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BIOMONITORING REPORT - MOYEN BAFING NATIONAL PARK

Phase 1 (2019-2021) and Phase 2 (2022-2023)

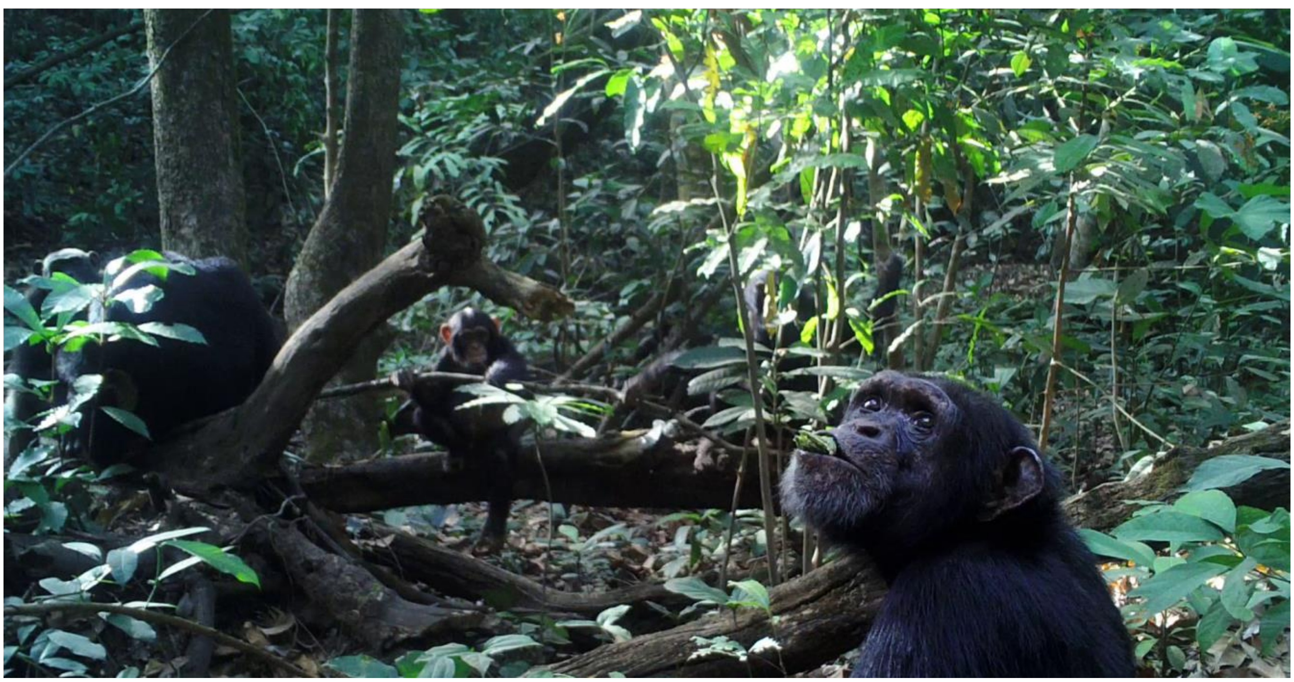

*Image of a western chimpanzee (*Pan troglodytes verus*) captured with a camera trap in the Moyen Bafing National Park, Guinea*

Prepared by the Wild Chimpanzee Foundation,
in collaboration with the Office Guinéen des Parcs Nationaux et Réserves de Faune

SUMMARY

1 – The 6 767 km² Moyen Bafing National Park is located in the Foutah Djallon region in the north of Guinea. It was created in 2021 as part of an offset project with the objective of increasing the population of wild western chimpanzees. The region is mountainous with a mosaic of habitats, ranging from grassy savanna to densely forested areas alongside the streams. This report presents the results of two phases of biomonitoring with camera traps, conducted between 2019 and 2021 (phase 1), and 2022 and 2023 (phase 2).

2 - The method used is distance sampling with camera traps, tested especially with chimpanzees in tropical forest and applied for the first time here at a large scale in a dryer region. We used a stratified design, sampling in three habitats that host most of the medium and large-sized mammals: gallery forests, clear forests, and bushy savannas. We sampled in the first phase a total of 530 camera locations that covered the whole park. The sampling was reduced in phase 2 to try to sample the whole area in one year. However, only two thirds of the park could be sampled (due to concerns from communities in the southern part, South of the Bafing river), and 253 cameras were set up. To compare the results between phase 1 and phase 2, the area that was not sampled in phase 2 was excluded from the analyses of the phase 1 data.

3 - The Moyen Bafing National Park hosts 43 different large mammal species that were captured with the camera traps. We estimated the density and abundance of five mammal species: western chimpanzees, bushbucks, red-flanked duikers, green monkeys, and warthogs. Additionally, we computed the relative abundance index for all mammals across the two phases. The density of the critically endangered western chimpanzee was estimated between 0.46 to 1.12 individuals/km^2 for phase 1 and between 0.2 and 0.61 individuals/km^2 for phase 2.

