig. 5f).

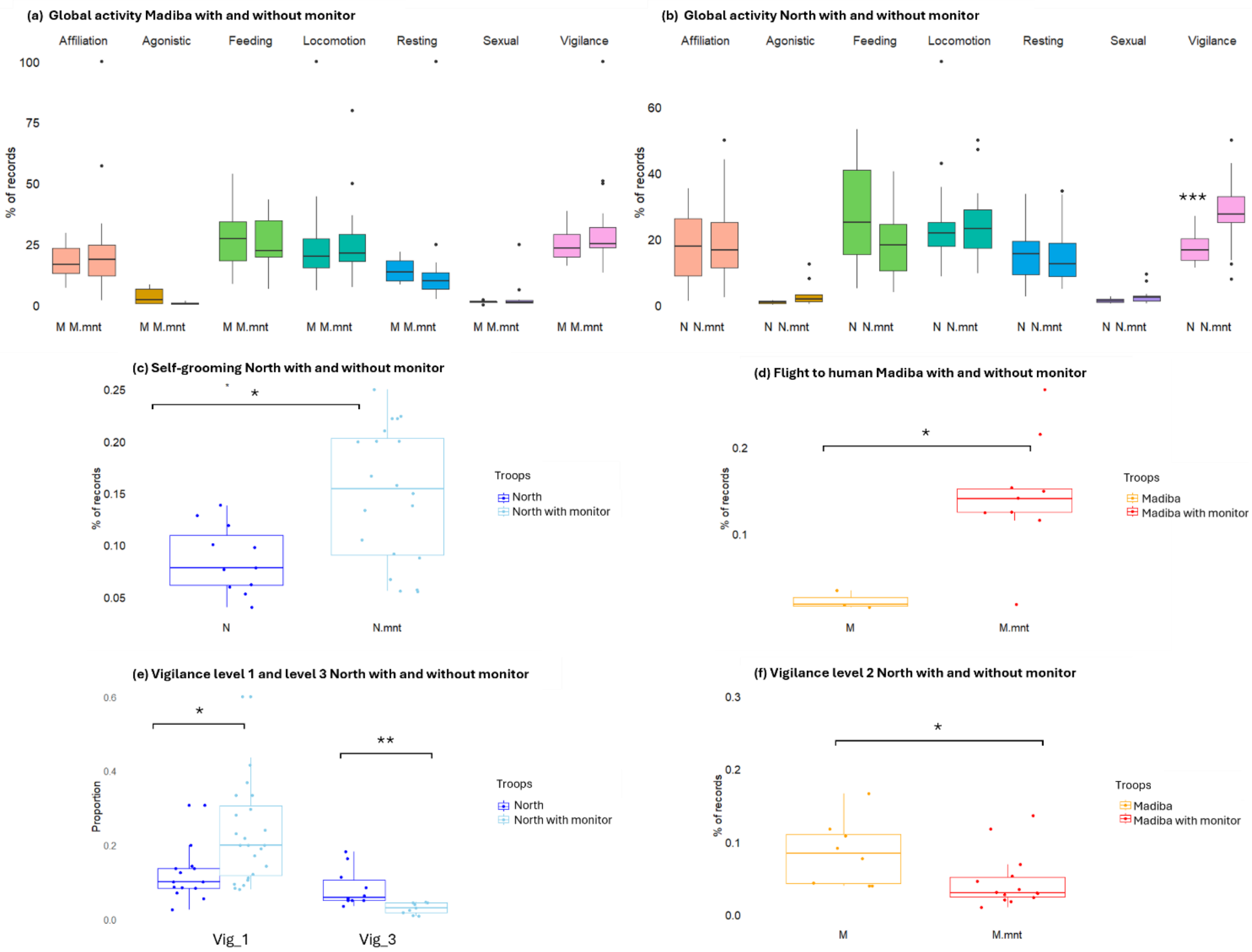

Figure 5: Proportion of behavioral categories and each subcategory in the activity of two chacma baboon troops with and without baboon monitors. Madiba (M), Madiba with monitor (M.mnt), North (N), North with monitor (N.mnt). (a) Percentage distribution of different behavioral categories across the activity budget of the Madiba troop with/without. (b)For the North troop with/without. (c) Self-grooming behavior distribution and (e) the first and third level of vigilance for the North troop with/without. (d)The flight to human behavior distribution and (f) The second level of vigilance for the Madiba troop with/without: boxes represent the interquartile ranges; horizontal lines within the boxes represent the medians; whiskers indicate the minimum and maximum values. Significant Kruskal-Wallis followed by Dunn's tests significant are represented by "**"; $p \leq 0.05$.

IV- Discussion

Chacma baboons (*Papio ursinus*) are known for their remarkable adaptability, allowing them to thrive in a wide range of environments across southern Africa, from arid savannas to coastal forests (P. Henzi and Barrett, 2003; Whiten and al., 1987). This adaptability is supported by their omnivorous diet, complex social structures, and behavioral flexibility, which enable them to exploit a variety of resources and habitats (Altmann and Muruthi, 1988). However, as human activities increasingly encroach upon their habitats, these non-human primates are forced to adapt to the challenges of living in close proximity to human settlements, leading to significant changes in their behavior and ecology (Hill, 