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# **Carnivore Diversity, Distribution, and Interactions with Other Wildlife at the Park-Human Community Interface in Rwanda**

A thesis submitted in partial fulfilment of the  
requirements for the degree of Master of  
Science in Biodiversity Conservation and  
Natural Resources Management

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Kigali, July 2024

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**DECLARATION**

I, Uzabaho Eustrate, declare that this master’s dissertation “Carnivore Diversity, Distribution, and interactions with Other Wildlife at the Park-human community interface in Rwanda” is the result of my own work in partial fulfilment of the requirements for the award of a master’s degree in Biodiversity Conservation and Natural Resource Management at the

University of Rwanda, College of Science and Technology and has not been submitted for any other degree at the University of Rwanda or any other institution. All sources that I have used or quoted have been indicated and acknowledged in the references.

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## **DEDICATION**

This thesis is dedicated to my wife Uwamabaza Marie Florence, to my daughter Uzabaho Audrey and to my son Uzabaho Bruno.

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## TABLE OF CONTENTS

DECLARATION .....	ii
DEDICATION .....	iii
ACKNOWLEDGEMENTS .....	iv
TABLE OF CONTENTS .....	v
LIST OF TABLES .....	vii
LIST OF FIGURES .....	viii
LIST OF SYMBOLS AND ACRONYMS .....	ix
ABSTRACT .....	x
CHAPTER 1. INTRODUCTION .....	1
1.1 Background .....	1
1.2 Problem statement .....	2
1.3 Objectives .....	4
1.3.1 Main objective .....	4
1.3.2 Specific objectives .....	4
1.4 Research Questions .....	5
1.5. Hypotheses .....	5
CHAPTER 2. LITERATURE REVIEW .....	6
2.1 Carnivores-human coexistence .....	6
2.2 Wildlife monitoring and occupancy modeling .....	7
2.3 Use and functioning of camera traps .....	8
2.4 Animal activity patterns .....	9
CHAPTER 3. MATERIALS AND METHODS .....	10
3.1 Study area .....	10
3.2 Data collection .....	12
3.3 Data analyses .....	13
CHAPTER 4. RESULTS .....	15
4.1 Species composition .....	15
4.2 Species occupancy and detection probability .....	15

4.3 Relationship between site variables and native carnivores .....	20
4.4 Interaction between carnivores and other species .....	21
4.5 Activity overlap of individual native carnivore and other taxa.....	24
4.6 Native carnivores' distribution patterns .....	26
CHAPTER 5. DISCUSSION.....	28
CHAPTER 6. CONCLUSION AND RECOMMENDATIONS .....	32
REFERENCES .....	34
APPENDIX.....	I
Appendix 1. Details of sampling designs and features for the camera trap survey .....	I

## LIST OF TABLES

Table 1. List of ground-dwelling species captured on cameras traps. Table includes class, family, scientific name, common name, behaviour, size, functional guild, IUCN assessment, number of sites where the species was detected, and the total number of events for each species. .....	16
Table 2. Occupancy probability and detection probability of detected species along VNP edge. .....	18
Table 3. Model comparison table for multi-species single-season occupancy models testing for the effect of covariates on occupancy ( $\Psi$ ) and detection probability ( $p$ ).....	19
Table 4. Co-occurrence results for non-native species (species A) and carnivores (species B) including the species interaction factor (SIF) at the interface between VNP and local communities.....	23
Table 5. Overlapping coefficients estimated for native carnivores and other species.....	25

## LIST OF FIGURES

Figure 1. A map showing the location of all sites along the Volcanoes National Park, Rwanda. .....	11
Figure 2. Map showing habitat types inside (50%) and outside (50%) around each camera trap location.....	11
Figure 3. Land use categories in the community land based on three types of uses (right), and distance of nearest human dwellings estimated in meters (left). .....	12
Figure 4. Relationship between estimated occupancy and the distance from the nearest settlements: (a) showing the relationship between individual carnivore species estimates and (b) representing the combined trend of all native carnivore species. ....	20
Figure 5. Occupancy estimates in different habitat types and land use for six identified native carnivores found along the park edge – community land interface. ....	21
Figure 6. Species interaction factor between native carnivores and other species – the coefficient greater than one shows an attraction or co-occurrence while the values below one is considered as an avoidance. ....	22
Figure 7. Relationship between native carnivores and other animal species, (a) showing the conditional probability of occupancy of species considered, given the native carnivore species is present ( $\psi_{BA}$ ) of each species while a select native carnivore is present and (b) showing the conditional occupancy of a given species given the native carnivore species is not present ( $\psi_{Ba}$ ). ....	24
Figure 8. Temporal activity of species found from camera-trap data calculated based on the kernel density. ....	26
Figure 9. Map showing the distribution of native carnivores along the VNP edge in (a) is the estimated species richness per site, and (b) is the individual species distribution map. ....	27

## **LIST OF SYMBOLS AND ACRONYMS**

AIC: Akaike information criterion

GIS: Geographic Information System

GMNP: Gishwati-Mukura National Park

IGCP: International Gorilla Conservation Programme

ORTPN: Office Rwandais de Tourisme et des Parks Nationaux

RDB: Rwanda Development Board

REMA: Rwanda Environmental Management Authority

SIF: Species Interaction Factor

TEAM: Tropical Ecosystem Assessment and Monitoring

VNP: Volcanoes National Park

WWF: World Wide Fund for Nature

## ABSTRACT

People, livestock, and carnivores are constantly interacting especially at the interface between community and protected areas. The carnivore guild category in Volcanoes National Park is important, and if well studied, could lead to additional research opportunities for improved wildlife management. We used single season occupancy models with multi-species data, to understand the factors affecting species occurrence, detection, and distribution among native carnivores of Volcanoes National Park while accounting for imperfect detection and the effects of site variables on the observed trends. Our findings showed that six native carnivores use the park edge, where the side-striped jackal (*Canis adustus*) and serval (*Leptairulus serval*) are the most widespread with  $\psi = 0.904$ (SE 0.051) and  $\psi = 0.415$  (SE 0.086) respectively, followed by African golden cat (*Caracal aurata*) with  $\psi = 0.198$  (SE 0.066), while the servaline genet (*Genetta servalina*), slender mongoose (*Herpestes sanguineus*) and spotted hyena (*Crocuta crocuta*) have very low probability of occupancy with  $\psi = 0.087$  (SE 0.045),  $\psi = 0.044$  (SE 0.032) and  $\psi = 0.022$  (SE 0.022) respectively. In addition, there is high occurrence of feral dogs and human presence in the park edge. Overall, the occupancy of native carnivores increases as distance from settlements increase ( $\beta = 0.559$  (SE 0.195)) except for hyena and mongoose which showed a decrease in occupancy as distance to settlements increased. In general, native carnivores preferred sites located close to pasture areas, compared to areas used for agriculture and agroforestry. High overlapping activity between native carnivores and other wildlife varied greatly between species. This study provides the baseline information for the understanding of native carnivores using the park edge and insights on their interactions with other wildlife, livestock, and human activities at the interface between the park and local communities. The co-occurrence of livestock, feral dogs and humans, and native wildlife is a challenge for both wildlife conservation inside the protected area and local communities who might be negatively affected in different ways including interspecific competition, disease exposure and increased conflicts. We anticipate that some of the current livestock keeping are hindered by the challenges of having native carnivores dwelling along the park edge and community interface.

**Key words:** Camera trapping, Edge, Habitat types, Human wildlife conflict, Carnivores, Occupancy models, Species distribution, Volcanoes National Park.

## CHAPTER 1. INTRODUCTION

### 1.1 Background

People, livestock, and carnivores are constantly interacting especially at the interface between communities and protected areas. These interactions are often reported as a source of human wildlife conflict, and can lead to retaliatory practices by local communities in response to the cost of damages from predation (Chinchilla et al., 2022; Sebsibe, 2022). There is always a cost to living closer to protected areas for people mainly because some adverse impacts may come from wildlife and the proximity. Conflicts were reported to affect threatened species including large carnivores and charismatic species (Gross et al., 2021), but the level of tolerance has increased in recent years mainly due to management strategies tackling human wildlife conflicts. Specifically, humans tend to adopt coexistence by changing their behaviours due to immense efforts to address the conflicts (Gross et al., 2021). Though many human-wildlife conflicts are attributed to large predators, a few studies have found that small and medium-sized carnivores provide ecosystem services in agro-ecosystems but also have an impact on livestock husbandry (Blaum et al., 2009; Williams et al., 2018).

The human-livestock carnivore's interactions result from human behaviour and porous human-wildlife conflict (HWC) mitigation strategies, but also, they may be due to continuous human intrusions into natural habitats. Conservationists have attempted to quantify and document HWC incidences using a variety of methods from interviews and more sophisticated monitoring programmes which provide insights to inform the conservation managers (Tobler et al., 2008). However, much still to be document on the carnivore's side in forested ecosystems. Being low in density, elusive and cryptic, studying carnivores requires the use of a different method which can help to record a wide range of information on diversity, occurrence, activity budget, and distribution (Balme et al., 2009). The camera trap is the most suitable for collecting required data on that challenging guild category. The Volcanoes National Park (VNP) is part of the Virunga Massif, a shared ecosystem between three countries Rwanda, Uganda and the Democratic Republic of Congo known for its rich, endemic, and rare biodiversity in the Albertine Rift, of Africa (Plumptre et al., 2007). The park has suffered from human demographic pressure for years in many different aspects and one of the issues include the human wildlife conflicts mostly caused by large mammals which mainly destroy crops (Babaasa, 2016). To address this, the park management, biodiversity conservation partners and the local communities erected a stone wall, and dug a trench along the stone wall to contain

large mammals to exit the park but still this is not effective for enclosing primates and other specialized species such as carnivores from exiting the park (Guinness, 2015). The main reason of the stone wall is to protect the community crops and structures, but the livestock was left exposed to probable attack from carnivores although not reported by communities. We hypothesize that small to medium sized livestock from the communities might be affected by predators frequently exiting the park including the vulnerable African golden cat. Nowadays, camera traps showed to be effective in collecting data on species occurrence and distributions, partly because they are, cost-effective and non-invasive method, allowing for 24-hour data collection with minimal human interference with wildlife (Tobler, et al. 2008).

## **1.2 Problem statement**

In the Virunga Massif, home to half of the remaining endangered mountain gorilla, an iconic umbrella species which brought much attention from scientists. The focus of research has been mainly on the mountain gorilla through surveys called “Censuses” which together with number of mountain gorillas, provide even information on the distribution of other large mammal sharing the same habitat with mountain gorillas (Gray et al., 2013; Hickey et al., 2019). However, not all mammal species are accounted for and even the types of signs recorded differ from on species to another. The mostly used methods for data collection include line transect, live trapping and point count and quadrats (Gray et al., 2013; Hickey et al., 2019; Owionji et al., 2005).

Each research is designed based on its objectives and intended results. For studying carnivores, one can use different methods to collect data including scat sampling on a line transect, point count of dungs, calls and others (O’Connell et al., 2011). To overcome the field challenges, scientists have been combining different methods for sampling specific to each guild category. Camera trap is one of recent technologies that can help in studying carnivores in different habitats including forest ecosystems, remote areas due to its high efficiency in recording a variety of information.