4 - For most mammals, the relative abundance index was lower in phase 2 compared to phase 1. However, for the species for which density and abundance could be computed in both phases, the confidence intervals are overlapping. We propose several hypotheses to explain that difference. First, there could indeed be a downward trend in some mammal populations in the area, even though there was no evidence of increase of exploitative activities by humans. Second, stochastic variation that influences the results of any sampling methods could cause such a difference and be enhanced by the reduced sampling effort in phase 2. Third, detection by the camera could be reduced and biased in phase 2 because part of the cameras used in phase 2 were older cameras.

Additionally, behavioral responses of some species to the camera traps added complexity to the analyses.

5 - The distance sampling method is a well-known method to account for imperfect detection depending on the distance of the animal to the observer but was recently adapted to camera traps. It is a novel method that we applied in a challenging environment, and it showed promising results. Continued biomonitoring is critical to understand the population dynamics and make more robust claims about the temporal trends of wild mammal population sizes. The future monitoring protocol must be adapted to build in controls for the new challenges that the second phase of data collection revealed.

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LIST OF ABBREVIATIONS

FC: Clear forest

FG: Gallery forest

IUCN: International Union for Conservation of Nature

MBNP: Moyen Bafing National Park

OGPNRF: Office Guinéen des Parcs Nationaux et Réserves de Faune

PIR: Passive infrared

RAI: Relative abundance index

SA: Bushy savanna

WCF: Wild Chimpanzee Foundation

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I. Introduction

Since 2010, the Wild Chimpanzee Foundation (WCF) works closely with the Guinean Government, especially the Office Guinéen des Parcs Nationaux et Réserves de Faune (OGPNRF) to help identify areas with high biodiversity and conservation value. The objective of the Guinean Government was to meet their commitment to protect 15% of their terrestrial area by 2020. Particularly, the WCF with OGPNRF was looking for areas with high densities of the critically endangered western chimpanzee (*Pan troglodytes verus*). Western chimpanzee populations have been drastically declining and decreased by 80% over a 24-year period (Kühl et al., 2017), due mainly to deforestation, poaching, and zooanthroponosis, all induced by the increased human encroachment on natural habitats. During that process, the WCF and the OGPNRF identified specifically an area in the Foutah Djallon region of Guinea with a high density of chimpanzees (WCF, 2016; Heinicke et al. 2019). It was chosen to become a national park, despite the presence of many villages in the area. To finance the park creation, which will eventually become the Moyen Bafing National Park (MBNP), the area was selected as an offset project by two mining companies, Guinea Alumina Corporation (GAC) and the Compagnie des Bauxites de Guinée (CBG) in September 2017. They need to achieve a net gain of 397 chimpanzees, lost due to their mining activities in the Region of Sangaredi, to follow the IFC environmental standard (Guidance Note 6, IFC 2019). In the long term, the creation of the MBNP and its maintenance, thanks to conservation actions such as forest restoration, control of wildfire, and sustainable agronomic practices, is meant to provide an environment that would permit the required increase of chimpanzees. The WCF was mandated to help on the creation process of the park, which was officially created under a presidential decree on May the 4th 2021, protecting an area of 6 767 km^2. The WCF was afterwards in charge of continuing conservation activities and work with the local communities until the management of the park could be handed over to a competent entity.

During that time, one of the main activities of the WCF in the MBNP was biomonitoring. It is a crucial activity, especially in an offset context, to ensure that the conservation plan and the creation of the park leads to an effective increase of the chimpanzee population (Nichols & Williams, 2006). The status of the population at the beginning of the project must be assessed and followed across years (decades) until the net gain is attained. However, biomonitoring at the scale of an entire national park is not trivial. Chimpanzees are elusive, and traditionally the population is estimated through indirect counts of nests with line transects (Kouakou et al., 2009).

Yet, this method comes with several challenges. By sampling signs of chimpanzees and not individuals directly, the number of signs (here the number of nests) needs to be transformed into a number of individuals. This transformation comes with bias and needs additional measurements – decay rates of nests, construction rates, proportion of individuals making nests – that are often taken from the literature. However, these rates are site and time specific (Bessone et al., 2021) – especially the nest decay rates – and are not easy to estimate but have a significant impact on the results. Additionally, nest decay rates need to be regularly updated, with climate change accelerating over the years. A camera trap method, as an alternative to nest counts, was developed in 2017 (Howe et al. 2017) and proven to give reliable estimates of chimpanzee density (Cappelle et al., 2019). Camera traps have many advantages. First, they record elusive species and require less field effort and expertise than the line transect method. Second, they allow for a precise estimate of species richness for medium sized terrestrial mammals, and third the estimates do not rely on signs but on actual individuals. However, as a trade-off, they require more work to process the massive amount of data recorded. As part of the biomonitoring, the WCF decided to use that novel camera trap method to improve the estimates compared to nest counts along line transects and applied it for the first time at a large scale in a savanna mosaic environment.