2000.; Hoffman and O'Riain, 2012). In particular, urbanization and agricultural expansion have introduced new pressures, such as increased human-baboon conflicts and reduced access to natural food sources, compelling baboons to modify their foraging strategies and activity patterns (Fehlmann and al., 2017; Strum, 2010). Studies on baboon species in different African regions, such as chacma baboons (*P. ursinus*), olive baboons (*Papio anubis*) in Kenya and Guinea baboons (*Papio papio*) in West Africa, have similarly documented shifts in diet, ranging patterns, and social behaviors in response to human influence, underscoring the impact of anthropogenic environments on primate behavior (Fortes and Bicca-Marques, 2005; Kennedy Overton and al., 2024; McLennan and al., 2017; Thatcher and al., 2020). Understanding how baboons adjust their behaviors in response to varying levels of anthropogenic influence is critical for both their conservation and the management of human-wildlife interactions. In this context, the first objective of this study was to provide a detailed examination of the behavioral ecology of three chacma baboon troops inhabiting environments with varying degrees of human influence in the Garden Route Region, South Africa. In addition, as monitors were introduced after the first month of data collection where the Madiba and North troops reside, the second objective of this study was to do a dual behavioral analysis of these two troops, enabling a comparison of their activity budgets before and after the introduction of monitors.

Different land uses and anthropization levels in the three studied chacma baboon's troops.