The carnivore guild category in VNP is important, and if well studied, could lead to additional research opportunities for improved wildlife management. Camera trapping is the first of this kind, which will provide baseline information on the carnivore community at the interface between the VNP and local community (Moore, et al., 2019, 2021; Uzabaho et al., 2023). In addition, this study helps the park management better understand the park’s carnivore diversity,

distribution, and activity patterns for effective planning, management of conflicts and other study designs intended for long term monitoring of wildlife inside and outside the park. Furthermore, the findings of this study could be utilized to assist park management in better understanding and directing human-wildlife conflict reduction efforts. Camera trapping is a one-of-a-kind, cost-effective, non-invasive tool to study animals with minimal human interference, which is beneficial for accurate and informative inferences (Moore, et al., 2021; Tsunoda et al., 2022). Carnivore studies provide information for the protected area authorities, and key stakeholders including communities necessary to tackle different challenges associated with carnivore's conflicts, community engagement in conservation intervention (Mekonen, 2020; Williams et al., 2018; Zúñiga et al., 2017) and better planning for co-habitation and sustainable carnivore's protection (Whittington et al., 2022).

In the recent study by Uzabaho et al. (2023), different species of carnivores were spotted using the park edge on a frequent basis and we hypothesized that there may be an interesting part of work needed to understand the reasons for their presence in the vicinity of the park boundary. Since there is no current buffer zone or monitoring program for carnivores happening around Volcanoes, we will be documenting these taxa, which would threaten the local communities by predated on their livestock or being attracted to human settings. At the park level, current efforts are put on mitigating the negative effects caused mainly by large mammals such as buffalo (*Syncerus caffer*) and antelopes, this study provided real data on the distribution of carnivores through evidence from camera traps. The use of technology for monitoring wildlife populations outside protected areas can provide insights on the existing management gaps and provide new opportunities for better managing populations. In addition, this project will reveal undocumented conflicts that may be resulting from native carnivores to the local community's livestock. Previous studies on conflicts involving wildlife focused on herbivores such as golden monkeys (*Cercopithecus mitis-kandti*), buffalo and gorillas (*Gorilla beringei beringei*) (Babaasa, 2016; Ndayishimiye et al., 2023). However, we cannot also forget that the human proximity to protected areas also expose their livestock to diseases because of interactions but also the beneficial coexistence with native species. Native species provide services of ecological and economic importance as rodent regulation in agroecosystems (Williams et al., 2018), and tourism revenues and benefits (Prugh & Sivy, 2020).

In addition, the park is surrounded by a high-density human population using the volcanic fertile soils (Guinness, 2015). Given the favourable climatic conditions, people are relatively dependent on ecological services from the forest and have been involved interacting with

wildlife in different ways, which are not mutually exclusive but tolerant. This has direct effects on the animals which exit the park through continuous conflicts. The Park lacks a buffer zone and agricultural and livestock activities are immediately occurring in proximity to the park. The Park is known for its endangered mountain gorilla (Kalpers et al., 2003) and golden monkey which are of international concern but the recent photographic evidence of a vulnerable African golden cat (Moore et al., 2019) and the endangered elephant, are the signs that conservation of this ecosystem are still important and really of great priority. The government of Rwanda through the Rwanda Development Board (RDB) is committed to ensuring the sustainable management of the park resources and sustain a modest livelihood to local community through conservation incentives ([ORTPN], 2005).

### **1.3 Objectives**

#### **1.3.1 Main objective**

The main goal of this study is to understand the carnivore community at the park – local community interface, for improving their conservation.

#### **1.3.2 Specific objectives**

- (1) To provide baseline information on existing carnivores using the edge and community land.
- (2) To document the effect of land use and habitat types on the distribution and occurrence of native carnivores.
- (3) To elucidate the interactions between humans, livestock and wildlife along VNP boundary.
- (4) To assess the temporal and spatial patterns of carnivores at the interface of the park and surrounding community land.

## **1.4 Research Questions**

This study seeks to answer the following questions:

- (1) What carnivore species are present along the VNP edge and what are the main drivers of their presence?
- (2) What are the factors determining distribution of carnivores along the park edge?
- (3) What relationships exist between different terrestrial mammals, native carnivores, and local site covariates?
- (4) What is the spatial-temporal distribution of the native carnivores along the park-community interface?

## **1.5. Hypotheses**

- (1) A few of native carnivore species access the park edge and are attracted by food availability such as livestock presence.
- (2) Carnivore species richness is higher in areas where the human settlements are far from the park edge
- (3) Site variables such as habitat types, land use and human activities influence the presence and interactions between animal species and carnivores
- (4) Distribution patterns of carnivores are directly linked to human activities and the presence of livestock along the park edge

## CHAPTER 2. LITERATURE REVIEW

### 2.1 Carnivores-human coexistence

Wildlife studies has always pushed scientists to develop different techniques to collect data. The goal has been to better understand deeply the natural world and drivers of its components. When it comes to carnivores, the focus is put on large and keystone species such as lions, leopards, tigers, jaguars, cheetahs, pumas, hyena and wild dogs (Ripple et al., 2014). However, given the roles of carnivores in each ecosystem, even small to medium sized would make attention and given their values in scientific world (Blaum et al., 2009).

Carnivores play important role in providing equilibrium in an ecosystem and contribute to recreational and eco-tourism opportunities especially in open areas such as the African savannahs (Prugh & Sivy, 2020). However, they are mostly reported to cause conflicts to humans and their livestock throughout their range, which makes them vulnerable to retaliatory practices and the overall economic losses associated with them (Verschuere et al., 2020). But humans are coping by adopting mitigation measures that enable them to coexist and overcome the negative impacts of living within a human-carnivore environment.

To promote human carnivore coexistence, different practices have been developed, including both lethal and non-lethal control mechanisms that enhance community resilience and development (Bodenchuk et al., 2002). Different interventions are developed where the conflicts are causing economic losses. Compensation can act as a control mechanism, while sometimes physical barriers or deterrents such as the construction of strong bomas, the use of electrical fences, guarding, provision of alternative livelihoods, and the adoption of zoning are effectively helping to address the conflicts (Gross et al., 2021). Tolerance may also result from payments for ecosystem services and the development of carnivore-based tourism (Störmer et al., 2019).

Camera traps are widely used to assess and monitor the status of wildlife in a given ecosystem. They help to examine anthropogenic and environmental factors that may influence carnivore activity and occupancy across their range. Standardized protocols were developed to better collect useful information on diversity, richness, and activity patterns for medium- to large-sized mammals and birds (TEAM Network et al., 2014). The use of camera traps for monitoring cryptic and elusive species have shown to be effective in monitoring different species, from common to cryptic and elusive taxa, in forested areas ( O'Connell et al., 2011; Moore et al.,

2021; Rovero et al., 2014; Uzabaho et al., 2023). Several techniques are used to gather the information based on the study objectives or intent. Camera-traps are widely used in mammal and ground dwelling surveys, and this has shown tangible results in terms of providing enough data that can be used in several ways. Camera traps are an effective tool for inventorying even cryptic and elusive species rarely found by other survey techniques. Camera trapping is the preferred method for assessing terrestrial mammal populations, measuring species richness, occupancy, absolute density and activity patterns (Ahumada et al., 2011; Mccallum, 2013; O'Connell et al., 2011; Tobler et al., 2015). Camera traps are also used in monitoring global biodiversity programs (Bowler et al., 2017; Linkie et al., 2013). For scientists, it is imperative to draw good inferences from quality datasets. Thus, the success of camera traps resides in sampling design and enough data. To this extend, we rely on the good implementation of sampling techniques in the field to maximize detections.

## **2.2 Wildlife monitoring and occupancy modeling**

The biodiversity monitoring programme provides primary information on the ecosystem and informs the conservation managers on the trends in animal population. The monitoring of wildlife helps managers in planning and management of the natural resources and can be a measure of the efforts on the implementation of different strategies in place (Tobler et al., 2008). In the gorilla habitats, data on key wildlife species are collected by trained rangers, scientists and other staff who are skilled in gathering such information (Gray & Kalpers, 2005). Currently, data collection protocols in Rwanda are regularly improved to include other species which are easily observable using both direct and indirect signs, and the data are managed using technological techniques that allow the managers for easy data analysis and utilization (Moore, et al., 2021). Managers use different techniques for recording wildlife occurrence data using both direct and indirect observations for better wildlife management (Moore, et al., 2019).Occupancy modelling is based on conducting independent visits to sample sites in a study to collect species detection data which are used to model, and then adjust for, the detection of species of interest. Surveys help in estimating wildlife populations found in an area and predict their distribution and evaluate the success of conservation efforts as well as mitigate the emerging threats (MacKenzie et al., 2017). The detection histories provide enough data to be used in occupancy modelling of ecological data.

Occupancy methods perform best when detection is high, occupancy is moderate, and we have many sampling sites. Low detection probabilities can cause problems for occupancy because

the estimates become increasingly less accurate as detection probabilities become very small. Mackenzie & Royle (2005) recommended to increase the number of sampling units and occasions to attain high accuracy and precision of occupancy estimates (Mackenzie & Royle, 2005). Such continuous biodiversity monitoring is important for conservation planning purposes and for advising managers in policy-making with regards to the state of the natural environment (Stork & Samways, 1995).

### **2.3 Use and functioning of camera traps**

The surveys using camera traps is one of the recent technologies used to gather data for such group of wildlife species with minimum disturbance and on relatively low cost and help record a varied array of information on different taxa (Mccallum, 2013; O'Connell et al., 2011). Camera trapping is cost effective method in gathering data on cryptic, elusive, and rare species such as carnivores (Ahumada et al., 2011; Tobler et al., 2015). Camera traps are also helpful in quantifying the number of different species in an area; this is a more effective method than attempting to count by hand every individual organism in a field. Different data management were developed to easy the processing and manipulation of many images (TEAM Network, 2018). Their advantage is that they can record very accurate data without disturbing the photographed animal and be able to annotate the images in simple ways. Camera traps are helpful in determining behavioral and activity patterns of animals. Camera traps have revolutionized wildlife research and conservation, enabling collection of photographic evidence of rarely seen and often globally endangered species. Camera traps can document wildlife presence, abundance, and population changes. Camera traps enable collection of baseline population data on elusive mammals.

The camera trap functioning is complex, and most modern-day camera trap types rely on a passive infrared sensor (PIR) to detect a differential in heat-and-motion between a subject and the background temperature, and on an infrared/LED flash array to illuminate the target area (Oliver R. & Glover-Kapfer, 2017). Another important element is the detection Zone or the area in which a camera trap can detect the target through its sensor, and this vary between camera trap models. Trigger speed (or "trigger delay"): the rapidity with which the camera captures an image relative to when the sensor detects the passing target (Rovero et al., 2013). When choosing camera trap type and model to be utilized, you should normally consider 10 camera features: trigger speed, flash type (white or infrared), detection zone, number of photos taken, recovery time, and video, sensitivity, flash intensity, power autonomy, image resolution,

sharpness and clarity, camera housing, and camera setting (Oliver R. & Glover-Kapfer, 2017). Considering camera performance and study designs, the TEAM terrestrial vertebrates protocols provides clear guidelines for designing a study according to the type of data to be collected (TEAM Network, 2011).

