FINAL REPORT:

Survey of wildlife population in the Grebo-Krahn National Park (GKNP), using Camera Trap and line transects Distance Sampling

(December 2019- August 2020)

Prepared by Wild Chimpanzee Foundation

In collaboration with the Forestry Development Authority, Liberia

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

SUMMARY

This report presents results from the first biomonitoring survey since the last five years in the Grebo-Krahn National Park (GKNP) conducted by survey team members from the Forestry Development Authority and local communities under the supervision of the Wild Chimpanzee Foundation. The survey also represents the first biomonitoring study in which camera trap were deployed through the entire park. Data were collected between December 2019 and August 2020. A total of 231.26 km of line transects with a set of two points transects assigned to each line transect were surveyed across the park following a systematic design of line transects that were placed in direction of latitudes using the Distance Software v.7.3. Data were collected on the signs of presence of all animals (from reptiles, to mammals and birds), hunting and habitat disturbance (mining, extraction of chewing sticks, etc.). Two types of information were recorded: direct observation of large mammals and other animals from captures made from camera trap, but also sighted during transect walk and indirect observations seen while surveying the line transects. These data were analyzed to determine the current status of wildlife and threats within the park as well as monitor their population trends from data collected from previous surveys within the area. The encounter rates of each species and the spatial distribution of vulnerable, endangered and critically endangered species were determined.

The population status of chimpanzees was also calculated and provided the current estimated of 114 weaned individuals from data analyzed from the line transects. The data for chimpanzees slightly differed within the confidence limits from the two previous studies conducted in the GKNP in 2014 and 2015. For mammal species, it is difficult to compare the distributions as the data here only represent partial results since the full data from the entire survey is still being processed for detailed analyses. The data collected on anthropogenic activities were considered in the same way as wildlife data. Results showed that hunting activities appear to be dominant followed by the extraction of chewing sticks compared to mining. As for mammals, it was difficult to compare the distributions of human activities with those of the previous because data were only analyzed partly. However, we found a similar diversity of mammals with the previous surveys. Then, these results must be used to avoid detrimental effects that will lead to extinction of potential species in the GKNP. As the demarcation of the park is almost completed, we beg the need for regular law enforcement patrols and station ranger posts to avoid intruders from the infiltration of one of Liberia's unique biodiversity landscape

1. INTRODUCTION

The concept of monitoring animal population for conservation priorities and planning is very important for the management of protected areas (Nichols and Williams, 2006). Population monitoring helps us to understand the number of species that are present as well as their spatial distribution, encounter rate and population abundance. In order to understand population dynamic of wildlife populations, the method used to monitor the animal population is a key factor that needs to be considered together with the particularity of the species being studied. In the past, biomonitoring surveys were done using line transect distance sampling in the Grebo-Krahn National Park (GKNP) to collect data that allow to estimate the density, abundance and spatial distribution of primates and large mammal population. However, it might fail to monitor species that are elusive, rare or even nocturnal because they tend to avoid human observers during field surveys, which creates biases in estimates (Plumptre and Reynolds, 1996; Buckland *et al.*, 2001; Rovero and Marshall, 2004; Buckland *et al.*, 2010; Buckland *et al.*, 2015). To overcome this problem, surveys that record indirect observations such as dung and nest have been developed, but require additional data to convert the estimates of sign abundance into estimates of animal abundance. Yet, they are often costly, labor intensive to obtain, and imprecisely estimated since they are dependent to environmental factors such as rainfall (Buckland *et al.*, 2001; Walsh and White, 2005; Kuehl *et al.*, 2007). Camera traps (CT), in the other hand, present a potential solution to these problems since they can provide clear evidences of the presence of the animal in the site (Burton *et al.*, 2015; Rovero and Zimmermann, 2016). Recently, the conventional point transect distance sampling has been extended to CTs (Howe *et al.*, 2017). This new camera trap distance sampling (CTDS) approach has been proved to be accurate and functional in the field (Cappelle *et al.*, 2019; Bessone *et al.*, 2020). Thus, offering innovative approaches for obtaining spatial distribution, density, abundance, behavior and community structure in a most reliably way.

At the end of the previous line transect biomonitoring survey conducted in 2015 before the establishment of the GKNP into a fully protected area, it was reported that the GKNP was very important for the protection of wildlife and promotes the migration of species moving towards the Taï National Park (TNP) in neighboring. During this time, recommendations were made to continuously monitor biodiversity trend and put into place measures that allows for healthy ecosystem, but increasing the sampling efforts and improving the methodology that will provide more detailed information on the landscape. The latter, however did not happen in a short period of time as it was more necessary to observe trend over a longer period (about 5- 7 years) to understand the real dynamic of happenings in an ecological landscape. Until recently, a funding was provided to WCF through the **West Africa Biodiversity and Climate Change project (WA BICC),** to obtain detailed reliable estimate of anthropogenic activities and large mammals' density, abundance, distribution and ecology that will guide management decision in protecting the Grebo-Krahn landscape, one of Liberia's most valuable protected areas. As a result, the objective of this study was to establish a baseline for the evaluation of wildlife population trend in GKNP. Specifically, we intended 1) to show effectively the density and distribution of wildlife populations and the anthropogenic activities, 2) provide information about key hot spots that show threatened, vulnerable, endangered and critically endangered species, 3) to evaluate the influence of human activities on the distribution and abundance of wildlife populations.

2. METHODS

2.1. Study area

The GKNP was enacted into law on August 22, 2017 as a fully protected area due to its prominence and unique biodiversity, and becoming Liberia's second larger protected area with a size of 96,149.89 ha next to the Sapo National Park. The Grebo-Krahn landscape is located in southeastern Liberia between the borders of two counties, Grand Gedeh and River Gee, but extends to the boundary of Taï National Park in Côte d'Ivoire and lies in the heart of a corridor complex linking the Sapo National Park to the Grebo National Park and then, the TNP. Since 2009, the governments of Côte d'Ivoire and Liberia have been working towards a transboundary collaboration for the Taï-Grebo-Sapo Forest Complex (TGSFC), which spans beyond the border of both countries and make up a significant part of world biodiversity hotspot 11, the Western African Forests from the global world's 25 biodiversity hotspots (Myers *et al.*, 2000). In Côte d'Ivoire, it consists of Taï National Park (UNESCO World Heritage Site and Biosphere reserve), and three adjacent classified forests (Cavally, Goin-Débé, Haute-Dodo). In Liberia, it consists of Sapo National Park, Grebo-Krahn National Park and a large logging concession, known as FMC F, run by Eurologging Ltd (Figure 1, Furnell *et al.*, 2015). Aside from the GKNP being in the heart of the TGSFC, the landscape is extremely important for the conservation of numerous endangered and endemic species, such as the Western chimpanzee, the red colobus, the pygmy hippopotamus, various exotic species of duikers, and the Liberian mongoose.

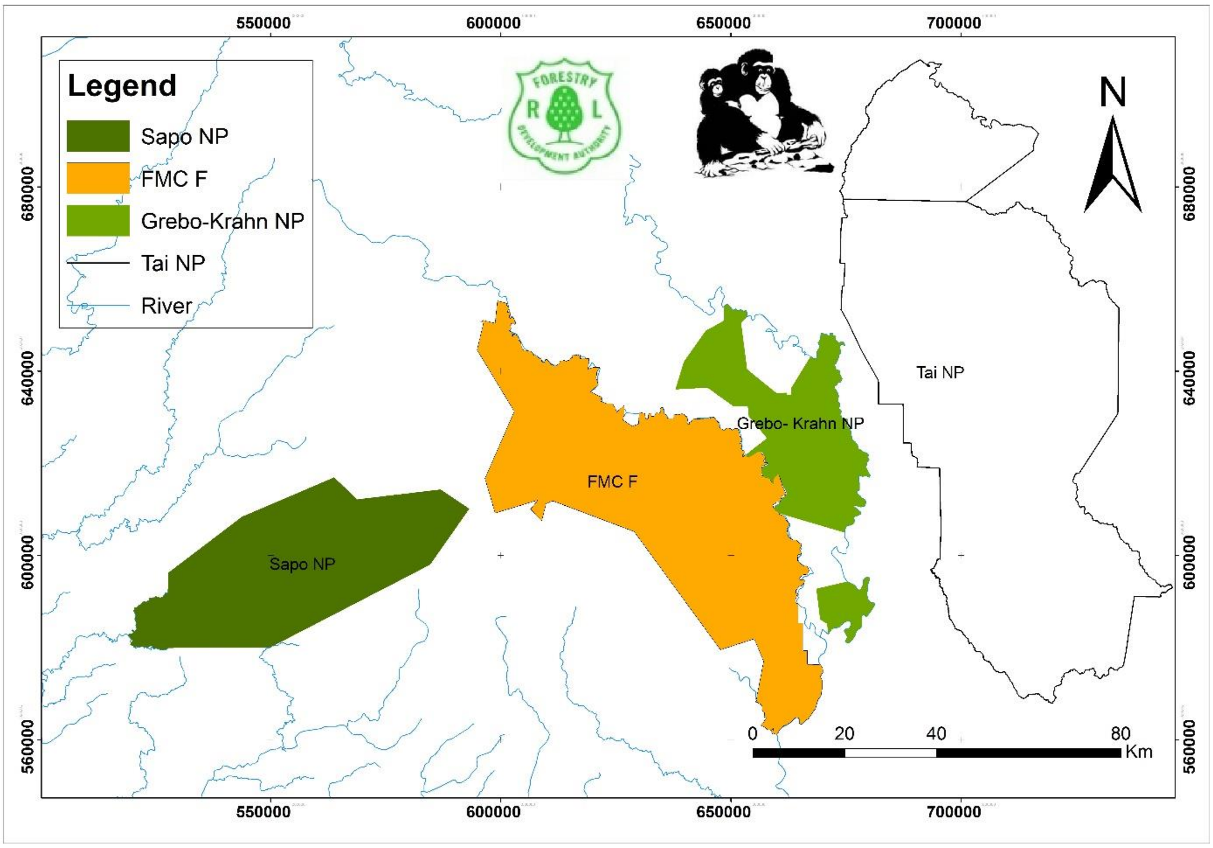

Figure 1: Diagram showing the GKNP and connected corridor complex

2.2. Survey design

We used a systematic design of line transect with random origin with a cluster of two points placed along each line transect (Buckland et al., 2001). However, we suggest that the same survey design be used for future surveys within the GKNP to allow for comparison unless a more intense survey is needed. The design follows IUCN guidelines for transect surveys for great apes (Kühl et al., 2008), in which the whole of the GKNP is covered using a systematic arrangement of transects. Such a spatial arrangement of survey transects is known to be effective for unbiased studies of the distribution and densities of large wild mammals in tropical forests (Plumptre, 2000; Buckland *et al.*, 2001). Figure 2 presents the sampling design composed of 250-1 km line transects and 500 point transects (2 point transect per line transect). The first point transect was placed at 250 m of each line transect and the next point at 750 m (Figure 2).