In this study, we first characterized the levels of land uses of the three chacma baboon troops to enable a proper comparison of their behaviors in a gradient of anthropization. The obtained results showed distinct patterns of habitat used among the Madiba, North, and Outeniqua troops, highlighting the varying degrees of adaptability within chacma baboon populations in response to different levels of anthropization. The Madiba troop exhibited a strong preference for anthropized environments, frequently occupying built-up areas and surrounding shrublands (Fig. 1.a and b). This proximity to human infrastructure, such as roads, buildings, and agricultural lands, suggests a high degree of behavioral flexibility, enabling the troop to exploit the resources available in these areas. The tendency of the Madiba troop to utilize anthropized habitats aligns with findings from other studies on chacma baboons, such as the one of (Kennedy Overton and al., 2024) studying the same troop that was characterized as the most anthropic one based on stable isotopes analysis or those by (Hoffman and O'Riain, 2012) on chacma baboon's troops in Cape Town, South Africa, where baboons have been observed raiding urban areas for food. The North troop demonstrated a more balanced use of both natural and anthropized habitats, reflecting an intermediate level of adaptability (Fig. 1a and b). This troop's use of grasslands and natural forests, along with occasional forays into built-up areas, suggests a dual strategy that maximizes resource availability while minimizing the risks associated with close human contact. This behavior is consistent with other observations of baboons such type of environments, such as again the study of Overton and al., 2024) that also studied this same troop using stable isotopes and those documented by Gilbert and al. (2017) in Tanzania, where olive baboons utilize both natural and agricultural landscapes depending on resource availability and human activity. In contrast, the Outeniqua troop displayed a strong preference for more natural habitats, such as plantation forests and cultivated lands, while avoiding built-up areas (Fig. 1a and b). This behavior suggests a lower level of anthropogenic adaptation, potentially reflecting the troop's reliance on natural resources and the lower level of human disturbance in their environment. Similar findings have already been reported in another study of chacma baboons inhabiting less disturbed environments, where troops tend to avoid human settlements and maintain traditional foraging patterns(Hill, 2000.). The patterns of habitats uses observed in these three troops are consistent with the current understanding of baboon adaptability to anthropogenic environments (Hoffman and al., 2012), underscoring the adaptability of baboons to exploit anthropogenic environments, though they also highlight the risks associated with increased human-baboon interactions.

Influence of anthropogenic and natural environmental pressures on the behavioral patterns and activity budgets of chacma baboons.

The next step of this study was to analyze the different behaviors exhibited by three troops of chacma baboons in environments with varying degrees of land use and anthropization within the Garden Route National Park in South Africa. Globally, the distribution of behaviors observed in the chacma baboons aligns with patterns already described in various studies, where feeding often emerges as a primary activity. In the current study, feeding was the most dominant behavior, accounting for 28.8% of the recorded activities, which is consistent with previous reports emphasizing the importance of feeding in non-human primate daily routines. For instance, Altmann and al. (1988) observed similar patterns in their long-term study of yellow baboons (*Papio cynocephalus*), where feeding accounted for approximately 30% of daily activities, underscoring the critical role of food acquisition in non-human primate behavior. Similarly, (Barrett and al., 2019) highlighted the prominence of feeding in chacma baboon behavior, particularly in environments where food resources are patchily distributed, necessitating increased foraging effort. These results align with broader patterns observed across various other non-human primate species. Indeed, in many non-human primates, such as chimpanzees (*Pan troglodytes*) and colobus monkeys (*Colobus guereza*), feeding often constitutes a significant portion of their daily activities, reflecting the fundamental need to acquire sufficient resources in often competitive and resource-variable environments (Balcomb et al., 2000); Goodall, 1986; Oates, 1994).