## **2.4 Animal activity patterns**

Species activity patterns are categorized into diurnal, nocturnal, crepuscular, and cathemeral (Bennie et al., 2014). Since camera traps record time-stamped images, they are an effective method for drawing inferences about the activity patterns of frequently detected wildlife species (Ridout & M., 2014). Understanding these patterns is important because the activity patterns and behaviour of a given animal can be affected by human disturbances including habitat fragmentation, tourism, hunting or even other environmental conditions (Norris et al., 2010). Thus, any fluctuation in activity patterns of species may represent strategies adopted by individuals to adapt with existing limiting factors. Graphical representation of activity patterns reflects aspects of temporal variability in species activity over the diel cycle, including basic behavioural categorizations and periods of peak activity (Frey et al., 2017). The so-called similarity theory by MacArthur & Levins (1967), predicts that no two species can coexist in time and space; consequently, sympatric species divide their resources to avoid their extinction due to competition. The coefficient of overlapping is used to investigate any potential competition and interaction possibilities between species (Linkie & Ridout, 2011) which can be adversely avoided through spatial-temporal trade-offs and species abundance.

## CHAPTER 3. MATERIALS AND METHODS

### 3.1 Study area

We conducted this study along the VNP (Rwanda) a montane forest, contiguous to the Mikeno sector of Virunga National Park (ViNP) in the Democratic Republic of Congo, and Mgahinga Gorilla National Park (MGNP) in Uganda. The elevation in VNP ranges from 2500 to 4507 m asl of altitude. There are six inactive volcano peaks found in the Virunga Massif namely Mikeno (4437 m), Karisimbi (4507 m), Bisoke (3711 m), Sabinyo (3634 m), Gahinga (3474 m), and Muhabura (4127 m) (Owiunji et al., 2005). Spinage (1992) described five major habitat types within the Virunga Massif: bamboo forest, woodland dominated by *Hagenia abyssinica* and *Hypericum revolutum*, herbaceous and meadow, mixed forest including *Neobutonia* forest, and subalpine; The massif contains six inactive volcanoes.

To avoid overestimating of the species occurrences, we have surveyed 47 sites with an initial sampling design of 61 sites (based on the more than 74 km of the park's stone wall perimeter, which is enough to depict the estimated occurrences linearly at one camera trap per kilometer) (Figure 1). Each camera was left in the area for at least 50 days to make independent detections following the protocols for studying terrestrial vertebrates (TEAM Network, 2011). To check whether the carnivores use the community land, nine camera traps were deployed outside of the stonewall.

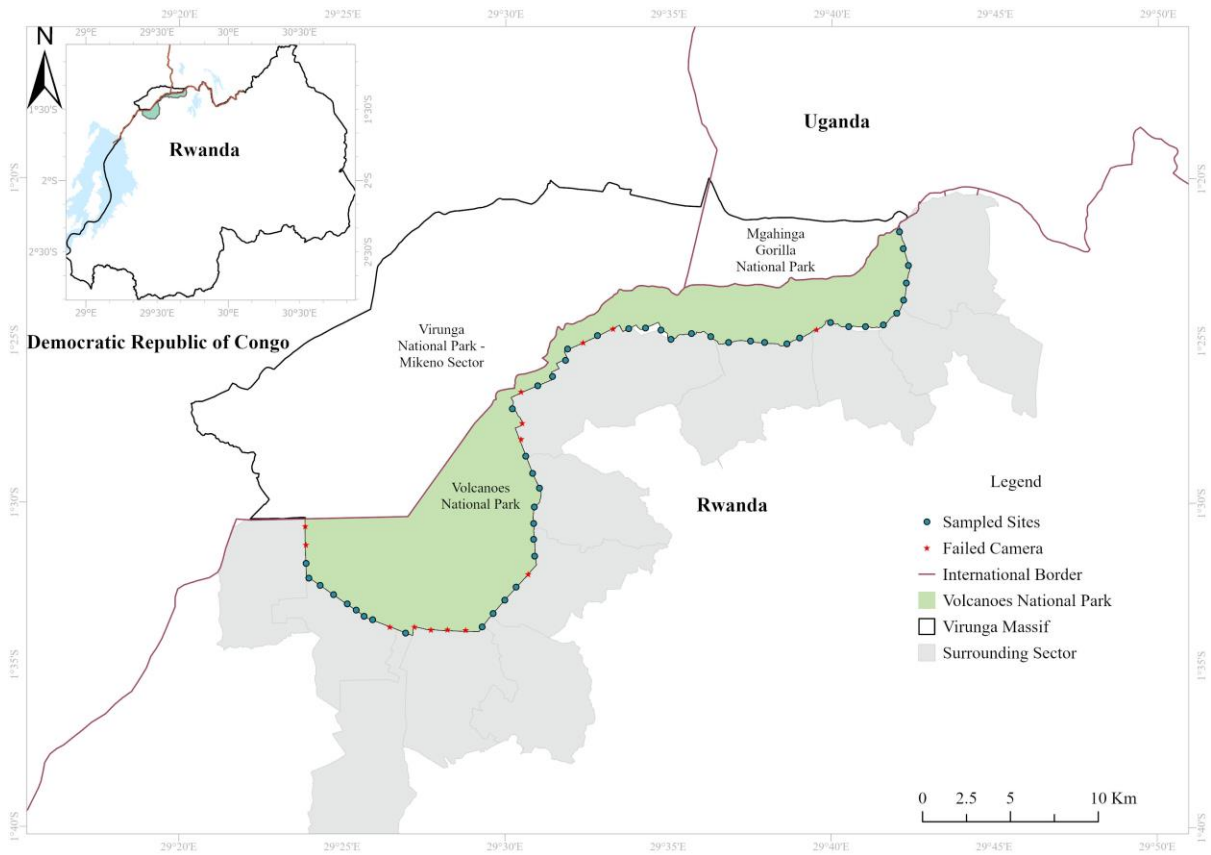


Figure 1. A map showing the location of all sites along the Volcanoes National Park, Rwanda.

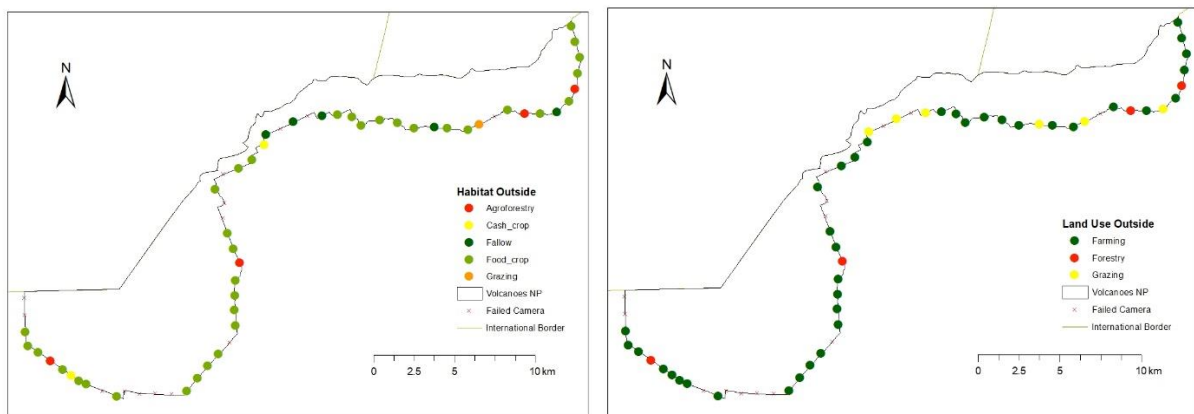


Figure 2. Map showing habitat types outside the protected area (right) and land use categories in the community land based on three types of uses (left)

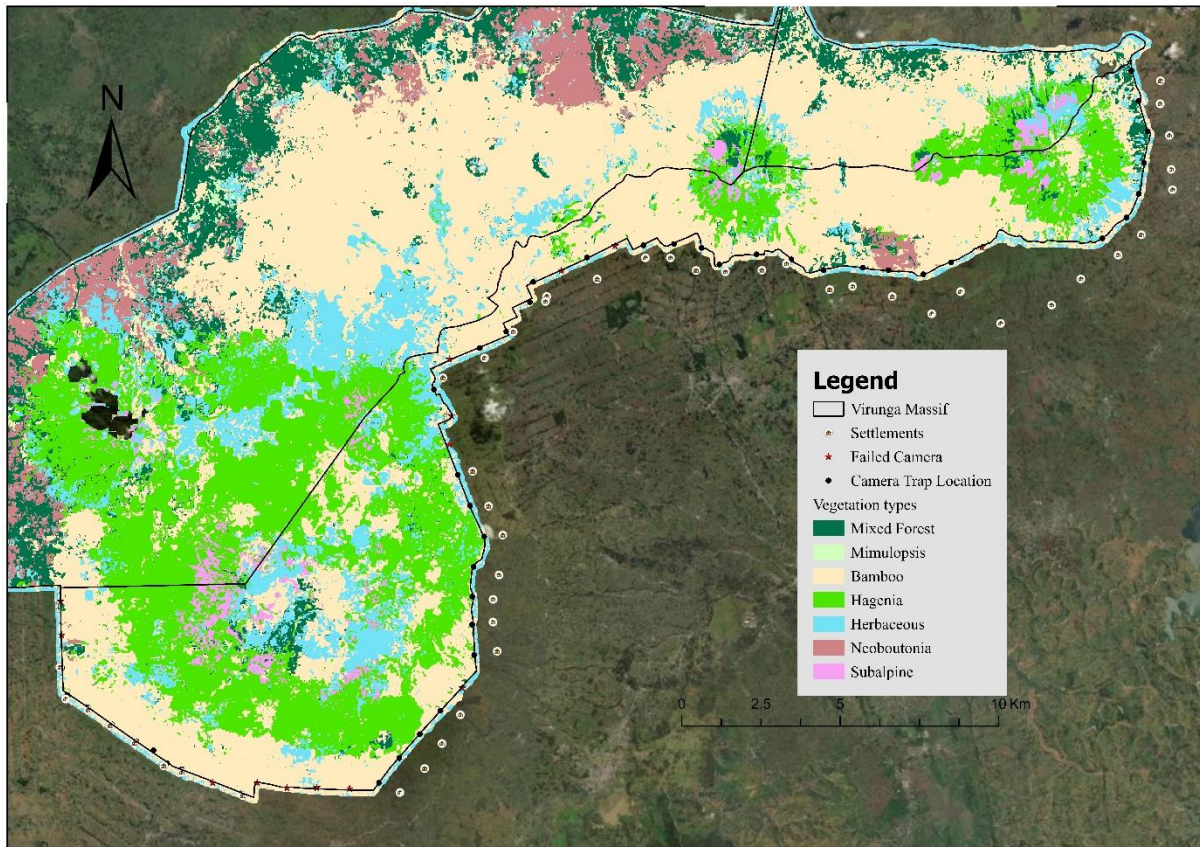


Figure 3. Map showing habitat types inside and location of human settlements around Volcanoes National Park

### 3.2 Data collection

#### 3.2.1 Sampling design

From 30 April to 14 November 2022, we deployed 61 camera traps along the VNP boundary and cameras were attached on a tree trunk or bamboo where trees were absent at ground level (~0.5 meters) facing the opposite direction of sunrise to minimize false triggers. Camera-trapping points were laid out in a linear pattern along the park edge at locations that are close to animal trails without using bait. The detailed setting and sampling design are summarized in the appendix 1. Each camera was left in the field for at least 50 days and was locked to prevent theft or damage. Ground cameras have previously been used inside other National Parks in Rwanda and they have proved to be an effective methodology for surveying the entire mammal community (IGCP/RDB, 2019; Moore et al., 2020; O’Brien et al., 2019). We used Reconyx Hyperfire model camera traps, and all cameras were set to capture 3 consecutive shots without delay when triggered (TEAM Network, 2011). At each camera site, we collected information

on habitat types inside the park, the crop type outside in a radius of 100 meters and we estimated the distance from the nearby settlements.