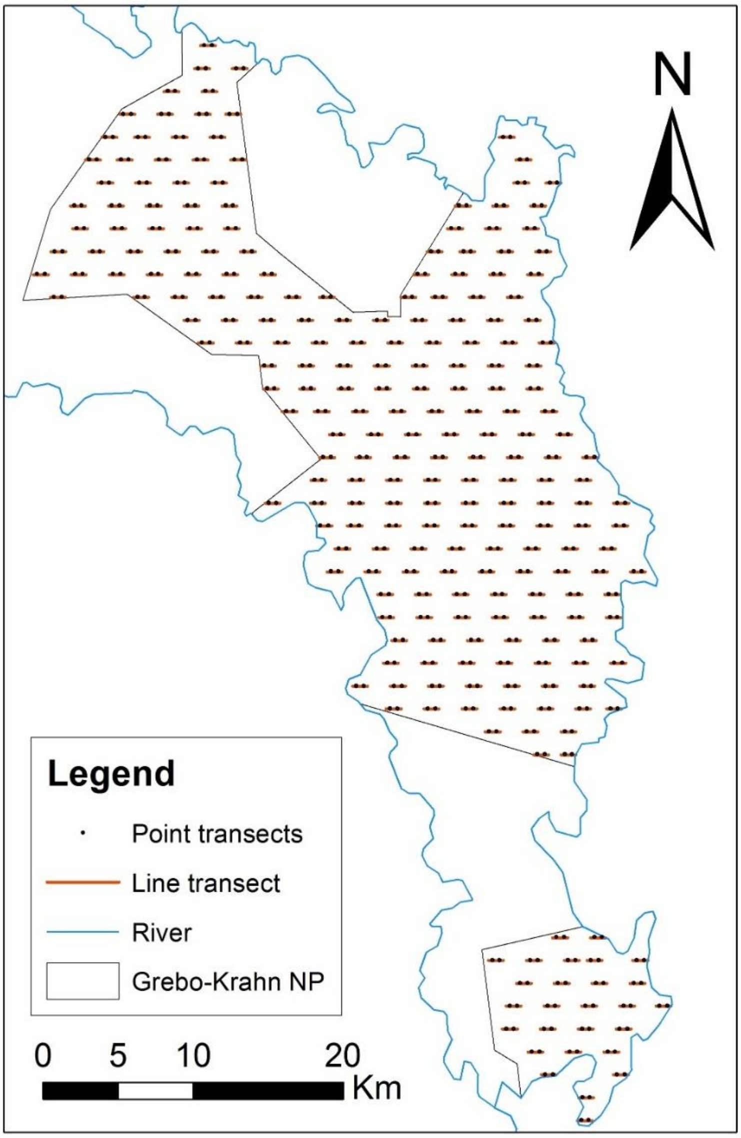

Figure 2: Map showing the systematic display of both line transect and point transect

2.2.1. Line transect

The line transects were walked to collect data on illegal human activities and wildlife signs, particularly large mammals, primates and birds. When observation was made, it was marked with a handheld GPS and coordinates were recorded on a line transect datasheet. In order to collect enough data of monkeys, line transects were walked twice (Buckland *et al.*, 2010). Therefore, we considered 250- 2 km of transect for the monkeys. For a human activity such as cartridges, they were removed whenever recorded by the biomonitoring team to avoid repetition of counts. Furthermore, the conditions of cartridges, poacher trails, traps, and hunting tents were also marked. When cartridges are spotted, the observers determine the physical condition of the cartridge as new, recent or old.

All traps and poacher trails were also noted as active or inactive. A poacher trail was determined by the regular cut of machete made along with trees or vegetation. In addition, off transect data were also collected for specific animals, such as chimpanzees, leopards, golden cats, elephants, and pygmy hippopotamus.

When a chimpanzee nest or elephant dung was found while walking on the line transect, the perpendicular distance was recorded from the transect line to the object. It is required to determine the detection probability function at which objects are most likely to be spotted, and the estimate of population density.

2.2.2. Point transect

Point transects were located 50 m away from the line transect, at 250 and 750 m from the beginning of the line. Camera traps were set within a radius of 30 m from the theoretical point transect to help find a tree with DBH at least 10 cm with sufficient visibility. The camera was placed at a tree height between 50 cm or 60 cm (depending on the landscape) with a chosen degree between 340 and 20 (Cappelle *et al.*, 2019). At the bearing chosen, we measured 15 m from tree on which the camera was placed and recorded a reference video showing the different distances at which animals might be detected by the camera trap (see more details in Howe et al., 2017). These distances were then used to estimate the densities from camera traps data.

2.3. Local capacity building

Data were collected from 7th of December 2019 until the 30th of August 2020 (but for this report, we only considered data collected from December 2019-May 2020 due to the limited time for analyzing all the videos) by four (4) teams supervised by staff from the Wild Chimpanzee Foundation (Jacquline M. Kiazolu, and Princess Yormie) alongside FDA Park biologist (Lassana Curly) and FDA auxiliary (Marcus Byee) and interns from the University of Liberia, Cutton University, Williams V.S Tubman University and the Forestry Training Institute (FTI). Prior to the survey, the six teams had recently completed a full intensive three (3) days (December 3- 6, 2019) of biomonitoring camera trap distance sampling training workshop in Ziah Town, Grand Gedeh County during which teams learned about survey methodology, species identification, use of GPS and other equipment, etc. Most team members have extensive experience in data collection and team supervision, having participated in previous surveys led by WCF/FDA in GKNP. Each team consisted of six persons, either FDA auxiliaries or local community members.

2.4. Data analysis

The collected data were saved and organized in an Excel file using mainly the following options: filter, sort, pivot table, and pivot chart. For the camera traps data, Excel software was used to select independent events for each species. We considered videos as independent events when they were recorded at the same camera location on the same day, with videos occurring outside 15 min of another (McCarthy *et al.*, 2018). Globally the encounter rates (ER) and densities were calculated for line transect data and the relative abundance index (RAI; Rovero et al., 2014) were calculated for camera trap data. The encounter rate and the relative abundance index were calculated using the following formula:

$$ER = \frac{Number\ of\ observations}{Distance\ covered}$$

$$RAI = \frac{Number\ of\ events}{sampling\ effort} \times 100$$

Where: the number of event is the number of independent videos, and the sampling effort is the entire time during which the cameras were running.

The density estimation was mas calculated with the software Distance 7.3 (Thomas *et al.*, 2010) using the following equation:

$$\widehat{D} = \frac{E_{(n)}}{2wL\widehat{P}_n}$$

Where $E_{(n)}$ is the number of observations detected, $\widehat{P_n}$ the probability of detecting an observation within truncation distance *w*, and *L* the total transect length.

To convert the abundance of chimpanzees' nest in abundance of chimpanzees, the following equation was used:

$$\widehat{D} = \frac{eqn.1}{rt}$$

Where *r* is the nest production rate and *t* the nest decay time.

The nest production and decay rate used for converting the nest abundance in chimpanzee abundance were 1.143 nest per individuals (standard error (SE)=0.04; Kouakou, Boesch, and Kuehl 2009) and 84.38 days (SE=4; N'Goran et al. 2011), respectively.

The hotspot analysis for mammals and human activities was conducted in ArcGIS 10.7 using the python package "arcpy" and the all the maps were made in the softwares ArcGIS 10.7 and R 4.0.2 (using the packages "sf", "rgdal" and "tmap") (R Core Team, 2020).

3. RESULTS

3.1. Summary of the survey effort

In total, 235-1 km line transects out of 250 were surveyed from December 2019 and July 2020 (Figure 3). On those transects, cameras were installed on 464 point transects out of 500 (Figure 4). Some transects were not completed due to large obstacles, water courses, valleys and sacred forest of the communities; which makes a total distance surveyed of 231.26 km, corresponding to 98.41% of the theoretical distance. Then, on two transects only one camera was installed. Up to now, the videos of 223 cameras were analysed and the videos of only 191 of them are being considered for the analysis of spatial distribution. The videos where the time was not recorded properly, and thus not allowing the determination of independent videos, were not considered in this report. For the cameras considered 10,620 (average = 55.66, SD = 49.12) videos were recorded, among which 210 were from researchers maintaining the cameras. The real capture accounted for 10,410 videos (average = 54.55, SD = 49.03) where 7,117 videos represented independent events (average = 37.34, SD = 30.08).