Differences in activity budgets among the three baboon troops were observed across various behavioral sub-categories, with the Outeniqua troop showing significant differences with either the Madiba or North troops, or with both, depending on the behavioral sub-category considered. For instance, the Outeniqua troop relied significantly less on human-derived food compared to the Madiba troop (p = 0.0282), indicating a potential adaptation to more natural foraging strategies. This finding is coherent with the fact that it does not have the same probability of access to human food as the other two troops and consistent with other studies on non-human primates that suggest primates living in more natural or less anthropogenically influenced environments tend to rely more on natural food sources. For example, a study by McLennan and Hill (2012) on chimpanzees (*Pan troglodytes*) in Uganda found that chimpanzee communities in less disturbed areas consumed a higher proportion of wild fruits and leaves compared to those in areas with greater human presence, where they resorted to crop-raiding. However, we did not find any difference in natural food consumption between the troops. This resemblance could be explained by a habitat still featuring natural forest formations (i.e. native forest, shrubland and fynbos...)(Fig. 1.a and b) for the campus area, providing the baboons with an assured food source when human food is in short supply. The study by Mazué and al. (2023), carried out on the same two troops, Madiba and North respectively, confirmed that baboon troops were very good at adjusting their food sources according to the availability of human food resources, and were therefore able to focus on foraging in the natural environment. In terms of travel modes, the Outeniqua troop engaged in significantly more climbing compared to the Madiba troop ($p = 0.0436$) and used running significantly less frequently as a mode of travel compared to both the Madiba ($p = 0.007$) and North troops ($p = 0.0142$). Similar patterns have been observed in other primate species, where differences in locomotion are often linked to habitat structure and resource distribution, as in the study of Fleagle (2013) on spider monkeys (*Ateles spp.*) that showed that troops in forested environments with abundant vertical structures exhibited more climbing behavior, while those in more open or disturbed habitats showed increased terrestrial locomotion, including running. Additionally, the Outeniqua troop demonstrated significantly higher levels of self-grooming than the North troop ($p = 0.0101$), which could suggest a greater emphasis on social cohesion or stress reduction in this troop inhabiting the more natural and so less stressing environment, in comparison to the two other troops Madiba and North. For example, the study of Kutsukake (2003) on macaques (*Macaca spp.*) has demonstrated that self-grooming increases in response to social or environmental stressors, indicating its role in individual stress management. These comparisons highlight that the observed behavioral differences among the chacma baboon troops in this study are not unique but rather reflect broader patterns seen across non-human primate species in more or less anthropic environments. The specific adaptations to different environmental conditions, such as reliance on natural versus human-derived food, variations in locomotion, and the use of grooming for social or stress-related purposes, underscore the flexibility and adaptability of primate behavior in response to varying ecological and social pressures.

This study revealed no significant differences in most behavioral activities among the three troops, except for vigilance, with the Madiba (the more anthropic troop) and Outeniqua (the less anthropic troop) troops showing significantly higher vigilance than the North troop (M: 20.7%; N: 17.1%; O: 22.5%) (M-N: $z = 3.3818$; $p = 0.0010$; N-O: $z = -2.7756$; $p = 0.0082$; M-O: $z = 0.5804$; $p = 0.8424$). These findings are consistent with previous research showing that primate behavior is highly influenced by environmental context. For example, a study on rhesus macaques (*Macaca mulatta*) by (Kumar and al., 2011) found that those living in urban environments exhibited more vigilant and socially engaged behaviors, similar to the heightened vigilance observed in the Madiba troop. Interestingly, the fact that the Outeniqua troop, despite inhabiting a less anthropic environment, also showed significantly higher vigilance than the North troop, suggests that factors other than direct human presence may be contributing to heightened vigilance, such as higher predation risk and other complex strategies. Similar observations have been made in studies of wild primates inhabiting natural but ecologically challenging environments. For instance, a study by (Kappeler and al., 2013; Schradin, 2013) on baboons (*Papio cynocephalus*) in the Namib Desert found that troops in areas with lower human presence but higher predation risk exhibited increased vigilance behaviors compared to those in less risky environments. This indicates that ecological factors such as predator presence, food scarcity, or environmental unpredictability can lead to increased vigilance even in less anthropized settings. The elevated vigilance in the Outeniqua troop might therefore reflect an adaptive response to other environmental pressures, such as predation risk or the need to remain alert due to the complexities of foraging in a more natural and potentially less predictable environment. These results underscore the significant impact of both anthropogenic and natural environmental pressures on the behavioral adaptations of chacma baboons, revealing a complex interplay between habitat use, social dynamics, and vigilance in shaping their activity budgets.