### **3.2.2 Site variables**

To determine the effect of site variables on the detection of species, we collected habitat types at each location, which consisted of half inside of the park and half outside. To properly assign this, we considered a 100-meter radius from the camera trap location, and we considered 50% inside and 50% outside. Based on the recent image classification done by WWF/IGCP (2018), we have only four types of habitats inside the park for our studied sites: namely mixed forest, bamboo forest, *Neoboutonia*, and *Hagenia* (Figure 2a). Outside the park, the habitats were categorized based on the plantations found during the sampling period; we have identified areas with industrial crops (Pyrethrum) and food crops (Irish potatoes, onion, garlic, wheat, millet), uncultivated area, areas for livestock grazing and forest plantations (Figure 2b). The outside habitats were further put in different land use classes including forestry, farming, and grazing (Figure 2c). We used GIS tools to extract the distance from the nearest settlements from each camera trap point location by overlying the satellite image to the park's shapefile and then extracting the distance in meters (Figure 2d). We fit occupancy models meant to answer hypotheses while accounting for the influence of habitat type inside the protected area, habitat outside in the community land, and land use.

## **3.3 Data analyses**

### **3.3.1 Occupancy models**

The information extracted from images was then manipulated using the software Wild.ID, and transformed in excel spreadsheet to make binary histories and subsequent data cleaning was conducted before sending them into the R statistics environment using the package 'RPresence' (TEAM Network, 2018). For the multi-species adaptation of occupancy models, a 'site' refers to a specific species (16) and site location (47), which corresponds to a total of 752 'sites'. We combined all detections into a detection history for each species for each site (1 = species detected, 0 = species not detected (Mackenzie et al., 2003)). We used 5-day intervals for a total of 10 occasions (i.e., any photos of a species within each 5-day occasion implied detection, and no photos during the 5-day period was recorded as a non-detection).

We have run multi-species occupancy models to calculate the diversity, distribution, detection probability and occupancy (MacKenzie et al., 2017; Moore, Hines, et al., 2019). To understand the activity patterns of native carnivores, in relation to the rest of animal detected and temporal variation, we computed the activity overlapping coefficient between different taxa and native carnivores using the package ‘overlap’ (Meredith & Ridout, 2023). We fit a multi-species occupancy model to detection/non detection data of jackal, serval, golden cat, slender mongoose, servaline genet and spotted hyena obtained from camera traps deployed along the VNP boundary.

To evaluate the likelihood effect of specific interactions, we have explored different activity pattern curves and quantified the level of overlapping among key important species using the overlap package available in R statistic. We considered activity patterns as probability density functions (Linkie and Ridout, 2011), and used R version 3.2.3 to build the functions with the package overlap (Meredith and Ridout, 2018; R Core Team, 2015). The overlap coefficient ranges from 0 (no overlap) to 1 (complete overlap) and is strongly influenced by sample size. For any densities  $f(x)$  and  $g(x)$ ,  $\Delta$  lies in the interval  $[0, 1]$ , with  $\Delta = 1$  if and only if the densities are identical and  $\Delta = 0$  if and only if  $f(x)g(x) = 0$  for all  $x$  (Clemons and Bradley, 2000). Thus, following Ridout and Linkie (2009) we used Dhat 4 instead of Dhat 1 which is recommended for small sample sizes. This measure, which is known as the coefficient of overlapping, has the advantage of being a natural measure of overlap that is easily interpreted geometrically. For activity patterns,  $\Delta = 0$  could arise if one species was strictly diurnal and the other strictly nocturnal, for example.

### 3.3.3 Species interaction analyses

To assess the species interactions, we considered all native carnivores namely the side striped jackal (*Canis adustus*), serval (*Leptailurus serval*), African golden cat (*Caracal aurata*), slender mongoose (*Herpestes sanguineus*), servaline genet (*Genetta servalina*) and spotted hyena (*Crocuta crocuta*). We fit the model for estimating the interactions they have had with the rest of animals detected including the feral dogs, livestock, humans, and other wildlife species. The interaction factor between two species ( $\phi$ ) is defined as the ratio of the occupancy of species A while species B is present divided by the factor of the occupancy of species A and that of species B (Equation 1).

$$\text{Equation 1: } \phi = \frac{\Psi_{AB}}{\psi_{iA} * \psi_{iB}}$$

## CHAPTER 4. RESULTS

A total of 47 sites were sampled. An additional 14 sites did not yield any images either from the camera trap unit failure or damage caused by individuals for unknown reasons. Our sampling success is then equivalent to 77%. We used time-stamped images captured along the park edge to examine and test our hypotheses and predictions. In 2,125 trap days, we obtained a total of 94,830 photographs of animal species belonging to 12 families excluding the domestic animal taxa.

### 4.1 Species composition

Twenty ground-dwelling vertebrates were identified, including four domestic animals, one non-native and six native carnivores, one species of bird, eight other mammal species and humans. In terms of species occurrence, only five species occurred at more than half of the total sites sampled. These include the bushbuck (*Tragelaphus scriptus*) which were detected at 91% of total sites, the side striped jackal (*Canis adustus*) which was found at 87% of sites, the African buffalo (*Syncerus caffer*) which occurred at 70%, feral dog (*Canis lupus familiaris*) which occurred at 62% of the sites and the golden monkeys (*Cercopithecus mitis kandti*) which occurred at 51% of total sites. The rest of species were found on relatively few sites ranging from 2% up to 47% (Table 1). Other species detected include humans, and livestock including the domestic cattle, goat, sheep and rabbit. Humans were detected at 40 sites or 85% of sampled sites, while the domestic animals combined occurred at 8 sites or 17% of all sites.

### 4.2 Species occupancy and detection probability

The multi-species occupancy model showed a high occupancy for bushbuck (93.4%), followed by side striped jackal (90.4%) and human (87.2%) while the low estimates were observed in spotted hyena (2.2%), servaline genet (4.4%) and slender mongoose (8.7%). Other native carnivores including the serval cat and African golden cat had occupancy estimates of 41.5% and 19.8% respectively. The occupancy of the feral dog was 63.7%. and that of livestock was estimated at 15.4%. The detection probability was very high in bushbuck (64%), livestock (57%), buffalo (46%), golden monkey (46%), and jackal (45%) (Table 2).

Table 1. List of ground-dwelling species captured on cameras traps. Table includes class, family, scientific name, common name, behaviour, size, functional guild, IUCN assessment, number of sites where the species was detected, and the total number of events for each species.

Class	Family	Scientific name	Common Name	Guild	Size	IUCN status	Total Events	Sites (Out of 47)
Mammalia	Bovidae	<i>Tragelaphus scriptus</i>	Bushbuck	Herbivore	Medium <sup>1</sup>	LC	2013	43
Mammalia	Bovidae	<i>Syncerus caffer</i>	African buffalo	Herbivore	Large <sup>2</sup>	LC	665	33
Mammalia	Bovidae	<i>Cephalophus nigrifrons</i>	Black-fronted duiker	Herbivore	Medium	LC	103	22
Mammalia	Canidae	<i>Canis adustus</i>	Side-striped jackal	Carnivore	Medium	LC	404	41
Mammalia	Canidae	<i>Canis lupus familiaris</i>	Feral dog	Carnivore	Medium	LC	139	29
Mammalia	Cercopithecidae	<i>Cercopithecus mitis-kandti</i>	Golden monkey	Herbivore	Medium	EN	335	24
Mammalia	Felidae	<i>Leptailurus serval</i>	Serval	Carnivore	Medium	LC	65	19
Mammalia	Felidae	<i>Caracal aurata</i>	African golden Cat	Carnivore	Medium	VU	13	9
Mammalia	Herpestidae	<i>Herpestes sanguineus</i>	Slender mongoose	Carnivore	Small <sup>3</sup>	LC	2	2
Mammalia	Hominidae	<i>Gorilla beringei beringei</i>	Mountain gorilla	Herbivore	Medium	EN	51	8
Mammalia	Hyenidae	<i>Crocuta crocuta</i>	Spotted hyena	Carnivore	Medium	LC	2	1
Mammalia	Hystriidae	<i>Atherurus africanus</i>	African brush tailed porcupine	Omnivore	Small	LC	20	6
Mammalia	Proboscidae	<i>Loxodonta africana</i>	African elephant	Herbivore	Large	EN	7	1

<sup>1</sup> Medium sized animal (5 - 300 kg average adult body mass)

<sup>2</sup> Large sized animal (> 300 kg average adult body mass)

<sup>3</sup> Small sized animal (< 5 kg average adult body mass)

Mammalia	Sciuridae	<i>Funisciurus carruthersi</i>	Carruther's mountain squirrel	Omnivore	Small	LC	1	1
Mammalia	Viverridae	<i>Genetta servalina</i>	Servaline genet	Carnivore	Small	LC	4	4
Aves	Phasianidae	<i>Pternistis nobilis</i>	Handsome francolin	Granivore	Small	LC	37	11
Mammalia	Hominidae	<i>Homo sapiens</i>	Humans <sup>4</sup>				645	40
Mammalia	Bovidae	<i>Bos taurus</i>	Domestic cattle				138	5
Mammalia	Bovidae	<i>Capra aegagrus hircus</i>	Goat				16	3
Mammalia	Bovidae	<i>Ovis aries</i>	Sheep				89	6
Mammalia	Leporidae		Rabbit <sup>5</sup>				7	1

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<sup>4</sup> Both legal (park staff, tourists, people maintaining the stone wall or other people using the edge but don't enter the park) and illegal combined.

<sup>5</sup> Not sure whether domestic or wild

Table 2. Occupancy probability and detection probability of species along VNP edge

Scientific name	Common name	$\Psi$ (SE)	p(SE)
<i>Atherurus africanus</i>	Porcupine	0.550 (0.088)	0.081 (0.013)
<i>Canis adustus</i>	Side-striped jackal	0.904 (0.051)	0.452 (0.026)
<i>Canis lupus familiaris</i>	Feral dog	0.639 (0.085)	0.234 (0.028)
<i>Caracal aurata</i>	African golden cat	0.198 (0.066)	0.063 (0.034)
<i>Cephalophus nigrifrons</i>	Duiker	0.485 (0.088)	0.253 (0.032)
<i>Cercopithecus mitis kandti</i>	Golden monkey	0.549 (0.088)	0.456 (0.033)
<i>Crocuta crocuta</i>	Spotted hyena	0.022 (0.022)	0.165 (0.137)
<i>Genetta servalina</i>	Servaline genet	0.087 (0.045)	0.009 (0.005)
<i>Gorilla beringei beringei</i>	Mountain gorilla	0.175 (0.063)	0.184 (0.050)
<i>Herpestes sanguineus</i>	Slender mongoose	0.044 (0.032)	0.005 (0.003)
<i>Homo sapiens</i>	Human	0.872 (0.057)	0.430 (0.026)
<i>Leptailurus serval</i>	Serval	0.415 (0.086)	0.247 (0.034)
<i>Pternistis nobilis</i>	Francolin	0.242 (0.073)	0.190 (0.043)
<i>Syncerus caffer</i>	Buffalo	0.723 (0.078)	0.456 (0.029)
<i>Tragelaphus scriptus</i>	Bushbuck	0.934 (0.042)	0.644 (0.024)
	Livestock	0.154 (0.059)	0.568 (0.062)

The averaged multi-species occupancy model (across all possible models) showed that the estimated occupancy was 0.437 (SE 0.063), and the detection probability was estimated at 0.374 (SE 0.016). The top-ranking model included habitat inside the park on occupancy and habitat outside on the detection probability ( $\Psi$ (Species+Hab1) p(Hab2)) with 61% weight over other models. The occupancy was high in mixed forest ( $\Psi=0.627$ (SE 0.095)), followed by *Hagenia* ( $\Psi=0.598$  (SE 0.091)), bamboo ( $\Psi =0.587$  (SE 0.095)), and *Neobutonia* forest ( $\beta=0.570$  (SE 0.108)). The detection probability was high in area occupied by industrial crops (p=0.521(SE 0.048), followed by agroforestry (p=0.383 (SE 0.033)), food crops (p= 0.378 (SE 0.010)), bare soil (p=0.315(SE 0.027)) and low in pasture area (p=0.287 (SE 0.052) (Table 3).