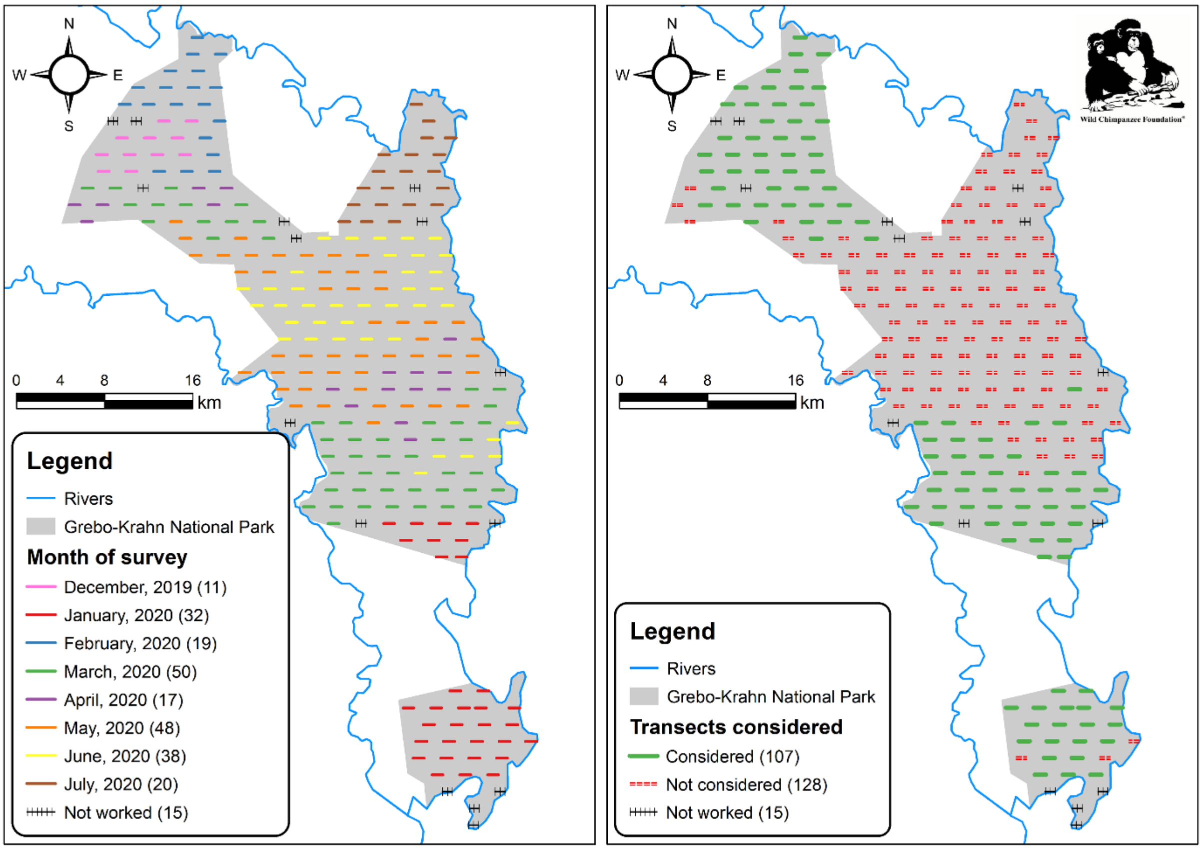

Figure 3: Line transect sampling effort

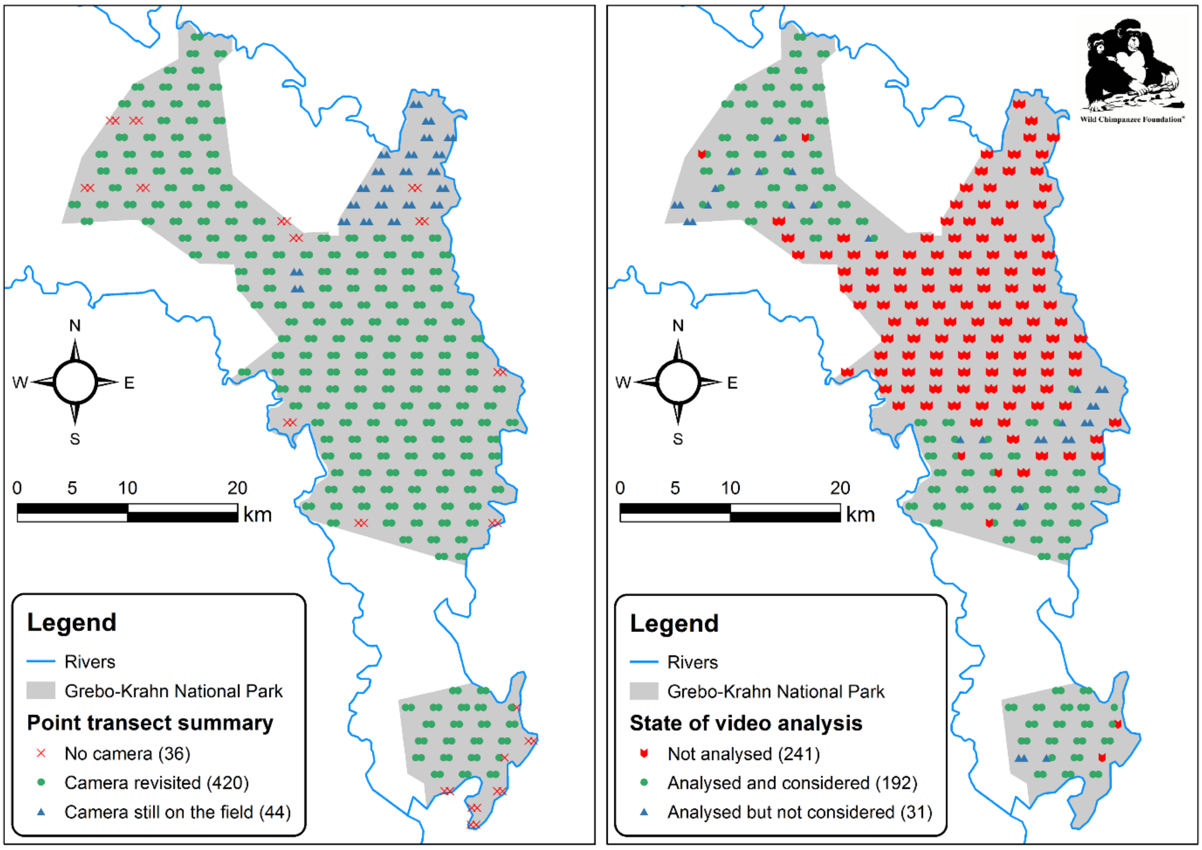

Figure 4: Camera trap sampling effort

3.2. Mammal species diversity

The richness of mammal species observed on line transects and camera traps was different. In total, 39 mammal species were found on line transects, including 14 threatened species (35.89%, Table 1) while 41 mammal species were found in camera traps, including 13 threatened species (31%, Table 2). However, 5 orders (Carnivora, Cetartiodactyla, Pholidota, Primates, Rodentia) were observed in camera traps (Figure 5), while 7 orders (Carnivora, Cetartiodactyla, Chiroptera, Pholidota, Primates, Proboscidea, Rodentia) were found on line transects (Figure 6). The orders Proboscidea and Chiroptera were only observed on transects. The Critically endangered Western chimpanzee was found both on line transects and camera traps.

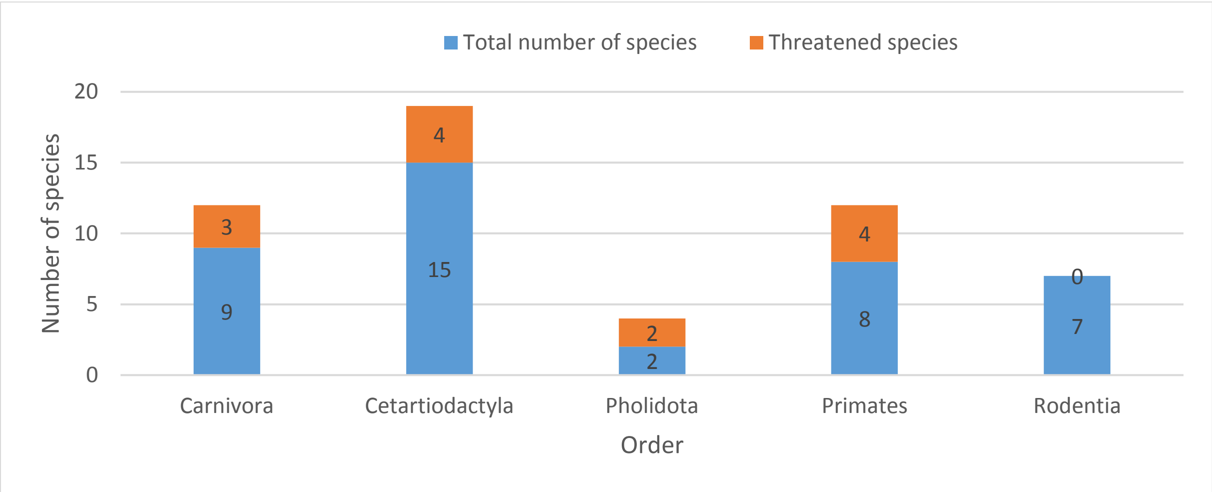

Figure 5: Number of species per Order found in camera traps

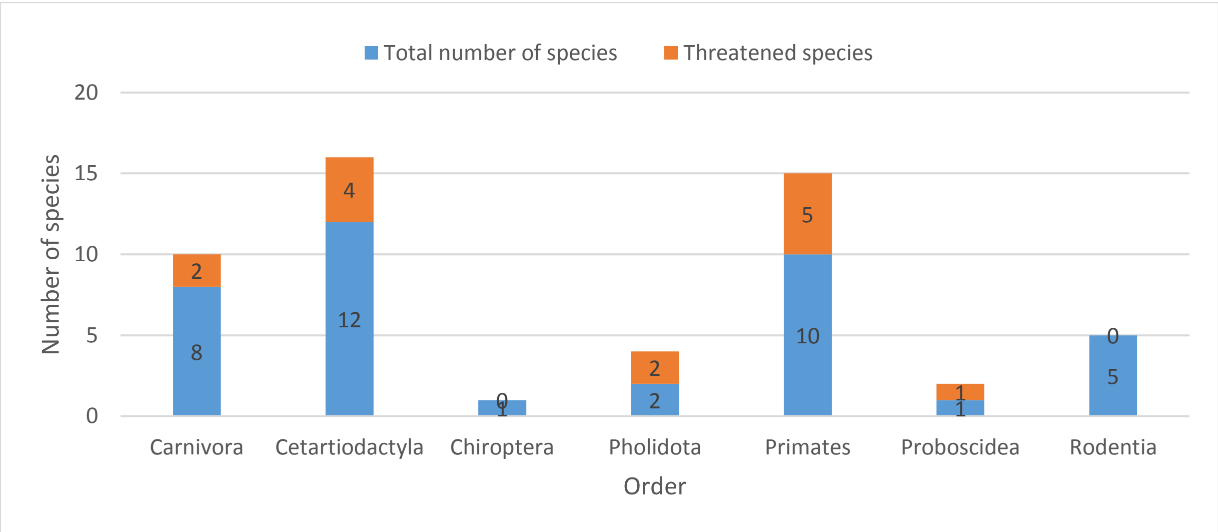

Figure 6: Number of species per Order found on line transects

Table 1: Global and average encounter rate (ER) of mammal species from line transect survey