Environmental variables have a very important role in the behavioral flexibility of primates, reflecting individual responses to environmental challenges (Kappeler and al., 2013; Schradin, 2013). This study revealed a significant adjustment of certain behaviors according to meteorological variables, habitat structure, and an anthropogenic variable characterized by the number of cars. Good weather tends to positively influence locomotion, affiliative interactions, vigilance, and feeding. The existence of this relationship between behaviors and meteorological values was explained in a study of baboons (*Papio cynocephalus*), revealing those variations in weather influence travel distance and foraging less in years with less clement weather conditions (Bronikowski and Altmann, 1982). The structure of the habitat, defined here as the openness or closure of the environment, may have highlighted that an open habitat significantly promotes the probability of affiliative interactions and vigilance. An open habitat could present a greater danger to baboons who may not have trees nearby to take refuge in case of danger, thus forcing them to increase their vigilance behavior to quickly detect threats. (Cowlishaw, 1998) showed in a desert baboon population a higher level of vigilance in open habitats, related to the distance from refuge, and an important need for occasional vigilance when passing through unexplored areas or close to predators, rather than continuous vigilance as might be the case in an open environment. The variable related to the presence of cars, defining the anthropogenic aspect of the model, highlighted a significant decrease in social activities and a slight variation in feeding behaviors. This indicates that baboons indeed adapt these two behaviors when the presence of cars is too prevalent. Several studies on long-tailed macaques, olive baboons, or vervet monkeys have also highlighted adjustments in their activities in urban settings, particularly a reduction in the time available for social interactions, grooming, resting, and modifications in their eating habits (Novak and al., 2014; Sha and Hanya, 2013; Strum, 2010; Thatcher and al., 2020). We also observed that this variable did not influence the vigilance of the baboons, reflecting a possible habituation of the species, which no longer considers these stimuli as a threat. Finally, through this analysis, we can determine that activity patterns are mainly driven by natural environmental conditions such as weather and habitat structure, but anthropogenic environmental conditions alter the behavior of baboons, pushing them to adapt to these new variables.

Vigilance and stress responses in chacma baboons following monitor implementation.

The implementation of the baboon monitor in the study area has provided valuable insights into how human interventions can differentially impact primate behavior, particularly within the context of conservation and human-wildlife conflict management. Our findings indeed demonstrate that even within the same species, different troops can exhibit varied behavioral adaptations in response to the same stimulus.

The obtained results first showed that a significant increase in overall vigilance observed in the North troop (N-N.mnt: $z = -4.6614$; $p = 9.42 \times 10^{-6}$) suggesting heightened alertness and potential stress in response to the presence of the monitor. This aligns with previous studies indicating that wild non-human primates often increase vigilance in the presence of novel stimuli or perceived threats (Cowlishaw, 1998; Treves and al., 2001). The specific increase in the first level of vigilance (Vig0) combined with a decrease in the more intense third level of vigilance (Vig3) may indicate a shift from intense threat monitoring to a more generalized alertness, potentially reflecting habituation to the monitor over time. This nuanced shift is consistent with findings from chacma baboons in human-modified landscapes, where initial high-alert responses often give way to more measured vigilance as the animals become accustomed to human presence (Altmann and Wagner, 1970; Hill, 2005). In contrast, the Madiba troop did not exhibit significant overall behavioral changes, suggesting either a lower sensitivity to the monitor or a more established habituation to human-related stimuli. Such a result is not that surprising, knowing that this troop has an history of being followed regularly by monitors on the Campus. However, the observed increase in fleeing from humans (M-M.mnt: $z = -2.4960$; $p = 0.0376$) and the decrease in the second level of vigilance (M-M.mnt: $z = 2.4180$; $p = 0.0466$) suggest a nuanced response. These behaviors may reflect an adaptive strategy where the troop engages in avoidance behaviors (fleeing) rather than sustained vigilance, potentially indicating a different coping mechanism in response to the monitor. Such a pattern has already been described, where similar avoidance strategies have been documented in other primate species, including vervet monkeys (*Chlorocebus pygerythrus*) and rhesus macaques (*Macaca mulatta*), which tend to flee rather than remain vigilant when faced with persistent human presence (Isbell and Young, 1993; Kumar and al., 2011). Finally, the increase in self-grooming in the North troop (N-N.mnt: $z = -2.5372$; $p = 0.0335$) further supports the notion of stress or anxiety, as self-grooming is often associated with stress alleviation and social bonding in primates (Kumar and al., 2011; Kutsukake, 2003). This behavior could serve as a coping mechanism to mitigate the stress induced by the monitor, reflecting the complex social dynamics within the troop.