Table 3. Model comparison table for multi-species single-season occupancy models testing for the effect of covariates on occupancy ( $\Psi$ ) and detection probability ( $p$ ). Model structure, AIC (Akaike information criterion), number of parameters,  $\Delta$ AIC (change in AIC between top model and selected model) and model weights are all presented. Sample size is 752 (47 sites\*16 species). Covariates are distance from settlements, land use, habitat type inside (Hab1) and habitat type outside (Hab2).

<b>Model</b>	<b>AIC</b>	<b>Npar</b>	<b><math>\Delta</math>AIC</b>	<b>Weight</b>
$\Psi(\text{Species}+\text{Hab1})p(\text{Hab2})$	4739.87	24	0.00	0.61
$\Psi(\text{Species})p(\text{Hab2})$	4742.43	21	2.56	0.17
$\Psi(\text{Species}+\text{Distance})p(\text{Hab2})$	4744.41	22	4.54	0.06
$\Psi(\text{Species}+\text{Hab1})p(\text{LandUse})$	4744.65	22	4.78	0.06
$\Psi(\text{Species}+\text{LandUse})p(\text{Hab2})$	4745.36	23	5.49	0.04
$\Psi(\text{Species})p(\text{LandUse})$	4747.15	19	7.28	0.02
$\Psi(\text{Species}+\text{Hab2})p(\text{Hab2})$	4747.62	25	7.75	0.01
$\Psi(\text{Species}+\text{Hab1})p()$	4748.61	20	8.73	0.01
$\Psi(\text{Species}+\text{Distance})p(\text{LandUse})$	4749.14	20	9.26	0.01
$\Psi(\text{Species}+\text{LandUse})p(\text{LandUse})$	4750.08	21	10.21	0.00
$\Psi(\text{Species}+\text{Hab1})p(\text{Distance})$	4750.25	21	10.38	0.00
$\Psi(\text{Species}+\text{Hab1})p(\text{Hab1})$	4750.61	23	10.74	0.00
$\Psi(\text{Species})p()$	4751.40	17	11.52	0.00
$\Psi(\text{Species}+\text{Hab2})p(\text{LandUse})$	4752.64	23	12.76	0.00
$\Psi(\text{Species})p(\text{Hab1})$	4752.77	20	12.90	0.00
$\Psi(\text{Species})p(\text{Distance})$	4753.06	18	13.18	0.00
$\Psi(\text{Species}+\text{Distance})p()$	4753.38	18	13.51	0.00
$\Psi(\text{Species}+\text{LandUse})p()$	4754.33	19	14.46	0.00
$\Psi(\text{Species}+\text{Distance})p(\text{Hab1})$	4754.74	21	14.87	0.00
$\Psi(\text{Species}+\text{Distance})p(\text{Distance})$	4755.05	19	15.18	0.00
$\Psi(\text{Species}+\text{LandUse})p(\text{Hab1})$	4755.79	22	15.91	0.00
$\Psi(\text{Species}+\text{LandUse})p(\text{Distance})$	4755.99	20	16.12	0.00
$\Psi(\text{Species}+\text{Hab2})p()$	4756.86	21	16.98	0.00
$\Psi(\text{Species}+\text{Hab2})p(\text{Hab1})$	4758.25	24	18.38	0.00

### 4.3 Relationship between site variables and native carnivores

To understand the relationship between site variables and carnivores, multi-species occupancy models were conducted to all native carnivores (jackal, serval, golden cat, slender mongoose, servaline genet, spotted hyena). The results showed that the occupancy of native carnivores increases as distance from settlements increases ( $\beta=0.559$  (SE 0.195)). The individual native species showed that this relationship is evident for jackal, African golden cat, serval and genet, contrary to hyena and, mongoose whose occupancy estimates decrease as distance to settlements increases (Figure 4a). The combined occupancy of native carnivores was estimated at 0.221 when the distance to the nearest settlements is 68 m, but 0.598 when the distance is 2818 m (Figure 4b).

It was found that occupancy is slightly higher in the areas used for farming, followed by the grazing area while the forested stand is poorly occupied. But when considering different farming uses, the estimates showed low occupancy in sites located in areas used for industrial agriculture, for direct consumption and areas not cultivated. The areas used for livestock keeping are highly attractive to native carnivores compared to areas covered by crops, and agroforestry. Considering the habitat types inside the protected area, the estimated occupancy was high in *Neoboutonia*, followed by mixed forest, bamboo and *Hagenia* (Figure 5).

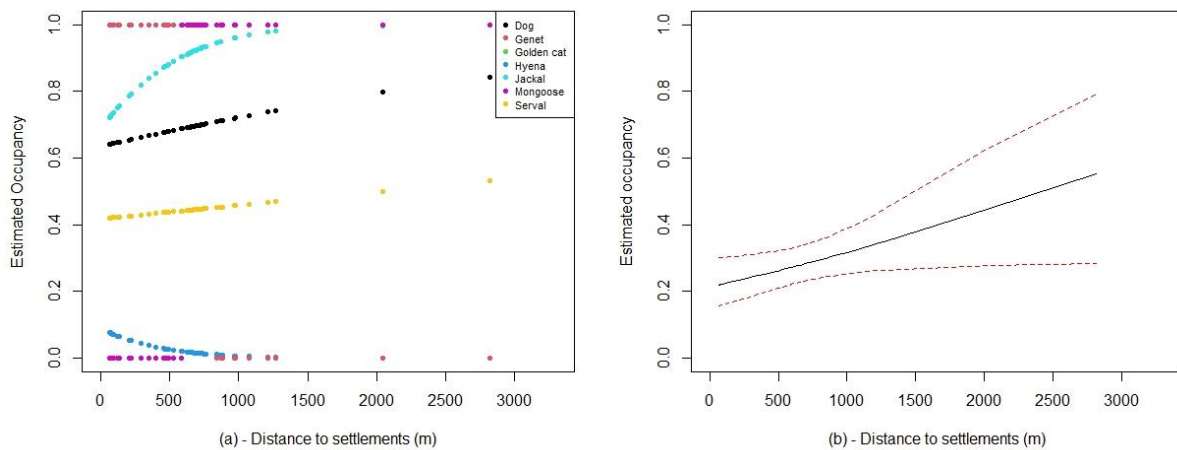


Figure 4. Relationship between estimated occupancy and the distance from the nearest settlements: (a) showing the relationship between individual carnivore species estimates and (b) representing the combined trend of all native carnivore species.

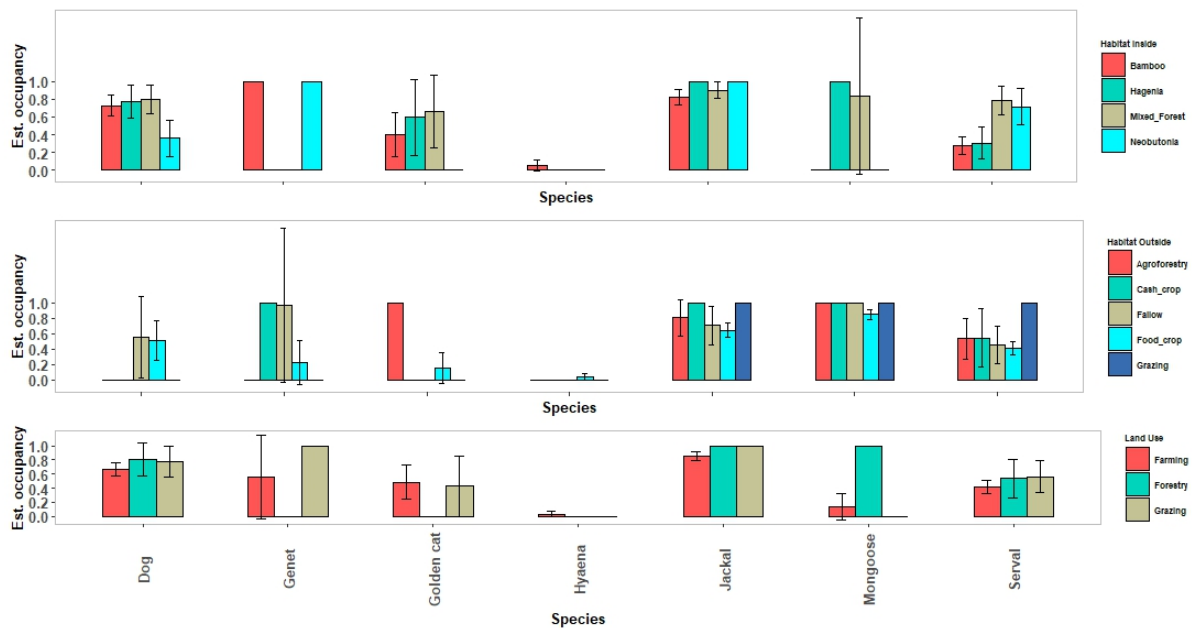


Figure 5. Occupancy estimates in different habitat types and land use for carnivores found along the park edge – community land interface.

#### 4.4 Interaction between carnivores and other species

Considering the major carnivore species detected, we have examined different parameters including the interaction factor, the occupancy of the considered carnivores in the presence of other species and the estimated occupancy while the carnivore species were absent. The species interacted by attraction or avoidance (Figure 6). The African golden cat was found to co-occur mostly with the mountain gorilla, livestock, golden monkey and duiker with a species interaction factor (SIF) of 2.42 (SE 0.728), 2.24 (SE 0.868), 1.37 (SE 0.411) and 1.32 (SE 0.307) respectively. The serval was attracted to francolin (1.31 (SE 0.32)), buffalo (1.26 (SE 0.119)) and feral dog (1.22 (SE 0.14)). While the side-striped jackal was attracted to gorillas (1.12 (SE 0.061)), mongoose (1.07 (SE 0.061)) and feral dog (1.04 (SE 0.049)). The golden cat showed an avoidance toward francolin (0.4 (SE 0.381)) and serval (0.4 (SE 0.315)); the Jackal showed an avoidance toward francolin (0.4 (SE 0.381)) and serval (0.4 (SE 0.315)); the Jackal showed an avoidance to golden monkey (0.93 (SE 0.051)) while the serval showed an avoidance toward livestock (0.4 (SE 0.315)), gorilla (0.6 (SE 0.339)), and golden monkey (0.7 (SE 0.167)) (Figure 7). The occupancy of buffalo, bushbuck, duiker, livestock, golden monkey, and gorilla was high when the African golden cat was present; in the presence of jackal, the probability of occupancy was high in buffalo, bushbuck, duiker, and the presence of serval favoured the occupancy of buffalo, bushbuck, duiker, feral dog, francolin, and human.