Order	Family	Scientific name	Common name	IUCN Status	CITES	Average ER	SD ER	Global ER
Carnivora	Felidae	*Caracal aurata*	African golden cat	Vulnerable	II	0.01	0.10	0.01
Carnivora	Felidae	*Panthera pardus pardus*	Leopard	Vulnerable	I	0.02	0.14	0.02
Carnivora	Herpestidae	*Crossarchus obscurus*	Cusimanse (mongoose)	Least concern		0.37	0.76	0.38
Carnivora	Herpestidae	*Atilax paludinosus*	Marsh mongoose	Least concern		0.08	0.28	0.08
Carnivora	Herpestidae	*Herpestes sanguineus*	Slender mongoose	Least concern		0.01	0.10	0.01
Carnivora	Mustelidae	*Mellivora capensis cottoni*	Honey badger	Least concern	III	0.01	0.10	0.01
Carnivora	Viverridae	*Civettictis civetta*	African civet	Least concern	III	0.16	0.42	0.16
Carnivora	Viverridae	*Nandinia binotata*	African palm civet	Least concern		0.05	0.21	0.05
Cetartiodactyla	Bovidae	*Cephalophus dorsalis*	Bay duiker	Near threatened	II	1.21	1.55	1.22
Cetartiodactyla	Bovidae	*Cephalophus niger*	Black duiker	Least concern		1.20	1.85	1.21
Cetartiodactyla	Bovidae	*Tragelaphus eurycerus*	Bongo	Near threatened		0.30	0.60	0.30
Cetartiodactyla	Bovidae	*Cephalophus ogilbyi brookei*	Brooke's duiker	Vulnerable	II	1.38	1.41	1.39
Cetartiodactyla	Bovidae	*Syncerus caffer nanus*	Forest buffalo	Least concern		0.31	0.72	0.30
Cetartiodactyla	Bovidae	*Cephalophus jentinki*	Jentink's duiker	Endangered	I	0.90	1.05	0.91
Cetartiodactyla	Bovidae	*Philantomba maxwellii*	Maxwell's duiker	Least concern		1.81	1.65	1.82
Cetartiodactyla	Bovidae	*Cephalophus silvicultor*	Yellow-backed duiker	Near threatened	II	0.10	0.36	0.10
Cetartiodactyla	Bovidae	*Cephalophus zebra*	Zebra duiker	Vulnerable	II	0.14	0.40	0.14
Cetartiodactyla	Hippopotamidae	*Choeropsis liberiensis*	Pygmy hippopotamus	Endangered	II	0.29	0.74	0.29
Cetartiodactyla	Suidae	*Hylochoerus meinertzhageni*	Giant forest hog	Least concern		0.11	0.46	0.11
Cetartiodactyla	Suidae	*Potamochoerus porcus porcus*	Red river hog	Least concern		1.34	1.71	1.31
Chiroptera	Pteropodidae	*Eidolon helvum*	African straw-coloured fruit-bat	Near threatened		0.01	0.10	0.01
Pholidota	Manidae	*Smutsia gigantea*	Giant ground pangolin	Endangered	I	0.01	0.10	0.01
Pholidota	Manidae	*Phataginus tricuspis*	White-bellied pangolin	Endangered	I	0.01	0.10	0.01
Primates	Cercopithecidae	*Cercopithecus mona campbelli*	Campbell's monkey	Least concern	II	0.11	0.40	0.11
Primates	Cercopithecidae	*Cercopithecus diana diana*	Diana monkey	Endangered	I	0.49	1.14	0.49
Primates	Cercopithecidae	*Cercopithecus nictitans nictitans*	Greater spot-nosed monkey	Near threatened	II	0.01	0.10	0.01
Primates	Cercopithecidae	*Procolobus verus*	Olive colobus	Vulnerable	II	0.08	0.46	0.08
Primates	Cercopithecidae	*Cercocebus atys atys*	Sooty mangabey	Near threatened	II	0.14	0.44	0.14

Primates	Cercopithecidae	*Cercopithecus petaurista buettikoferi*	Western lesser spot-nosed monkey	Least concern	II	0.05	0.21	0.05
Primates	Cercopithecidae	*Colobus polykomos*	Western pied colobus	Vulnerable	II	0.17	0.58	0.17
Primates	Cercopithecidae	*Piliocolobus badius*	Western red colobus	Endangered	II	0.17	0.83	0.17
Primates	Hominidae	*Pan troglodytes verus*	Western chimpanzee	Critically endangered	I	0.78	1.71	0.78
Primates	Lorisidae	*Perodicticus potto*	West african potto	Near threatened	II	0.01	0.10	0.01
Proboscidea	Elephantidae	*Loxodonta cyclotis*	Forest elephant	Vulnerable	I	0.10	0.58	0.10
Rodentia	Anomaluridae	*Anomalurus peli*	Flying squirrel	Data deficient		0.04	0.23	0.04
Rodentia	Hystricidae	*Atherurus africanus*	African brush-tailed porcupine	Least concern		0.04	0.19	0.04
Rodentia	Hystricidae	*Hystrix cristata*	Crested porcupine	Least concern		0.02	0.14	0.02
Rodentia	Nesomyidae	*Cricetomys emini*	Giant pouched rats	Least concern		0.03	0.17	0.03
Rodentia	Sciuridae	*Paraxerus poensis*	Green bush squirrel	Least concern		0.08	0.31	0.08

Table 2: Global and average Relative Abundance Index (RAI) of mammal species from camera traps

Order	Family	Scientific name	Common name	IUCN Status	CITES	Mean RAI	SD RAI	Global RAI
Carnivora	Felidae	*Caracal aurata*	African golden cat	Vulnerable	II	0.01	0.19	0.02
Carnivora	Felidae	*Panthera pardus pardus*	Leopard	Vulnerable	I	0.02	0.21	0.03
Carnivora	Herpestidae	*Atilax paludinosus*	Marsh mongoose	Least concern		1.17	2.73	1.37
Carnivora	Herpestidae	*Crossarchus obscurus*	Cusimanse (mongoose)	Least concern		0.28	1.77	0.33
Carnivora	Herpestidae	*Liberiictis kuhni*	Liberian mongoose	Vulnerable		0.72	1.92	0.86
Carnivora	Mustelidae	*Mellivora capensis cottoni*	Honey badger	Least concern	III	0.24	1.39	0.30
Carnivora	Viverridae	*Civettictis civetta*	African civet	Least concern	III	2.35	4.47	2.89
Carnivora	Viverridae	*Genetta spp*	Genet			0.65	1.96	0.78
Carnivora	Viverridae	*Nandinia binotata*	African palm civet	Least concern		0.05	0.32	0.07
Cetartiodactyla	Bovidae	*Cephalophus dorsalis*	Bay duiker	Near threatened	II	3.06	9.57	4.02
Cetartiodactyla	Bovidae	*Cephalophus jentinki*	Jentink's duiker	Endangered	I	2.00	3.87	2.45
Cetartiodactyla	Bovidae	*Cephalophus niger*	Black duiker	Least concern		3.39	6.05	4.33
Cetartiodactyla	Bovidae	*Cephalophus ogilbyi brookei*	Brooke's duiker	Vulnerable	II	10.25	14.81	13.08
Cetartiodactyla	Bovidae	*Cephalophus silvicultor*	Yellow-backed duiker	Near threatened	II	0.34	1.41	0.44
Cetartiodactyla	Bovidae	*Cephalophus zebra*	Zebra duiker	Vulnerable	II	1.39	3.75	1.77
Cetartiodactyla	Bovidae	*Neotragus pygmaeus*	Royal antelope	Least concern		0.01	0.20	0.02
Cetartiodactyla	Bovidae	*Philantomba maxwellii*	Maxwell's duiker	Least concern		7.46	16.52	10.40
Cetartiodactyla	Bovidae	*Syncerus caffer nanus*	Forest buffalo	Least concern		0.05	0.55	0.05
Cetartiodactyla	Bovidae	*Tragelaphus eurycerus*	Bongo	Near threatened		0.32	1.10	0.44
Cetartiodactyla	Bovidae	*Tragelaphus scriptus*	Bushbuck	Least concern		0.06	0.61	0.07
Cetartiodactyla	Hippopotamidae	*Choeropsis liberiensis*	Pygmy hippopotamus	Endangered	II	0.15	1.10	0.18
Cetartiodactyla	Suidae	*Hylochoerus meinertzhageni*	Giant forest hog	Least concern		0.10	0.53	0.14
Cetartiodactyla	Suidae	*Potamochoerus porcus porcus*	Red river hog	Least concern		0.87	2.30	1.24
Cetartiodactyla	Tragulidae	*Hyemoschus aquaticus*	Water chevrotain	Least concern		0.05	0.43	0.07
Pholidota	Manidae	*Phataginus tricuspis*	White-bellied pangolin	Endangered	I	0.10	0.60	0.13
Pholidota	Manidae	*Smutsia gigantea*	Giant ground pangolin	Endangered	I	0.05	0.40	0.08
Primates	Cercopithecidae	*Cercocebus atys atys*	Sooty mangabey	Near threatened	II	3.79	4.33	5.41
Primates	Cercopithecidae	*Cercopithecus diana diana*	Diana monkey	Endangered	I	0.10	0.54	0.13

Primates	Cercopithecidae	*Cercopithecus mona campbelli*	Campbell's monkey	Least concern	II	0.45	1.22	0.66
Primates	Cercopithecidae	*Cercopithecus petaurista buettikoferi*	Western lesser spot-nosed monkey	Least concern	II	0.16	0.94	0.23
Primates	Cercopithecidae	*Colobus polykomos*	Western pied colobus	Vulnerable	II	0.02	0.21	0.02
Primates	Cercopithecidae	*Procolobus verus*	Olive colobus	Vulnerable	II	0.06	0.39	0.10
Primates	Galagonidae	*Galagoides demidoff*	Demidoff's galago	Least concern	II	0.01	0.17	0.02
Primates	Hominidae	*Pan troglodytes verus*	Western chimpanzee	Critically endangered	I	0.66	2.54	1.05
Rodentia	Hystricidae	*Atherurus africanus*	African brush-tailed porcupine	Least concern		6.94	17.89	11.17
Rodentia	Hystricidae	*Hystrix cristata*	Crested porcupine	Least concern		0.09	0.56	0.14
Rodentia	Nesomyidae	*Cricetomys emini*	Giant pouched rats	Least concern		7.85	14.81	13.07
Rodentia	Sciuridae	*Funisciurus pyrropus*	Fire-footed rope squirrel	Least concern		3.54	8.03	5.93
Rodentia	Sciuridae	*Heliosciurus rufobrachium*	Red-legged sun squirrel	Least concern		0.27	1.35	0.45
Rodentia	Sciuridae	*Paraxerus poensis*	Green bush squirrel	Least concern		0.44	2.00	0.73
Rodentia	Thryonomyidae	*Thryonomys swinderianus*	Greater cane rat	Least concern		0.03	0.25	0.04

The most abundant mammal species found on line transects according to decreasing order of the of encounter rate are Maxwell's duiker, Brooke's duiker, Red river hog, Bay duiker, and Black duiker (Table 1), while Brooke's duiker, Giant pouched rats, African brush-tailed porcupine, Maxwell's duiker and Fire-footed rope squirrel are the most abundant mammal species found in camera traps according to decreasing order of the of RAI (Table 2). Brooke's duiker, Jentink's duiker, Western chimpanzee and Diana monkey are the most abundant threatened mammal species on line transects among the first 10 most abundant species (Table 1), while Brooke's duiker and Jentink's duiker are the most abundant threatened mammal species among the first 10 most abundant species in camera traps (Table 2).

The average number of observations of most of the species is the standard deviation of their encounter rates or RAI (Table 1 and Table 2). This indicates that the observations of the mammal species are heterogeneous among transects, for instance, no sign was found on most of the transects for the majority of the species. Similarly many mammal species were not captured at many camera point transects.

Although the difference between the number of mammal species found on line transects and in camera traps is only two (2), 16 mammal species were found only either on line transects or in camera traps, among which three (3) are threatened species (Western red colobus, Liberian mongoose and Forest elephant, Table 3). Forest elephant and Western red colobus appeared only on line transects while Liberian mongoose appeared only in camera traps (Table 3).