These findings are consistent with broader research on non-human primates, which suggests that primates exhibit a wide range of adaptive behaviors in response to human-induced changes in their environment (McLennan and Hill, 2012). The variations between the North and Madiba troops highlight the plasticity of primate behavior, influenced by factors such as prior exposure to humans, troop structure, and individual temperaments. The differential responses observed in this study underscore the importance of considering the specific ecological and social contexts when implementing conservation interventions. The fact that one troop exhibits increased vigilance and stress-related behaviors while the other adopts avoidance strategies highlights the need for tailored management approaches. These results suggest that in areas of high human-wildlife conflict, like the one studied here, a one-size-fits-all approach to conflict management may be insufficient. The differential responses of the North and Madiba troops suggest that more nuanced and context-specific strategies are needed. For instance, in regions where baboons exhibit heightened vigilance and stress, conservation managers might consider less intrusive monitoring methods or increase efforts to habituate troops to human presence in a controlled manner. In contrast, areas where baboons tend to flee could benefit from strategies that reduce human presence or buffer zones to minimize encounters.

Given the differential behavioral responses observed in the North and Madiba troops, future studies should aim to explore the long-term effects of monitoring tools on primate behavior. Longitudinal studies could provide deeper insights into whether initial stress responses, such as increased vigilance or fleeing behaviors, persist over time or diminish as troops habituate to human presence. In addition, integrating behavioral data with physiological measures, such as stress hormone levels, could provide a more comprehensive understanding of the impact of human interventions on primate health and well-being. These future studies could contribute significantly to refining conservation strategies and enhancing the effectiveness of human-wildlife conflict management practices.

V- Conclusions and perspectives

This study shows the important influence of environmental factors, including habitat structure, weather conditions, and human presence, on the behaviors of chacma baboons in anthropogenic landscapes. The observed behavioral adaptations, such as changes in feeding strategies, social interactions, and vigilance, highlight the remarkable flexibility of baboons in adapting to varying environmental pressures, which is aligning with broader patterns seen across non-human primates, where environmental challenges drive behavioral modifications that are crucial for survival. It must be noticed that the different patterns observed between the North and Madiba troops emphasize the complexity of primate behavior and the importance of context-specific conservation strategies. The North troop's increased vigilance and stress-related behaviors in response to the baboon monitor contrast with the Madiba troop's avoidance strategies, suggesting that a one-size-fits-all approach to conservation and human-wildlife conflict management may be insufficient. Human-baboon conflicts, often exacerbated by habitat encroachment and urban expansion, require nuanced, tailored interventions that consider the unique ecological and social contexts of each population. Implementing strategies that specifically address the root causes of these conflicts, such as modifying human activities or enhancing natural habitat buffers, could effectively mitigate tensions and promote coexistence between humans and baboons. Future studies should focus on the long-term effects of human interventions on primate behavior, particularly through longitudinal studies tracking changes over time. Integrating behavioral observations with physiological measures, such as stress hormone levels. Additionally, exploring the role of other environmental variables, such as noise pollution, environmental polluants or specific habitat features, could further refine our understanding of non-human primate adaptation in a world with constant growth of anthropic areas.