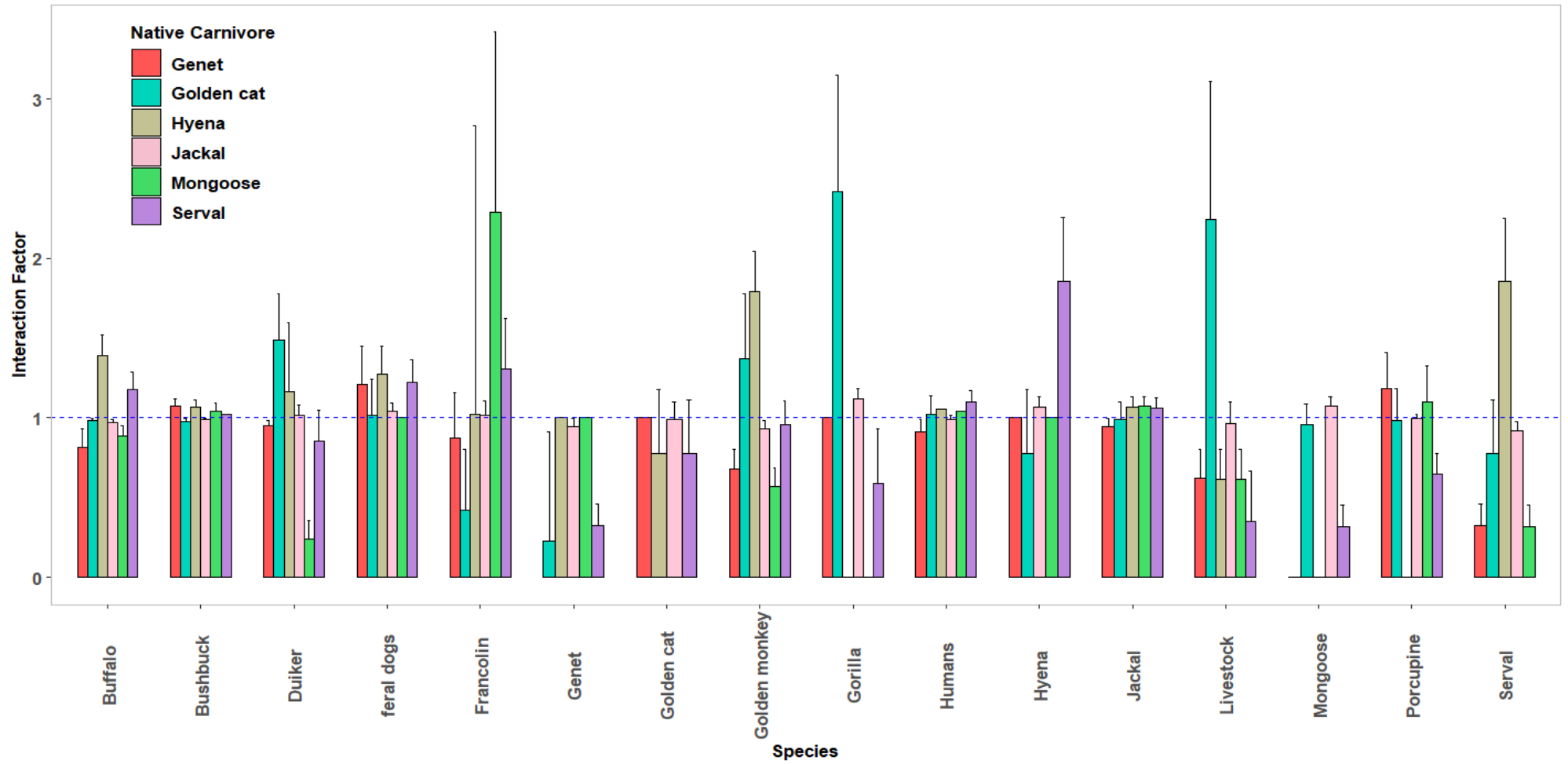


Figure 6. Species interaction factor between native carnivores and other species – the coefficient greater than one shows an attraction or co-occurrence while the values below one is considered as an avoidance.

In terms of species interaction, we found that all native carnivores avoided livestock; serval, mongoose and genet avoided human presence, while the genet avoided the feral dog ( $SIF < 1$ ) (Figure 7). The attraction was observed in jackal, golden cat, and hyena to humans. All native carnivores except the genet were attracted to feral dogs ( $SIF > 1$ ) (Table 4).

Table 4. Co-occurrence results for non-native species (species A) and carnivores (species B) including the species interaction factor (SIF) at the interface between VNP and local communities.

	$\psi_{BA}$	$\psi_{Ba}$	$r_{BA}$	$r_{Ba}$	SIF ( $\phi$ )
Livestock-Serval	0.86 (0.06)	1.00 (0.00)	0.36 (0.04)	0.52 (0.04)	0.99 (0.01)
Livestock-Mongoose	0.87 (0.07)	1.00 (0.00)	0.72 (0.14)	0.25 (0.03)	0.96 (0.02)
Livestock-Jackal	0.86 (0.13)	1.00 (0.00)	0.67 (0.27)	0.75 (0.04)	0.91 (0.08)
Livestock-Hyena	0.09 (0.05)	1.00 (0.00)	0.00 (0.00)	0.31 (0.09)	0.62 (0.19)
Livestock-Genet	0.09 (0.05)	1.00 (-)	0.00 (0.00)	0.31 (0.09)	0.62 (0.19)
Livestock-Golden cat	0.14 (0.05)	1.00 (0.00)	0.61 (0.12)	0.68 (0.08)	0.6 (0.15)
Human-Serval	0.07 (0.04)	1.00 (-)	0 (-)	0.86 (0.07)	0.46 (0.19)
Human-Mongoose	0.33 (0.17)	1.00 (0.00)	0.5 (0.35)	0.62 (0.1)	0.42 (0.18)
Human-Jackal	1.00 (-)	0.94 (0.11)	0.5 (0.35)	0.75 (0.04)	1.04 (0.08)
Human-Hyena	1.00 (-)	0.92 (0.09)	1.00 (-)	0.8 (0.04)	1.06 (0.07)
Human-Genet	0.72 (0.09)	0.79 (0.66)	0.29 (0.05)	0.2 (0.04)	0.99 (0.1)
Human-Golden cat	1.00 (-)	0.76 (0.12)	0.5 (0.35)	0.62 (0.1)	1.27 (0.18)
Dog-Serval	0.94 (0.04)	0.7 (0.14)	0.4 (0.08)	0.31 (0.03)	1.08 (0.06)
Dog-Mongoose	0.84 (0.09)	0.69 (0.24)	0.31 (0.08)	0.29 (0.04)	1.1 (0.18)
Dog-Jackal	1.00 (0.00)	0.51 (0.39)	0.5 (0.35)	0.12 (0.06)	1.21 (0.24)
Dog-Hyena	0.92 (0.14)	0.44 (0.23)	0.2 (0.13)	0.14 (0.03)	1.16 (0.16)
Dog-Genet	0.13 (0.07)	0.18 (0.08)	1.00 (0.00)	0.85 (0.07)	0.84 (0.36)
Dog-Golden cat	0.28 (0.16)	0.07 (0.05)	0.25 (0.22)	0.45 (0.08)	1.84 (0.89)

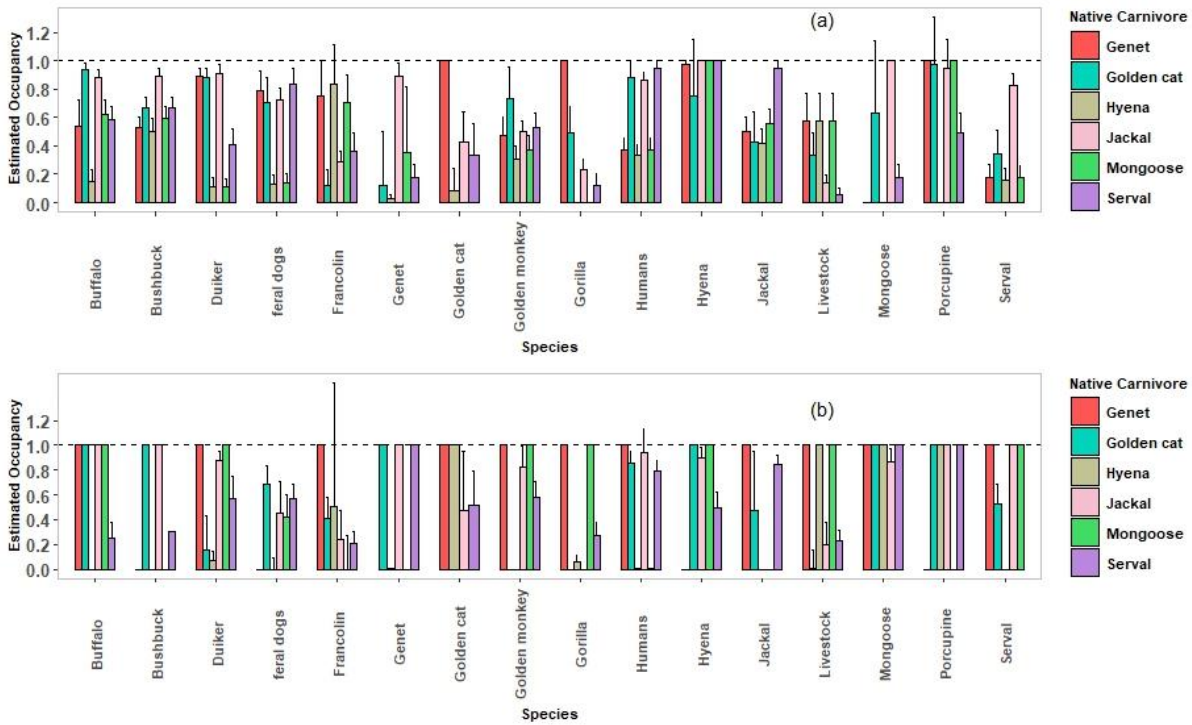


Figure 7. Relationship between native carnivores and other animal species, (a) showing the conditional probability of occupancy of species considered, given the native carnivore species is present ( $\psi_{BA}$ ) of each species while a select native carnivore is present and (b) showing the conditional occupancy of a given species given the native carnivore species is not present ( $\psi_{Ba}$ ).

#### 4.5 Activity overlap of individual native carnivore and other taxa

High overlapping activity between native carnivores and other wildlife varied greatly between species. The serval cat had a high degree of activity overlap with the jackal ( $\hat{\Delta}=0.86$ ), feral dog ( $\hat{\Delta}=0.84$ ), bushbuck ( $\hat{\Delta}=0.69$ ), and duiker ( $\hat{\Delta}=0.69$ ). The jackal activity overlapped with feral dog ( $\hat{\Delta}=0.78$ ), bushbuck ( $\hat{\Delta}=0.69$ ), and duiker ( $\hat{\Delta}=0.62$ ). The golden cat had a high overlap with genet ( $\hat{\Delta}=0.73$ ), buffalo ( $\hat{\Delta}=0.73$ ), porcupine ( $\hat{\Delta}=0.67$ ), bushbuck ( $\hat{\Delta}=0.64$ ), and hyena ( $\hat{\Delta}=0.69$ ). The mongoose had a high activity overlap with gorilla ( $\hat{\Delta}=0.64$ ), livestock ( $\hat{\Delta}=0.67$ ) and human ( $\hat{\Delta}=0.74$ ). Hyena overlapped with porcupine ( $\hat{\Delta}=0.66$ ), buffalo ( $\hat{\Delta}=0.69$ ) and genet ( $\hat{\Delta}=0.71$ ). The genet overlapped with porcupine ( $\hat{\Delta}=0.91$ ), and buffalo ( $\hat{\Delta}=0.89$ ). Both livestock and humans showed medium activity overlap with jackal ( $\hat{\Delta} = 0.40$ , and  $\hat{\Delta} = 0.44$ ), and serval ( $\hat{\Delta} = 0.33$ ,  $\hat{\Delta} = 0.41$ ), and very low overlap with golden cat ( $\hat{\Delta} = 0.10$ ,  $\hat{\Delta} = 0.17$ ), hyena ( $\hat{\Delta} = 0.04$ ,  $\hat{\Delta} = 0.06$ ) and genet ( $\hat{\Delta} = 0.05$ ,  $\hat{\Delta} = 0.06$ ) (Table 5).