Table 3: List of species found either on line transects or captured in the cameras

Common name	Scientific name	IUCN Status	Camera	Transect
African straw-coloured fruit-bat	*Eidolon helvum*	Near threatened		●
Bushbuck	*Tragelaphus scriptus*	Least concern	●	
Demidoff's galago	*Galagoides demidoff*	Least concern	●	
Fire-footed rope squirrel	*Funisciurus pyrropus*	Least concern	●	
Flying squirrel	*Anomalurus peli*	Data deficient		●
Forest elephant	*Loxodonta cyclotis*	Vulnerable		●
Genet	*Genetta spp*		●	
Greater cane rat	*Thryonomys swinderianus*	Least concern	●	
Greater spot-nosed monkey	*Cercopithecus nictitans nictitans*	Near threatened		●
Liberian mongoose	*Liberiictis kuhni*	Vulnerable	●	
Red-legged sun squirrel	*Heliosciurus rufobrachium*	Least concern	●	
Royal antelope	*Neotragus pygmaeus*	Least concern	●	
Slender mongoose	*Herpestes sanguineus*	Least concern		●
Water chevrotain	*Hyemoschus aquaticus*	Least concern	●	
West african potto	*Perodicticus potto*	Near threatened		●
Western red colobus	*Piliocolobus badius*	Endangered		●

3.3. Density of primates on line transects

We obtained 72 observations of nests for the chimpanzees, which is in the range of the minimum sample size (60-80 observations) recommended by Buckland et al. (2001). We only obtained 39 direct observations of groups of monkeys; thus, this estimate should be interpreted cautiously. The density of chimpanzees was estimated at 0.118 ind./km² (CI = 0.072-0.193 ind./km²) and the density of all monkeys at 1.69 ind./km² (CI = 0.763-3.780 ind./km²). The density of chimpanzees was smaller to those found in 2014 and 2015 but the differences were not significant (Table 4).

Table 4: Comparison of density estimates of primates between the present study and the years 2015 and 2014

Species	Year	Density	Coefficient of variation	95% Confidence Interval
Chimpanzee	Present	0.118	25.53	(0.072-0.193)
	2015	0.230	22.60	(0.148-0.358)
	2014	0.161	24.15	(0.101-0.257)
Group of monkeys	Present	1.690	42.18	(0.763-3.780)

3.4. Mammal species distribution

There were more mammal species observed with CTs in the northwestern part of the park, while there was more observation at the center of the park with the line transects (Figure 7). There was a cold spot in the northwest from line transect data. Similarly, there were significatively more threatened mammal species observed with CTs in the northwestern part of the park and significantly less in the southern part, with another cold spot at the center (Figure 8).

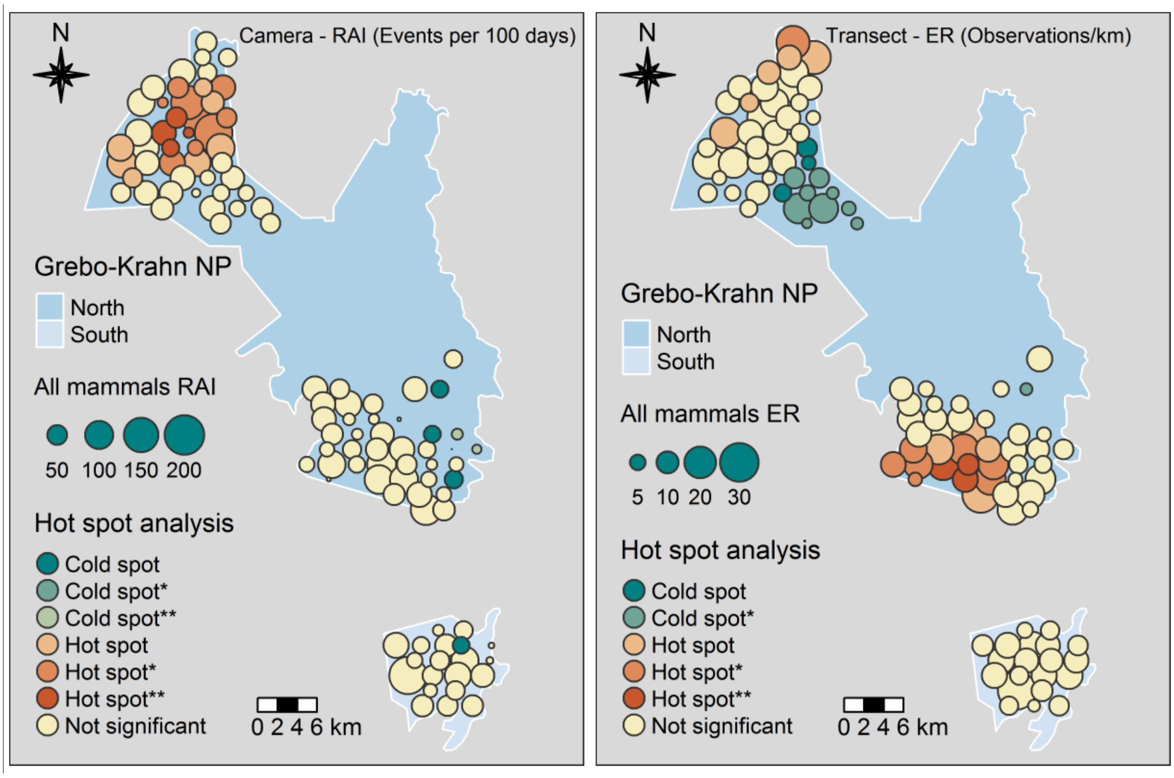

*Figure 7: Total abundance of all mammal species (RAI = Relative abundance index, ER = Encounter rate, * significant at 95%, ** significant at 99%, hot spot is area of high abundance and cold spot is area of low abundance)*

The encounter rate of threatened mammals obtained from line transects was significantly higher at the center of the park (Figure 8). For both CTs and line transects, the encounter rate and RAI of threatened mammals was significantly lower in the southern part of the park (Figure 8). The distribution of primates showed a slightly different pattern. The RAI of primate species depicted by CTs was higher in the northwest and lower in the south with a cold spot at the center (Figure 9), while the encounter rate of primates from line transects is relatively homogeneous with a small cold spot north (Figure 9).

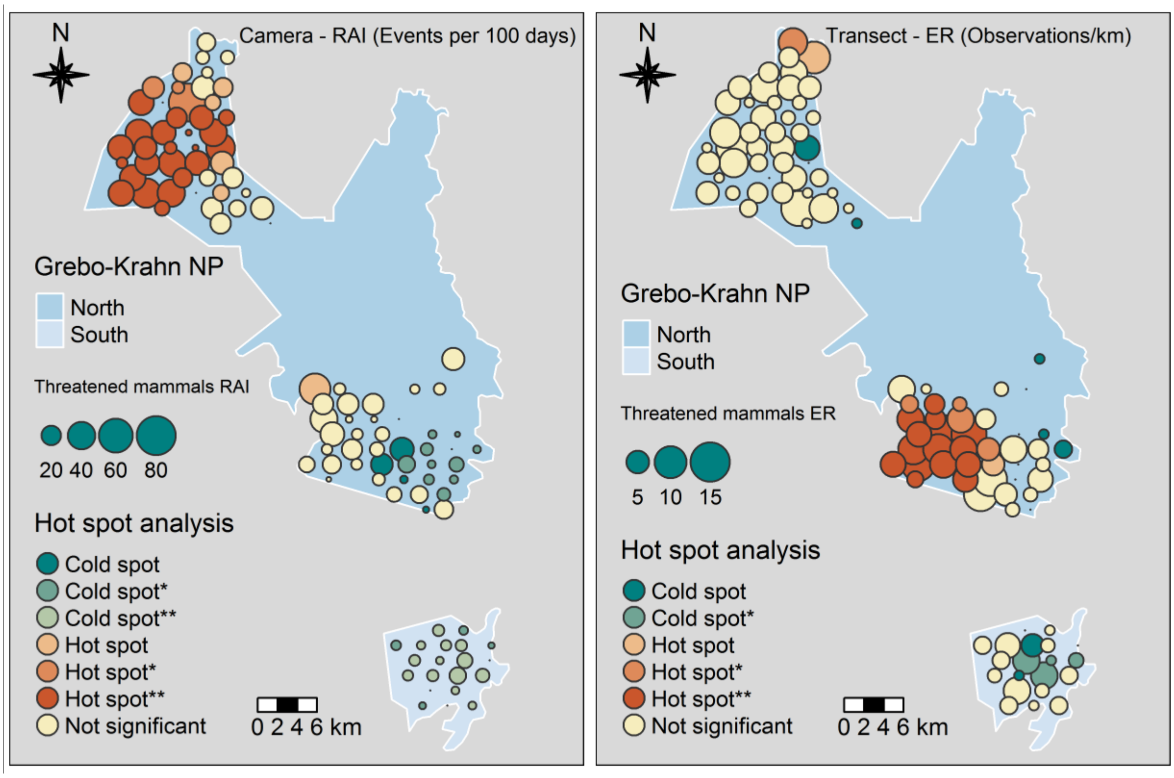

Figure 8: Distribution of total abundance of threatened mammal species (RAI = Relative abundance index, ER = Encounter rate, * significant at 95%, ** significant at 99%, hot spot is area of high abundance and cold spot is area of low abundance)

The distribution of four selected threatened mammals (Diana monkey, Western chimpanzee, Pygmy hippopotamus and Jentink's duiker) was marked by a small cluster for CTs and line transects (Figure 10, Figure 11, Figure 12, and Figure 13). Only the distribution of the Jentink's duiker appeared to be more spread in the park as depicted by the line transect data (Figure 13). Observations of Diana monkeys from CTs were higher in the northwest, while observations from line transects were higher at the center of the park (Figure 10). The observations of chimpanzees obtained from the CTs and line transects occurred almost at the same locations, with cold spots in the northwest (Figure 11). The Pygmy hippopotamus was spotted at the center of the park in camera traps, while it was observed only on some line transects in the northwest (Figure 12).