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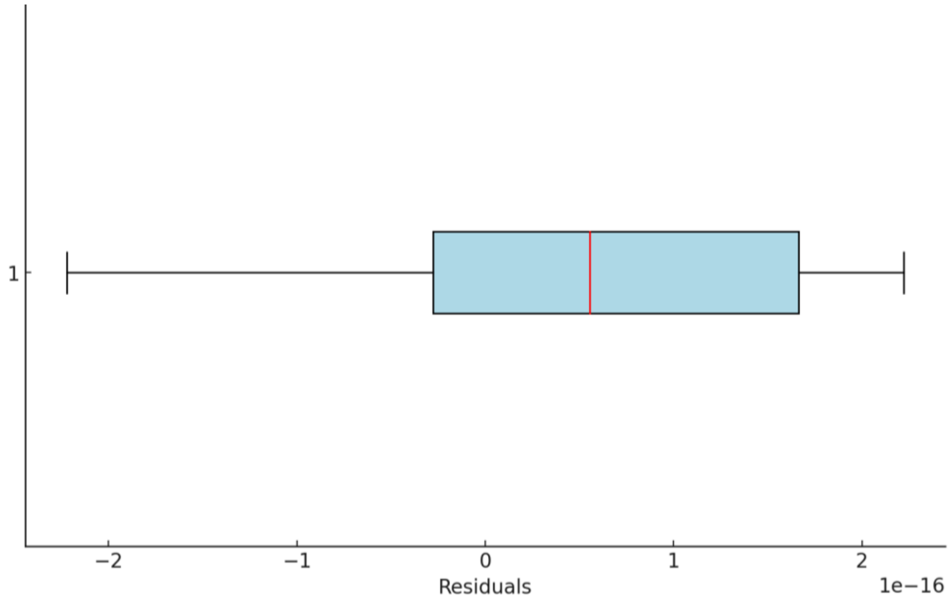
Supplementary table 1: Ethogram of the chacma baboons behaviors used for the Boris analysis

Activity	Description	Subcategory
Locomotion	Non-social directional movement	Walking; Running; Climbing; Flight: human, baboon avoidance, other animals, cars
Feeding	Foraging and ingesting food (chewing, ingesting, handling food or water with hands, feet, or mouth)	Human food; Natural food; Agricultural food; Water
Resting	Stationary state, the individual is inactive, lying down or asleep	Alone; In-group; Alone; Self-grooming
Affiliative	All positive social interactions (grooming, social-play, lipsmaking, sweet-grunt, clasping, parents with baby)	Grooming; Social-play; Lipsmaking; Sweet-grunt; Clasping; Parents with baby
Agonistic	Aggression (pushing, hitting, biting, grabbing); Threat (silent or vocalized facial displays, rushing forward, tapping the ground, jumping and chasing, barking, growling, roaring)	Visual threat; Sound threat; Attack
Sexual	Aggression (pushing, hitting, biting, grabbing) Threat (silent or vocalized facial displays, rushing forward, tapping the ground, jumping and chasing, barking, growling, roaring)	Anogenital presentation; Mount
Vigilance	Eyes open and head held high: the focus should not be another individual in the group or a food source	Vig0: slow glance with a passive position and routine scan; Vig1: repeated glances with a passive position and intense scanning; Vig2: individual on these four legs with an active position and routine scan; Vig3: individual on these two hind legs achieving a quick glance from both sides with an active and intense stance

Supplementary Table 2: ***Residuals for the multinomial logistic regression of the model***



Supplementary Table 3: ***Timetable of the current internship***

TIMETABLE

MONTH	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
Week 1	Bibliography and protocol development	Fieldwork Video records on the baboon	Fieldwork Video records on the baboon	Break	Boris analysis Behavioural data	R analysis and writing report
Week 2	Bibliography and protocol development	Fieldwork Video records on the baboon	Fieldwork Video records on the baboon	Break	Boris analysis Behavioural data	R analysis and writing report
Week 3	Bibliography and protocol development	Fieldwork Video records on the baboon	Fieldwork Video records on the baboon	Fieldwork Video and Boris analysis Behavioural data	Boris analysis Behavioural data	R analysis and writing report
Week 4	Fieldwork Video records on the baboon	Fieldwork Video records on the baboon	Fieldwork Video records on the baboon	Fieldwork Video and Boris analysis Behavioural data	R analysis + writing report	R analysis and writing report