In terms of daily activity partitioning, the serval and side striped jackal are active throughout the day, but crepuscular; the spotted hyena, servaline genet, and porcupine are mostly nocturnal. The feral dog,

bushbuck and duiker showed an activity pattern running throughout the day with peak in the morning hours for dog, and for duiker and bushbuck the activity peak in the evening hours. Golden monkey, mountain gorilla, francolin, human, mongoose and livestock showed a diurnal activity preference (Figure 8).

Table 5. Overlapping coefficients estimated for native carnivores and other species.

Species	Dhat					
	Serval	Jackal	Golden cat	Mongoose	Hyena	Genet
Porcupine	0.21	0.27	<b>0.67</b>	0.01	<b>0.66</b>	<b>0.91</b>
Gorilla	<b>0.57</b>	0.49	0.20	<b>0.64</b>	0.09	0.09
Monkey	0.50	0.42	0.13	<b>0.57</b>	0.04	0.05
Buffalo	0.39	0.39	<b>0.76</b>	0.08	<b>0.69</b>	<b>0.89</b>
Duiker	<b>0.69</b>	<b>0.62</b>	0.25	0.41	0.20	0.19
Bushbuck	<b>0.69</b>	<b>0.69</b>	<b>0.64</b>	0.17	<b>0.57</b>	<b>0.56</b>
Francolin	0.47	0.39	0.11	<b>0.54</b>	0.03	0.04
Livestock	0.40	0.33	0.10	<b>0.67</b>	0.04	0.05
Human	0.49	0.41	0.17	<b>0.74</b>	0.06	0.06
Dog	<b>0.84</b>	<b>0.78</b>	<b>0.56</b>	0.42	0.36	0.35
Golden Cat	<b>0.54</b>	<b>0.54</b>	1.00	0.12	<b>0.69</b>	<b>0.73</b>
Jackal	<b>0.86</b>	1.00	<b>0.54</b>	0.26	0.35	0.33
Serval	1.00	<b>0.86</b>	<b>0.54</b>	0.29	0.36	0.34
Mongoose	0.31	0.28	0.16	1.00	0.03	0.03
Genet	0.34	0.33	<b>0.73</b>	0.01	<b>0.71</b>	1.00
Hyena	0.36	0.35	<b>0.69</b>	0.03	1.00	<b>0.71</b>

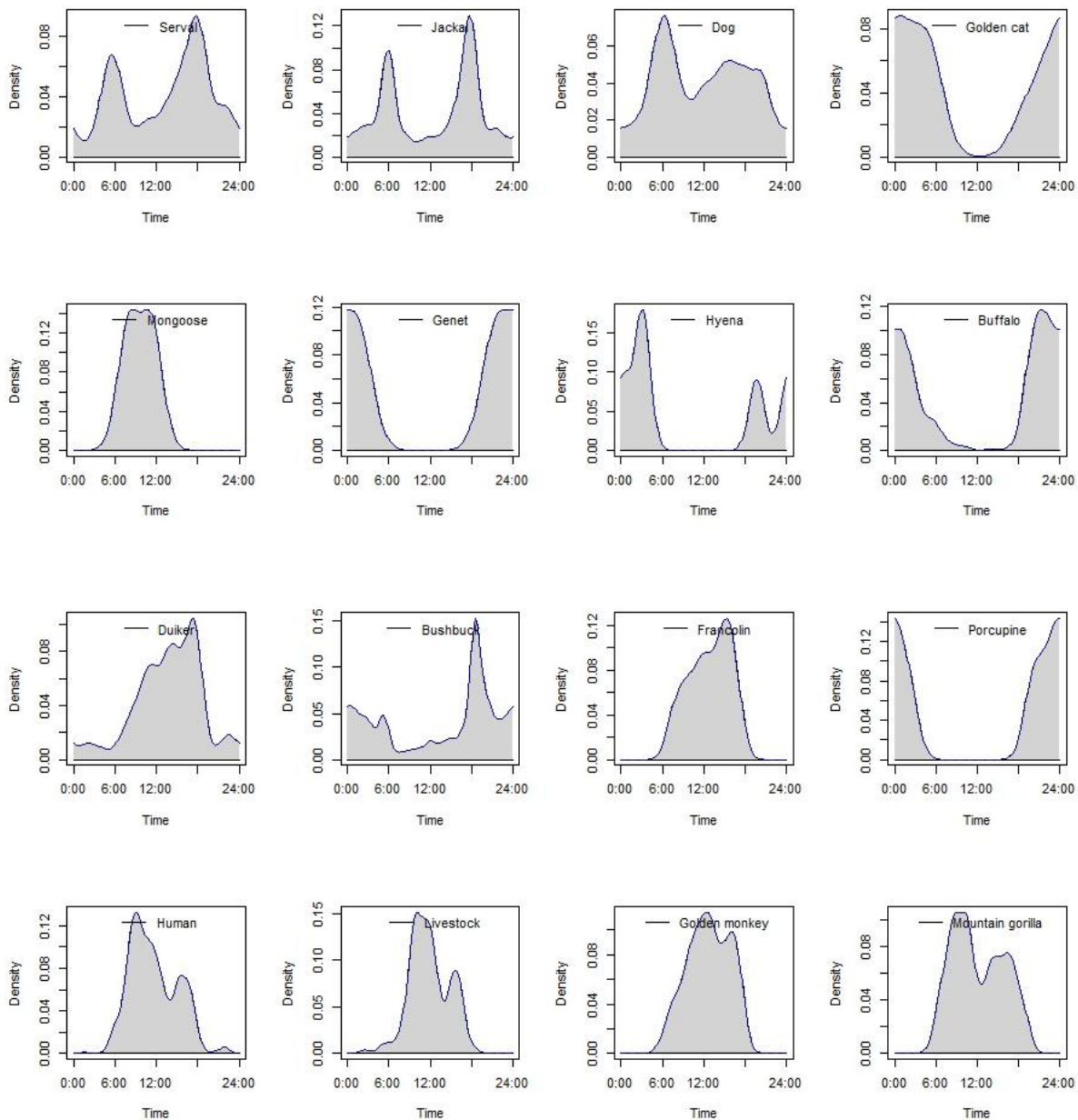


Figure 8. Temporal activity of species found from camera-trap data calculated based on the kernel density.

#### 4.6 Native carnivores' distribution patterns

For species distribution, we present model-averaged results from the entire model set, with all covariates. The proportion of sites where a given species was estimated to be present ( $\psi$ ) varied from 0.404 to 0.522 (mean=0.463 (SE 0.074)), which corresponds to a distribution of 19 to 25 sites out of 47 total sites (mean=22 sites (SE 4)). Considering the distribution of native carnivores, we found a high site-specific

distribution in side-striped jackal, followed by the serval cat, and golden cat and very few sites for the genet, slender mongoose, and hyena (Table 2). The distribution map showed that sites in the Eastern part of the park had more native carnivores compared to the rest of the sites. One site showed to have four species out of 6 identified species, one site had three species, 22 sites had on average 2 species, while 23 sites had only one species (Figure 9a). The native carnivore species distribution, show that the jackal, serval, and golden cat were widely distributed across sites, while genet, mongoose and hyena occurred at few sites. Native carnivores were absent on three surveyed sites (Figure 9b).

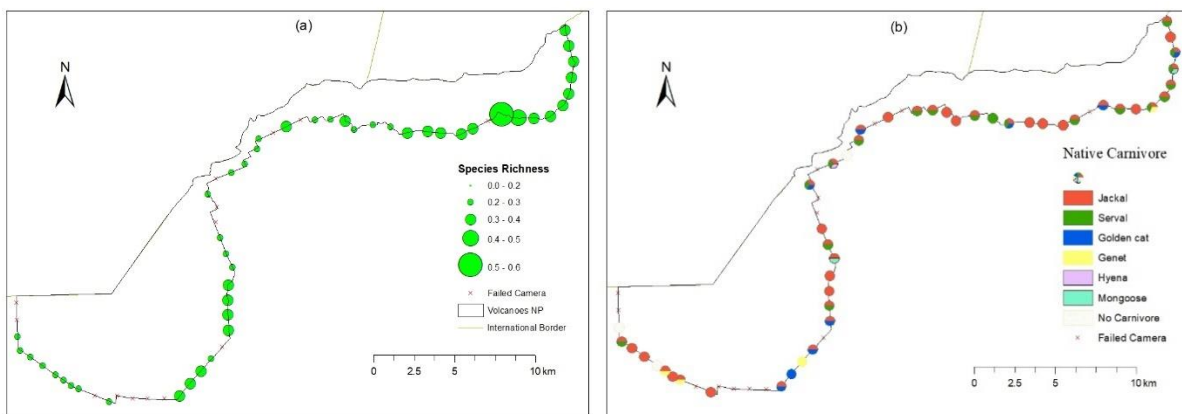


Figure 9. Map showing the distribution of native carnivores along the VNP edge in (a) is the estimated species richness per site, and (b) is the individual species distribution map.

## CHAPTER 5. DISCUSSION

The results of this study were not able to quantify the extend at which carnivores are involved in livestock predation around the park. The findings provided the baseline information on carnivore using the park edge and insights on their interactions with other wildlife, livestock, and human activities at the interface between the park and local communities. Camera traps are a non-invasive method, allowing for the detection of cryptic or rare species (Chatterjee et al., 2020; O'Connell et al., 2011). The results of this study were not able to quantify the extend at which carnivores are involved in livestock predation around the park.

The identified 20 species included native species, feral dogs, livestock and humans (Table 1). The current study, helped to detect more species compared to the species published by Uzabaho et al. (2023). For example, two more wildlife species (spotted hyena, and the porcupine), reported to inhabit the forest were missed in previous surveys (Ebert & Fowler, 2021). Apart from the wildlife species, we have also detected four different livestock taxa namely the cattle, goat, sheep and rabbit mostly using the park edge for grazing. The spotted hyena is believed to have been involved in killing livestock in many protected area including the recent problem reported around Gishwati-Mukura National Park (GMNP) (Uzabaho et al., 2022). The co-occurrence of livestock, feral dogs and humans and native wildlife is a challenge for both wildlife conservation inside the protected area and local communities who are negatively affected in different ways including interspecific competition, disease exposure and increased conflicts. The presence of carnivores at the edge of the park, can lead to depredation of livestock and directly affect the local community's livelihood (Verschueren et al., 2020).