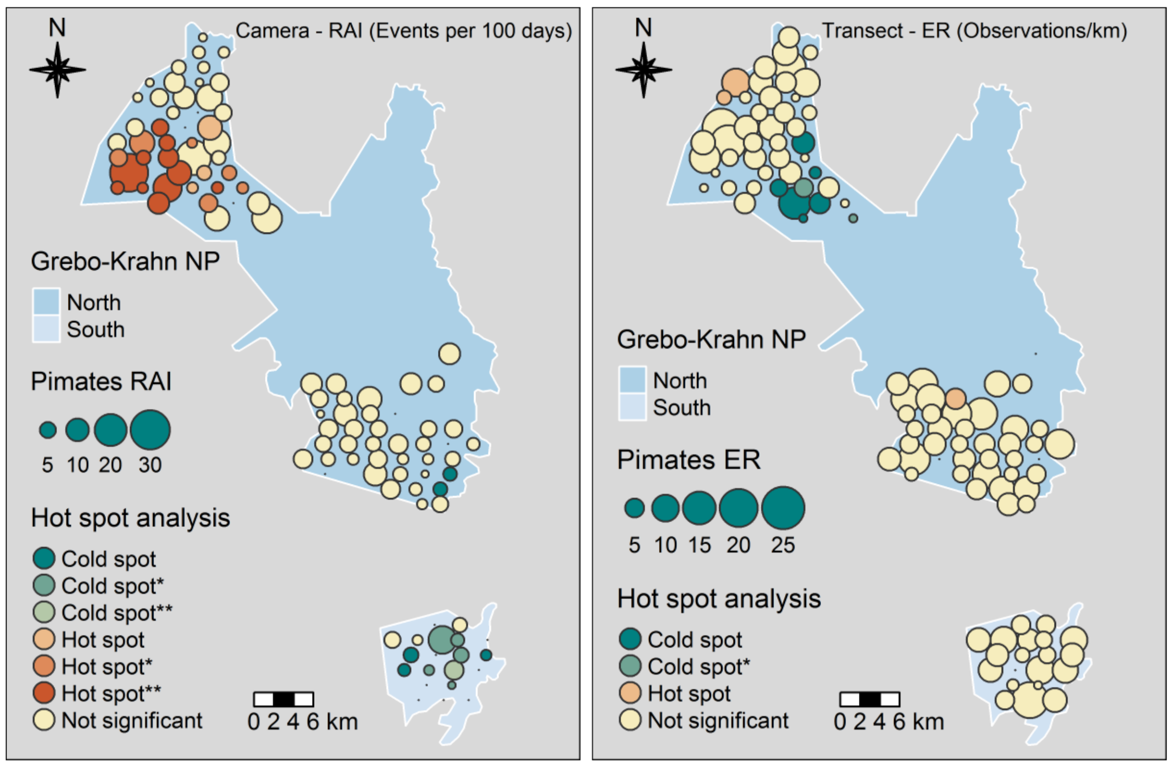

Figure 9: Distribution of total abundance of primate species (RAI = Relative abundance index, ER = Encounter rate, * significant at 95%, ** significant at 99%, hot spot is area of high abundance and cold spot is area of low abundance)

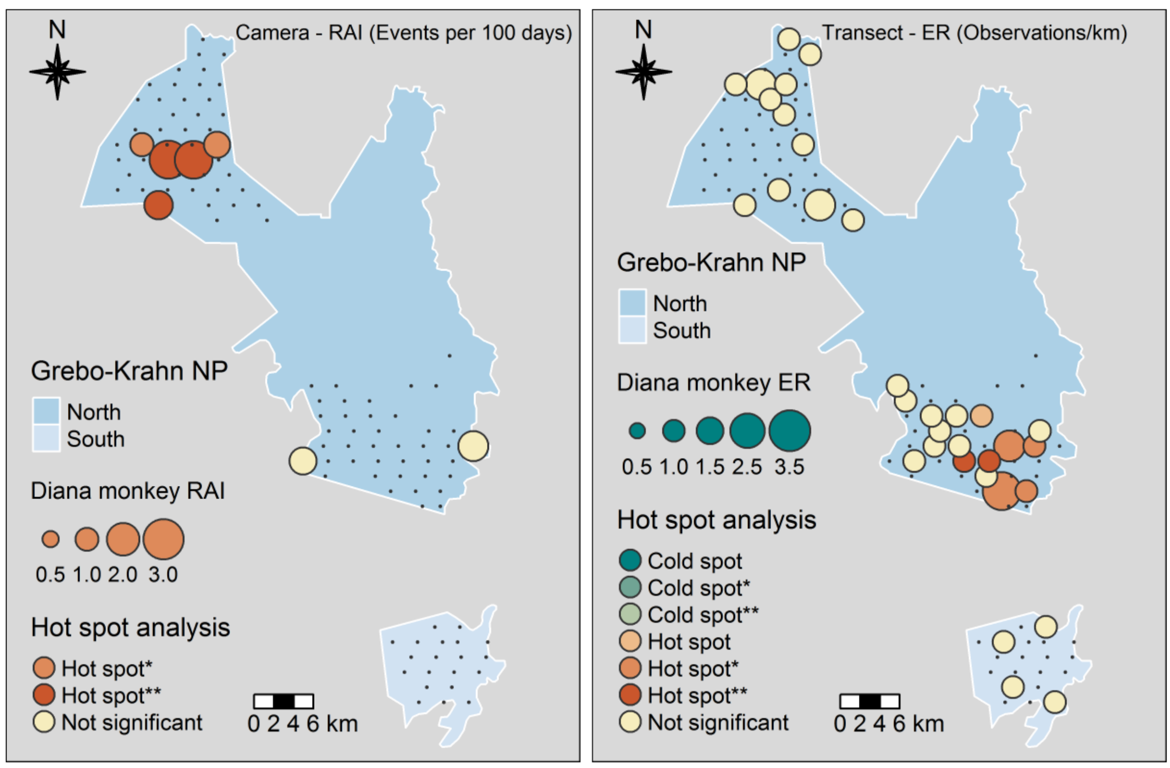

Figure 10: Distribution of the abundance of Diana monkey (RAI = Relative abundance index, ER = Encounter rate, * significant at 95%, ** significant at 99%, hot spot is area of high abundance and cold spot is area of low abundance)

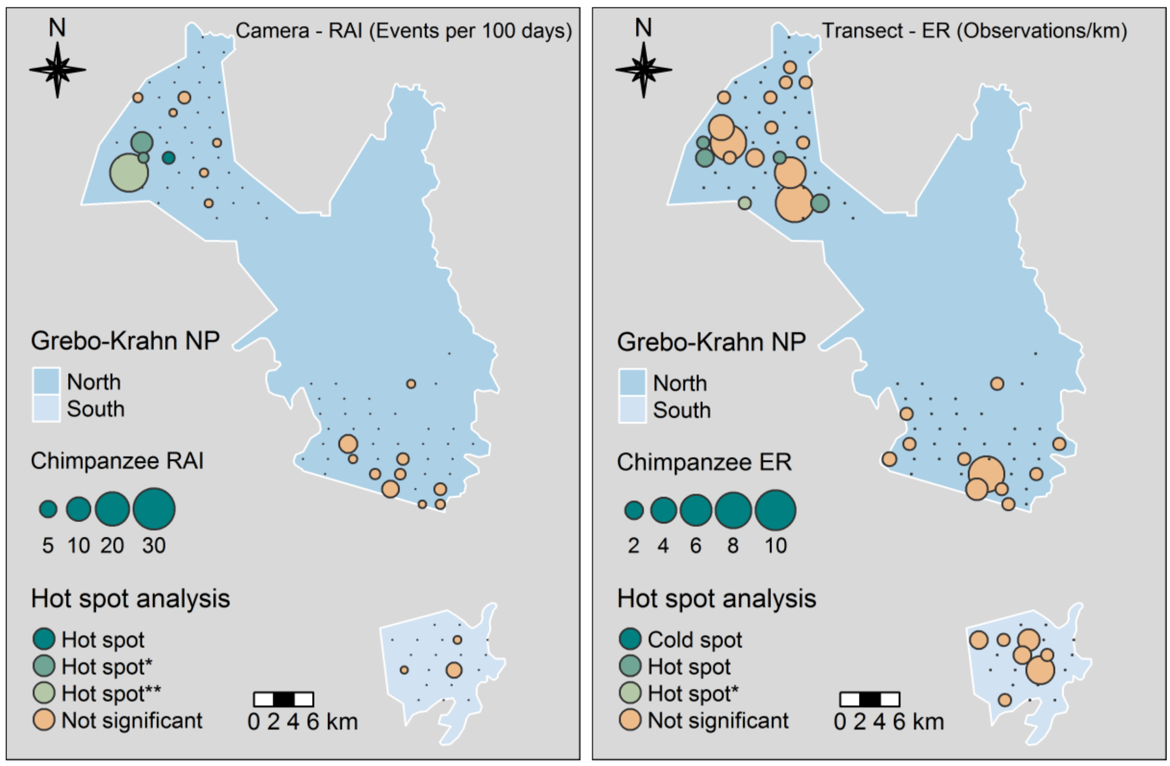

*Figure 11: Distribution of the abundance of Western chimpanzee (RAI = Relative abundance index, ER = Encounter rate, * significant at 95%, ** significant at 99%, hot spot is area of high abundance and cold spot is area of low abundance)*

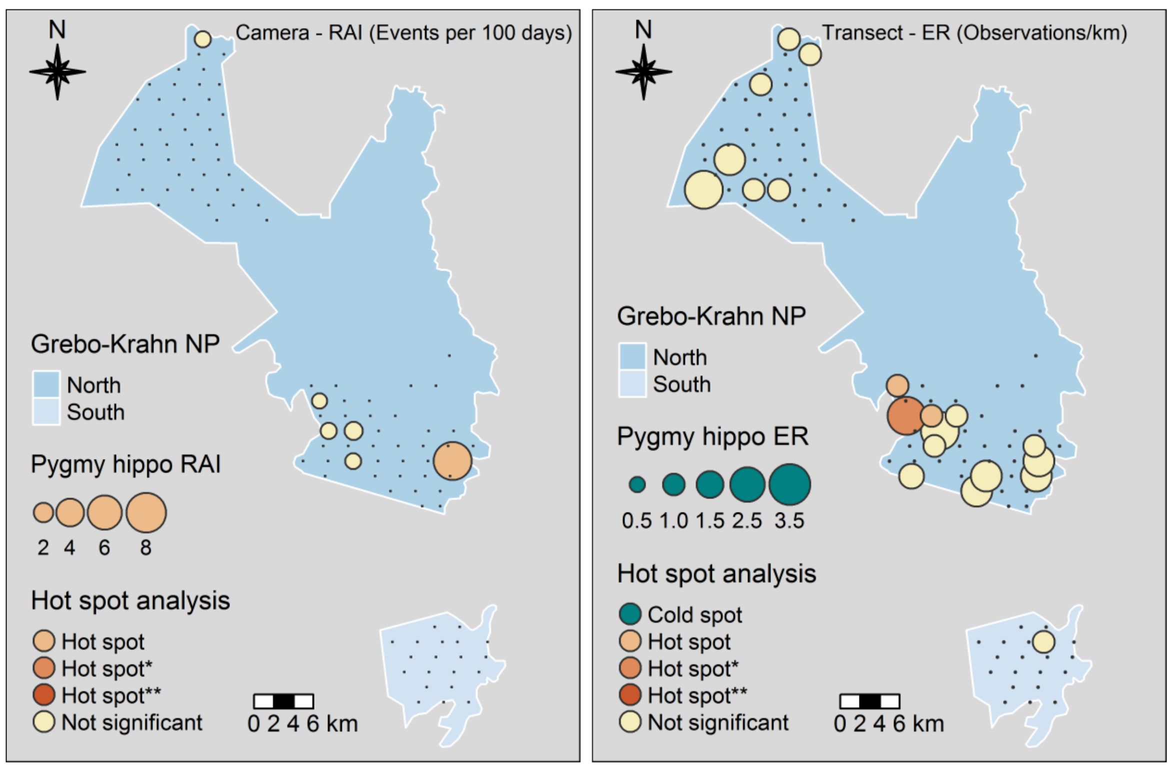

*Figure 12: Distribution of the abundance of Pygmy hippopotamus (RAI = Relative abundance index, ER = Encounter rate, * significant at 95%, ** significant at 99%, hot spot is area of high abundance and cold spot is area of low abundance)*

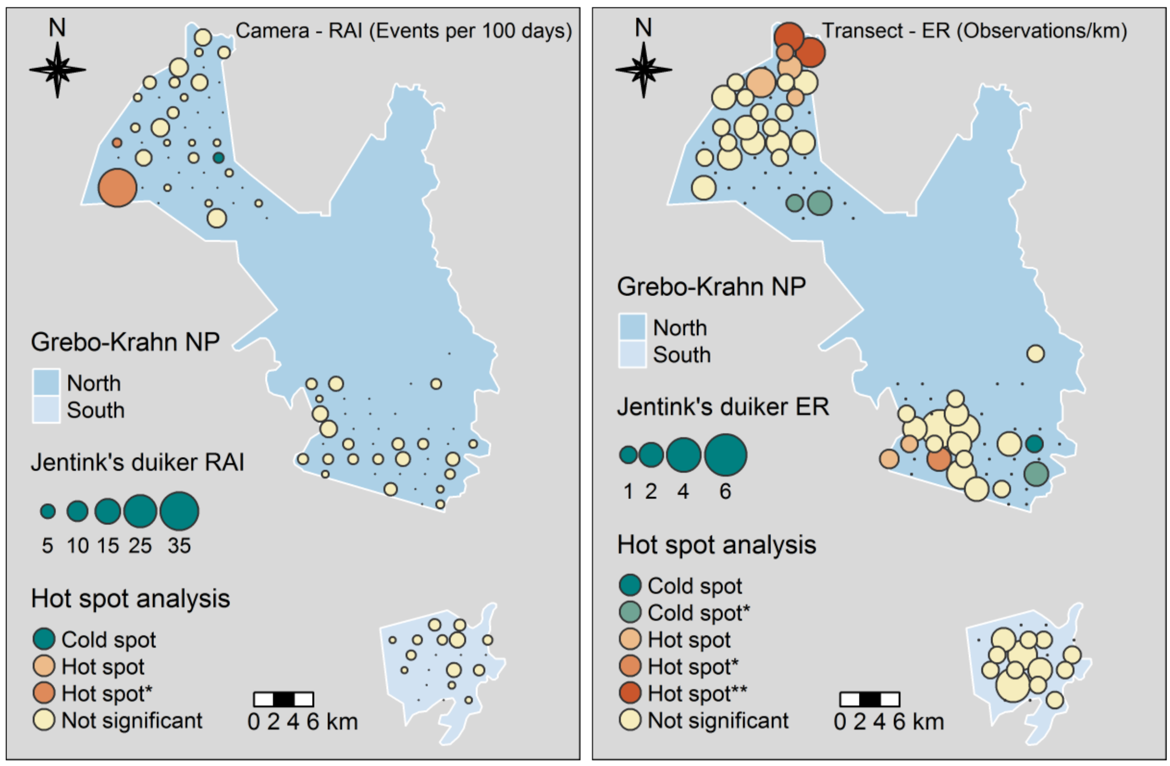

Figure 13: Distribution of the abundance of Jentink's duiker (RAI = Relative abundance index, ER = Encounter rate, * significant at 95%, ** significant at 99%, hot spot is area of high abundance and cold spot is area of low abundance)

3.5. Abundance and distribution of human activities

On the line transects, 468 human activity indices were observed with a global encounter rate of 4.42 indices/km (Table 5). Human paths were the most abundant human activities indices in the GKNP, followed by cartridges, chewing sticks and logging (Table 5). Like the mammal species, and apart from human paths, the average abundances of all human activities were lower than their corresponding standard variation, indicating that their distribution is heterogeneous across the GKNP. Hunting appeared to be the most important activity in the park.

Table 5: Abundance of human activities obtained from line transects

Category	Activity type	Number observed	Average ER	SD ER	Global ER
Human paths and roads	Human paths	354	3.36	2.17	3.34
Human paths and roads	Road	3	0.03	0.17	0.03
Hunting activities	Cartridges	60	0.75	1.69	0.57
Hunting activities	Gunshot	3	0.03	0.26	0.03
Hunting activities	Poacher's camp	6	0.06	0.30	0.06
Hunting activities	Trap	3	0.04	0.23	0.03
Other human activities	Clearing	1	0.01	0.10	0.01
Other human activities	Logging	13	0.12	0.36	0.12

Other human activities	Mining/Gold-washing site	1	0.01	0.10	0.01
Other human activities	Settlement	1	0.01	0.10	0.01
Other human activities	Pit-sawing	1	0.01	0.10	0.01
Chewing stick	Chewing stick	22	0.22	0.80	0.21
Grand Total		**468**			**4.42**

The encounter rate of human paths was higher in northwest while the encounter rate of hunting signs chewing stick sites was higher at the center of the park (Figure 14).

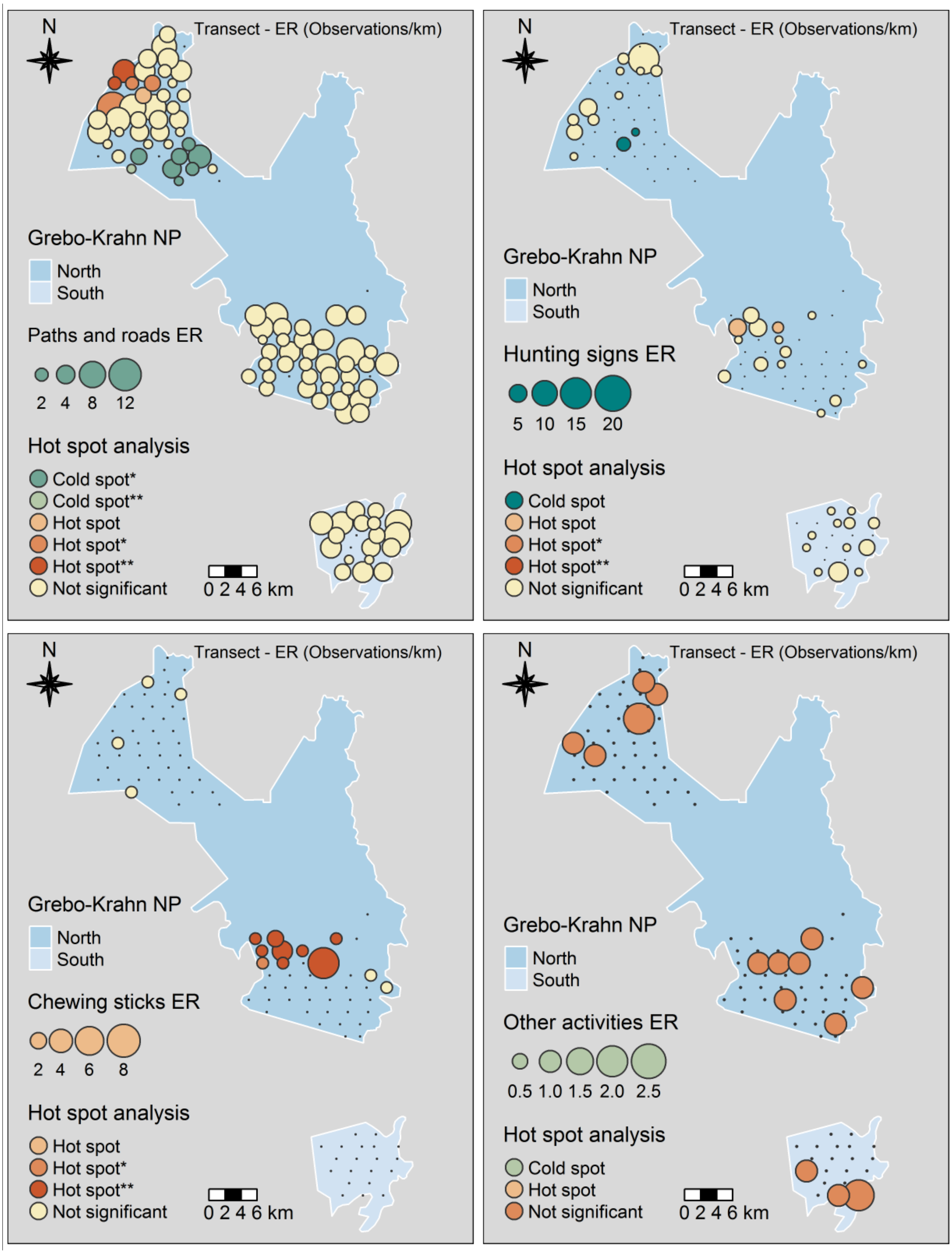

Figure 14: Distribution of human activities obtained from line transects (RAI = Relative abundance index, ER = Encounter rate, * significant at 95%, ** significant at 99%, hot spot is area of high abundance and cold spot is area of low abundance

DISCUSSION

The present biomonitoring survey provides important results for the management of the Grebo-Krahn National Park and presents a better understanding of the Grebo-Krahn Landscape from the implementation of CTs and line transects distance sampling altogether. The 2020 phase is the first biomonitoring survey that involve the entire spectrum of the park since the last five years and allows comparisons from previous data set collected from the GKNP in 2014 and 2015.

The distribution of large mammal species from both CTs and line transects obtained in this study seems to be similar to those obtained from the previous surveys conducted in the GKNP. However, our comparisons are limited since all our data could not be included in the analyses due to a limited amount of time.

We obtained sufficient data to estimate reliably the density of chimpanzees with the line transects (n>60; Buckland et al., 2001). The density estimate shows a precision of CV=25.53%, and suggest decrease by 46.34% of individuals in 2015 and 55.88% of individuals in 2014, though the differences were not significant (Table 4) (Furnell *et al.*, 2015). This might be due to the sensitivity of indices conversion factors that vary with the environment and are site-specific (Buckland et al. 2001; Kühl et al. 2007; Plumptre & Reynolds 1996; Walsh & White, 2005). Because of limited budget and time, the nest decay time used was not estimated from survey despite the recommendation made by Buckland et al. (2001). In addition, the coefficients of variation in those years are larger than the 20% recommended by Plumptre (2000).

We were also able to estimate the density of monkeys despite a lower amount of observations (n=39). As it is under the minimum amount recommended by Buckland et al. (2001), our estimates of the groups of monkeys need to be interpreted with caution. In addition, the monkeys displayed strong reactions to observers, such as avoidance, that could explain the low amount of observations and might have caused bias in our estimates (Buckland et al., 2001).