In terms of richness, there were more species per site in the eastern part of the park, partly due to the available habitats and land use in the community as well as the long distance to settlements. The covariates are important predictors of species occurrence (Rovero et al., 2014) and more often the disturbance level was less noticed in the eastern part of the park compared to the western and central parts of the park, which are busy with tourism activities and human illegal activities, plus the number of damaged camera trap units (Figure 9 ). For example, it was found that native carnivores occurred mostly in areas used for livestock grazing and farming rather than in areas occupied by forest plantations. This may be due to the good conditions prevailing in those areas, offering more food resources to them. The six native carnivores showed uneven distribution, which can be explained by the available habitats and land use outside the park. Though we did not quantify the contribution of the existing conditions, it is evident that some wildlife will prefer living where disturbance is high – such that they make profit of available habitat types (Oberosler et al., 2017). The relative species

richness varied from two to four species per site, confirming complex between carnivore interactions (Glen & Dickman, 2005).

The results show that native carnivore diversity is relatively low but dominated by only three species and are affected by existing site variables. The side-striped jackal has a high occupancy ( $\psi=0.83$ ), represent a major proportion of the native carnivore population using the edge; this may be because the species diet is varied as canids tend to be classified as omnivores, feeding on a range of food items including insects, fruits, small vertebrates, carrion, and plant materials. This might be one of the reasons pushing them to come closer to the park boundary, where there is a variety of food and could explain its extensive distribution (Atkinson et al., 2002). Similar behaviour was found in GMNP, where the side-striped jackal is common, while the diversity of herbivore is very reduced to only primates (REMA, 2018; Uzabaho, Turikunkiko, et al., 2022).

The loss of livestock due to predation is not commonly reported but there is a high probability of this happening. These predation events are sometimes attributed to feral dogs or local native carnivores that are hard to identify and recognize. It was found that for example, the African golden cat can even reach further distances from the park edge as observed from the recent evidence around Bwindi impenetrable by Mugerwa et al. (2013). Domestic dogs are sometimes used by local communities to guard their land against crop raiders; this may pose a high risk of disease transmission from feral dogs to native species including endangered species (Guinness, 2015). For example, the side striped jackal is also prone to this risk as they are closely related to dogs being in the same Canidae family (Atkinson et al., 2002).

In a similar study using camera traps, feral dogs were thought to come from the community and this study confirms this because their occupancy and detection seem to be higher in the current sites compared to that of a previous study (Uzabaho et al., 2023). The feral dogs not only threaten wildlife inside the protected area, but also the local communities because they might also prey on livestock if not well managed. The results also indicate the positive interaction between feral dogs and all native carnivores ( $SIF >1$ ), this may negatively affect the small population of native carnivores in the area. In many situations, native carnivores are attracted by the availability of food in the agricultural land, or carrion from the people's home (Williams et al., 2018). With current household capacity to sustainably manage their pets, those dogs sometimes escape the owners and end up being free roaming around and may also be causing some of the conflicts.

High occupancy and detection probabilities were recorded in bushbuck and jackal as species mostly using the edge. The presence of the African golden cat reveals the value of this habitat and its surroundings. However, the presence of high human activities in the vicinity of the park threatens the diversity in general.

The edge is mostly a disturbed area (Oberosler et al., 2017), and disturbance offers many opportunities and a variety of habitats and conditions fitting many ecological niches – we infer then that the protection of edges is ultimately important for wildlife and communities but also brings disadvantages in terms of sustainability and gene pool within the wildlife populations. It is an area prone to disease transmission, and gene adaptation but also on a social economic aspect, it is a challenge for managing conflicts between local farmers and wildlife populations especially the less valued taxa. The schedule of the native carnivores of daily activity showed a bimodal pattern, with peaking activity at the dusk and dawn hours for most occurring species namely side-striped jackal and serval cat. The moderate overlapping activity observed between serval and jackal with humans, can be attributed to the existing coexistence which might be linked to resources partitioning, and availability in the interface between community and the park. However, little was investigated regarding these resources, hence it should be interpreted as simple species interactions. Though the serval or jackal and human pairwise activity overlap more than any other native carnivore, there is a shift to crepuscular/cathemeral activity patterns for serval and jackal translating an avoidance behaviour to humans by these two species and this may be attributed to the fact that these areas are mostly frequented by human activities – tourism, illegal activities and or agricultural activities. Other species (African golden cat, servaline genet and spotted hyena) strongly showed a very low activity overlap with humans, which may be due to their elusive behaviour but also to the low density as they were less detected in the area. But a high overlap ( $\hat{\Delta}=0.69$ ) observed between slender mongoose and humans may be interpreted with caution given low data captured and its generalist feeding behaviour where it feeds on insects, rodents and poultry. This could explain its diurnal behaviour as to maximize the hunting in the open space (Hoffmann & Taylor, 2013).

However, studies on activity patterns showed that human disturbance does not always affect the temporal partitioning among carnivores, because some species may maximize their co-occurrence frequencies in less disturbed areas, with less human activities, or narrow their activity peaks in certain hours (Chen et al., 2023; Sévêque et al., 2022). The fact that the serval and jackal activity patterns

were mostly peaking at dawn or dusk hours, may be linked to a strategy of human activities avoidance which mainly are intense during day's hours.

The activity overlap patterns between native carnivores and livestock are similarly identical with that of humans, simply because most of the time, the livestock are with humans, except when humans were involved in other activities including tourism, antipoaching and illegal activities. However, we can confidently highlight that the interaction of livestock and native carnivores can create negative interactions especially linked to predation, competition of resources, and disease transmission possibilities. The use of the livestock and carnivores for the same space is evidenced and might threaten both wildlife and livestock hence jeopardize the livelihoods income (Verschueren et al., 2020). There is always a cost attached to staying close to the park especially for poor communities as the park act as a source of fodder for their livestock (Tolbert et al., 2019) but also the presence of livestock may attract native carnivore in this case as potential prey, which are not even adapted to wild behaviours. For example, the African golden cat showed a strong attraction to livestock ( $SIF > 1$ ), though having a low overlap coefficient with humans– this can be due to the presence of humans as a deterrent but provide strong evidence of the potential conflict to livestock.

Native carnivores also show a high overlap with feral dogs and this has effects on both their occurrence and distribution along the park edge (Farris et al., 2015). The dogs are an important competitor for both jackal and serval as well as to African golden cat, and they generally originate from the neighbouring settlements because of improper pet keeping methods. Looking at the native carnivore activity partitioning, we realised that the dog's activity peak in the morning hours while the serval and jackal showed the peaking activities in the evening hours. This is an avoidance strategy displayed toward the feral dog and threatens the native carnivore community. Except for slender mongoose, which seems to be less interacting with dogs, the other five species showed an attractive behaviour ( $SIF \geq 1$ ), coupled with overlapping activities mostly with serval, side-striped jackal, and African golden cat and relatively moderate with spotted hyena, servaline genet and slender mongoose. Carnivore coexistence was obvious and unavoidable, which resulted in the partition of niches to allow coexistence. However, the interaction with other species and humans that results in a different niche partitioning at most of sites still raises significant worries regarding temporal unpredictability and area use. We are not sure if this is the result of the edge effect, despite the fact that the current patterns might potentially imply its influence on what we found.

## CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

This study helped to understand the distribution and preferences of native species along the park edge, using similar trapping methods while accounting for imperfect detection. The approach allowed to estimate the species occupancy probabilities of rare species by associating with commonly detected species. This was the first study assessing the native carnivore diversity, distribution, and effect of site covariates such as habitat types, land use and distance to settlements.

The findings indicated the extent at which wildlife exits the park and the level of disturbance shows that native carnivores, livestock, humans and other wild species interact more often at the edge than we believed. These interactions provide evidence of a complex coexistence of all species and interdependence in maintaining the integrity of the ecosystem. However, the negative effects of native carnivores on livestock cannot be undermined in the human/livestock wildlife context.

The study provided baseline information on our understanding of the carnivore community along the park boundary. We can absolutely confirm that generally the conditions are good for sustaining the population of native carnivores, given the importance of carnivores in ecosystem health, and the direct impact to communities living in adjacent areas (Jay, 1996). Our findings reveal strong temporal overlap among carnivores and other wildlife, human and livestock. Combining the co-occurrence information with that overlapping information, we found that feral dogs mostly interact with native carnivores.

Overall, our findings provide information on the trends of native carnivore species using the interface that inhabit the VNP in Rwanda, and their implications to human-wildlife interactions. These results can be used to inform species monitoring protocols and overcome the current challenges posed by animal causing conflicts to the local communities.

The lack of buffer zone around protected areas poses a direct threat to wildlife that is subject to death and the resulting human wildlife conflicts. The occurrence of feral dogs throughout the area indicates the level of threat they may cause to the native wildlife including native carnivores. This may lead to disease transmission and disturbance of wildlife as an exotic species but also competition for food resources. However, subsequent illegal activities and or mismanagement of pets around the natural habitats may negatively affect native species and biodiversity equilibrium in the future.

We recommend that the park management and partners find solutions to free roaming dogs and enforce the policy for keeping dogs as pet animal – through proper handling. Secondly, we propose the community to make strong defensive structures for keeping livestock including poultry, rabbit and small cattle for avoiding carnivore – livestock conflicts. We also encourage the local community to adopt the modern techniques for livestock keeping which not only is a source of income for the households but also for reducing the pressure faced by the protected wildlife against poaching.

We suggest close monitoring of the carnivore community and implementing mitigation plans for tackling the likely conflicts that might affect wildlife, livestock, and local communities' livelihood and costing them resources. We anticipate that some of current livestock keeping are hindered by the challenges of having native carnivores interacting along the park and community interface.

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## APPENDIX

### Appendix 1. Details of sampling designs and features for the camera trap survey

	Objective	Carnivore Diversity, Distribution and their interactions with other wildlife at the park-human community interface in Rwanda
Study Design	Species Targeted	<i>Syncerus caffer</i>
		<i>Loxodonta africana</i>
		<i>Cephalophus nigrifrons</i>
		<i>Tragelaphus scriptus</i>
		<i>Cercopithecus mitis kandti</i>
		<i>Canis lupus familiaris</i>
		<i>Canis lupus familiaris</i>
		<i>Gorilla beringei beringei</i>
		<i>Pternistis nobilis</i>
		<i>Crocota crocuta</i>
		<i>Genetta servalina</i>
		<i>Leptailurus serval</i>
		<i>Caracal aurata</i>
		<i>Homo sapiens</i>
	Livestock (cattle, goat, sheep and Rabbit)	
	<i>Canis adustus</i>	
	Site	Volcanoes National Park, Rwanda
Habitat	Montane forest	
	elevation range 2500 - 3884 m	
	At 5 m from the park boundary	
	Human pop. density > 500 hab. km <sup>-2</sup>	
Trap layout	Linear along the stone wall	
	Navigate to point and set camera within 50 traps deployed for up to 50 days; sampling period considered 5 days samples	
	Total 62 points, distance of approximately 1 km between points.	
	Camera trap setup follows TEAM protocol, using single camera deployment per site	
Survey design	Traps used	Reconyx HC500 Semi-Covert IR Reconyx PC800 Hyperfire Professional IR
	Trap placement	50-60 cm above ground level
perpendicular to most likely pathway		
3 m to centre of detection zone		
Horizontal orientation		

	Habitat modification	Minimal
	Lure	None
	Mode of operation	Still
Trap settings	Flash	none
	Delay period	No delay
	Images per trigger	3 images per trigger
	Trigger speed	High