A total of one species and a group of species had their density estimated using line transects. With the data obtained using CTDS, we consider that a total of 22 different species. Similarly, 13-yers of monitoring with line transects in the TNP allowed to estimate the abundance of two species and two groups of species (Tiedoue et al., 2019; Cappelle et al., in prep). A year of CTDS in the entire TNP yielded enough data to estimate the density of 34 different species (unpublished results), and in only a 200 km² of the same park, 31 species (Cappelle et al., 2020). In another CTDS survey of one year and a half lead in the Salonga National Park, Democratic Republic of Congo, they considered that they could estimate the density of 29 species. This shows that CTDS can be particularly efficient for monitoring multiple species. However, this method can also be limited when surveying rare species or species with particular behavior, such as avoidance (Cappelle et al., 2020). In addition, other approaches need to be used complementary if arboreal species are targeted since CTDS is not meant to monitor such species.

CONCLUSION AND RECOMMENDATIONS

The first intensive biomonitoring study within the Grebo-Krahn NP over the past five years has confirmed the continued rich biodiversity of several classes of species including endangered, vulnerable and critically endangered species inhabiting the GKNP. All the 10 primate species found in 2015 were also recorded in this study on line transects, confirming high biodiversity reported in the previous years. Most significantly, it confirms several hot spots of biologically important species that are presence in the Taï-Grebo-Sapo Corridor Complex as well as human activities.

The protection of the GKNP is vital to ensure integrity of the last remnant of forest within the Upper Guinea Ecosystem. We provide recommendations at local and national scales:

1. As the demarcation of the park is being almost finalized, FDA should provide continue law enforcement in the Grebo-Krahn National Park. These patrols will complement the community Ecoguard patrols in the park, have a positive impact on the level of hunting, chewing stick extraction and mining, and improve the park protection.

2. The need for ranger posts at strategic entries and border points into the park are very much necessary. The proximity of rangers' station to the park will remind communities that the Grebo-Krahn National Park remains protected at all time under the law of Liberia.

3. The eviction of intruders particularly along the borders and various hot spots that have been highlighted during this study. The illegal infiltration inside the park is causing a detrimental effect on the surrounding forest and wildlife through hunting and habitat degradation.

4. It is imperative to continue providing awareness towards the importance of the forest and the consequence in breaking the law. The awareness should be done in local vernacular as well.

5. The state of the park should be evaluated regularly in order to verify the efficiency of the conservation decisions and monitor the long-term trends of threatened species.

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Appendix

Table 6: Global and average Relative Abundance Index (RAI) of birds from camera traps

Order	Family	Scientific name	Common name	IUCN Status	CITES	Average RAI	SD of RAI	Global RAI
Accipitriformes	Accipitridae	*Accipiter toussenelii*	Red-chested goshawk	Least concern	II	0.06	0.51	0.07
Accipitriformes	Accipitridae	*Stephanoaetus coronatus*	Crowned eagle	Near threatened	II	0.03	0.25	0.03
Bucerotiformes	Bucerotidae	*Horizocerus albocristatus*	Western long-tailed hornbill	Least concern		0.05	0.37	0.05
Columbiformes	Columbidae	*Turtur brehmeri*	Blue-headed wood-dove	Least concern		0.02	0.24	0.03
Cuculiformes	Cuculidae	*Centropus leucogaster*	Black-throated coucal	Least concern		0.09	0.67	0.10
Galliformes	Numididae	*Agelastes meleagrides*	White-breasted guineafowl	Vulnerable		1.14	2.61	1.21
Galliformes	Numididae	*Guttera verreauxi*	Western crested guineafowl	Least concern		0.41	1.29	0.45
Galliformes	Phasianidae	*Francolinus lathami*	Latham's forest francolin	Least concern		0.17	0.69	0.17
Gruiformes	Rallidae	*Himantornis haematopus*	Nkulengu rail	Least concern		0.26	1.04	0.30
Passeriformes	Muscicapidae	*Alethe diademata*	White-tailed alethe	Least concern		0.30	1.79	0.33
Passeriformes	Muscicapidae	*Stiphrornis erythrothorax*	Orange-breasted forest-robin	Least concern		0.05	0.35	0.06
Passeriformes	Muscicapidae	*Tychaedon leucosticta*	Forest scrub-robin	Least concern		0.06	0.50	0.06
Passeriformes	Pycnonotidae	*Bleda canicapillus*	Grey-headed bristlebill	Least concern		0.18	0.92	0.19
Passeriformes	Pycnonotidae	*Bleda syndactylus*	Red-tailed bristlebill	Least concern		0.02	0.21	0.01
Passeriformes	Pycnonotidae	*Criniger olivaceus*	Yellow-bearded greenbul	Vulnerable		0.21	1.14	0.22
Passeriformes	Turdidae	*Neocossyphus poensis*	White-tailed ant-thrush	Least concern		0.01	0.19	0.02
All birds								3.56

Table 7: Global and average encounter rate (ER) of birds from line transects

Order	Family	Scientific name	Common name	IUCN	CITES	Average ER	SD ER	Global ER
Accipitriformes	Accipitridae	*Stephanoaetus coronatus*	Crowned eagle	Near threatened	II	0.06	0.23	0.06
Bucerotiformes	Bucerotidae	*Tockus fasciatus*	African pied hornbill	Least concern		0.34	1.04	0.33
Bucerotiformes	Bucerotidae	*Tockus hartlaubi*	Black dwarf hornbill	Least concern		0.04	0.19	0.04
Bucerotiformes	Bucerotidae	*Ceratogymna atrata*	Black-casqued hornbill	Least concern		0.97	1.49	0.97
Bucerotiformes	Bucerotidae	*Bycanistes cylindricus*	Brown-cheeked hornbill	Vulnerable		0.13	0.50	0.13
Bucerotiformes	Bucerotidae	*Bycanistes fistulator*	Piping hornbill	Least concern		0.02	0.19	0.02
Bucerotiformes	Bucerotidae	*Tockus camurus*	Red-billed dwarf hornbill	Least concern		0.14	0.50	0.14
Bucerotiformes	Bucerotidae	*Horizocerus albocristatus*	Western long-tailed hornbill	Least concern		0.25	2.04	0.25
Bucerotiformes	Bucerotidae	*Ceratogymna elata*	Yellow-casqued hornbill	Vulnerable		0.07	0.32	0.07
Cuculiformes	Cuculidae	*Centropus senegalensis*	Senegal coucal	Least concern		0.08	0.31	0.08
Galliformes	Numididae	*Guttera verreauxi*	Western crested guineafowl	Least concern		0.08	0.31	0.08
Galliformes	Numididae	*Agelastes meleagrides*	White-breasted guineafowl	Vulnerable		0.05	0.40	0.05
Musophagiformes	Musophagidae	*Corythaeola cristata*	Great blue turaco	Least concern		0.71	0.93	0.72
Musophagiformes	Musophagidae	*Tauraco macrorhynchus*	Yellow-billed turaco	Least concern	II	1.04	1.21	1.04
Passeriformes	Picathrtidae	*Picathartes gymnocephalus*	White-necked rockfowl	Vulnerable	I	0.01	0.10	0.01
Psittaciformes	Psittacidae	*Psittacus timneh*	Timneh grey parrot	Endangered	I	0.02	0.19	0.02
All birds								3.99

Table 8: List of animal species for which abundance can be estimated based on camera trap data for future reference

Row Labels	Order	Family	Scientific name	Common name	IUCN Status	CITES
Bird	Galliformes	Numididae	*Guttera verreauxi*	Western crested guineafowl	Least concern	
Bird	Galliformes	Numididae	*Agelastes meleagrides*	White-breasted guineafowl	Vulnerable	
Bird	Gruiformes	Rallidae	*Himantornis haematopus*	Nkulengu rail	Least concern	
Bird	Passeriformes	Muscicapidae	*Alethe diademata*	White-tailed alethe	Least concern	
Mammal	Carnivora	Viverridae	*Civettictis civetta*	African civet	Least concern	III
Mammal	Carnivora	Herpestidae	*Crossarchus obscurus*	Cusimanse (mongoose)	Least concern	
Mammal	Carnivora	Viverridae	*Genetta spp*	Genet		
Mammal	Carnivora	Mustelidae	*Mellivora capensis cottoni*	Honey badger	Least concern	III
Mammal	Carnivora	Herpestidae	*Liberiictis kuhni*	Liberian mongoose	Vulnerable	
Mammal	Carnivora	Herpestidae	*Atilax paludinosus*	Marsh mongoose	Least concern	
Mammal	Cetartiodactyla	Bovidae	*Cephalophus dorsalis*	Bay duiker	Near threatened	II
Mammal	Cetartiodactyla	Bovidae	*Cephalophus niger*	Black duiker	Least concern	
Mammal	Cetartiodactyla	Bovidae	*Tragelaphus eurycerus*	Bongo	Near threatened	
Mammal	Cetartiodactyla	Bovidae	*Cephalophus ogilbyi brookei*	Brooke's duiker	Vulnerable	II
Mammal	Cetartiodactyla	Suidae	*Hylochoerus meinertzhageni*	Giant forest hog	Least concern	
Mammal	Cetartiodactyla	Bovidae	*Cephalophus jentinki*	Jentink's duiker	Endangered	I
Mammal	Cetartiodactyla	Bovidae	*Philantomba maxwellii*	Maxwell's duiker	Least concern	
Mammal	Cetartiodactyla	Hippopotamidae	*Choeropsis liberiensis*	Pygmy hippopotamus	Endangered	II
Mammal	Cetartiodactyla	Suidae	*Potamochoerus porcus porcus*	Red river hog	Least concern	
Mammal	Cetartiodactyla	Bovidae	*Cephalophus silvicultor*	Yellow-backed duiker	Near threatened	II
Mammal	Cetartiodactyla	Bovidae	*Cephalophus zebra*	Zebra duiker	Vulnerable	II
Mammal	Pholidota	Manidae	*Smutsia gigantea*	Giant ground pangolin	Endangered	I
Mammal	Primates	Cercopithecidae	*Cercopithecus mona campbelli*	Campbell's monkey	Least concern	II
Mammal	Primates	Cercopithecidae	*Cercocebus atys atys*	Sooty mangabey	Near threatened	II
Mammal	Primates	Hominidae	*Pan troglodytes verus*	Western chimpanzee	Critically endangered	I
Mammal	Rodentia	Hystricidae	*Atherurus africanus*	African brush-tailed porcupine	Least concern	
Mammal	Rodentia	Sciuridae	*Funisciurus pyrropus*	Fire-footed rope squirrel	Least concern	

Mammal	Rodentia	Nesomyidae	*Cricetomys emini*	Giant pouched rats	Least concern
Mammal	Rodentia	Sciuridae	*Paraxerus poensis*	Green bush squirrel	Least concern
Mammal	Rodentia	Sciuridae	*Heliosciurus rufobrachium*	Red-legged sun squirrel	Least concern