Besides being elusive, chimpanzees have a slow life history, meaning that population growth would be extremely slow. To know whether the conservation actions have a positive impact on the wildlife, in addition to the chimpanzee population, we monitored the abundance and density of four other species as indicators. They are less elusive than chimpanzees and captured relatively often by cameras in the region. The bushbuck (*Tragelaphus scritpus*) is a large-sized species that is hunted by the local communities. The red-flanked duiker (*Cephalophus rufilatus*) is a medium-sized mammal, also hunted, and that has an affinity to more forested areas. The green monkey (*Chlorocebus sabaeus*) is a primate with a higher reproductive rate than chimpanzees, and the warthog (*Phacochoerus africanus*) is a medium-sized mammal that is rarely hunted in the area because of a cultural taboo, which is also the case for chimpanzees (Boesch et al., 2017).

Here we present the results of two phases of biomonitoring with the camera trap distance sampling method in the MBNP. The main objective was to estimate a baseline density of the five species of interest and tailor this recent method to the specificities of the Moyen-Bafing region.

II. Methods

a. Study site

Data were collected in the Moyen Bafing National Park (10.97°N to 11.46°N and 11.67°W to 10.97°W, Figure 1) located in the Foutah-Djallon region of Guinea. The preliminary limits of the park, on which the camera design was created, delineate a surface of 6 428 km^2 (the final area of the park is 6 767 km^2). The dry season in this region lasts from November to April and the rainy season from May to October. The mosaic habitat in this mountainous landscape varies from grassy savannah on plateaus to gallery forest along the rivers, with woodland savannahs and bushy savannahs scattered in-between.

b. Preliminary data collection (2018)

The whole area of the Moyen Bafing National Park could not be sampled all at once, so we divided the park into three sections, South, Northwest, and Northeast. A preliminary data collection took place in 2018 in the Northwest of the park, where pairs of cameras were set up systematically – every 3.275 km – in 148 locations from the 27th of February 2018 to the 19th of October 2018. The objective was to automatically extract the animal-camera distances with a software developed by a team from the "*Hochschule für Technik, Wirtschaft und Kultur*" in Leipzig, Germany. Hence, two cameras were placed at each location to mimic eyes, enabling the creation of depths by merging the videos of the two cameras, and ultimately the estimation of the distances. The two cameras of a pair were screwed on a single metal bar, separated by 50 centimeters. The bar was then attached about 50 centimeters above the ground to a tree with straps following these recommendations: the tree needed to be the closest to the GPS point coordinates and able to support the device, with good visibility in either the geographic north or south, where the cameras should be oriented. However, by placing the cameras systematically, a lot of them ended up being placed in open habitats (six locations were gallery forest), which led to a lot of empty videos, and too few videos of chimpanzees (N=83 events) after nearly eight months of data collection. Consequently, we changed the design from systematic to stratified for the first phase of data collection.

c. *Data collection during phase 1 (2019-2021)*

We placed the cameras at regular distances in three different strata, characterized by their habitat: gallery forest (FG), clear forest (FC) and bushy savanna (SA).

The locations of the cameras were determined using the regular point tool in QGIS (QGIS Development team). We planned to set more cameras in the gallery forest, the habitat used more often by chimpanzees, and more in clear forest than in bushy savanna. At first, aided by a habitat map made from satellite images from February 2018, we planned to place nearly half the cameras (45%) in gallery forest, 35% in clear forest, and 20% in bushy savanna. However, the habitat map was not perfect, and even though we defined a buffer of 200 meters around the GPS point to find the adequate habitat, many locations did not have the planned habitat. Eventually, 35% of the cameras were placed in gallery forest, 23% in clear forest, and 42% in bushy savanna (Table I). Motion detectors (Bushnell Trophy Cam HD aggressor no glow) were programmed to trigger with high sensitivity, active 24 hours/day, and set to record videos of 60 seconds, with the minimum triggering interval between the end of one video and the trigger of the next one being 0.6 second. At each location, reference videos were recorded, by filming a person holding a panel with the distance to the camera (from 1 to 25 meters, 1-meter intervals until 15 meters then at 17, 20 and 25) to estimate camera-animal distances in the video footage (Howe et al., 2017). For the south portion of the park, during the first part sampled in 2019, 132 locations were sampled with two cameras per location, attaching them to a metal bar as described in the preliminary data collection section (b.). However, the automation and the calibrating of the algorithm turned out to be problematic, and did not work as expected. For the subsequent sampling, we hence used a single camera by location.

d. Data collection during phase 2 (2022-2023)

Phase 1 lasted three years, to ensure that we had enough data to conduct the analysis with distance sampling reliably. However, we wanted to be able to sample the whole park in one year of data collection in phase 2. To this end, the design plan of phase 1 was reduced, by randomly selecting a subset of the locations in each habitat. Various issues with logistics and opposition by local communities delayed the work, and eventually not the whole park could be sampled, as shown in Figure 1. The number of locations sampled in phase 2 is indicated in Table I. The cameras were set in a similar way as the cameras during phase 1 in the Northwest and Northeast. As the whole park was not sampled during the second phase, to compare the estimates between the two phases, we computed the density and abundance of the first phase using only the cameras that were in the same area as the area sampled in phase 2 (see Table I).

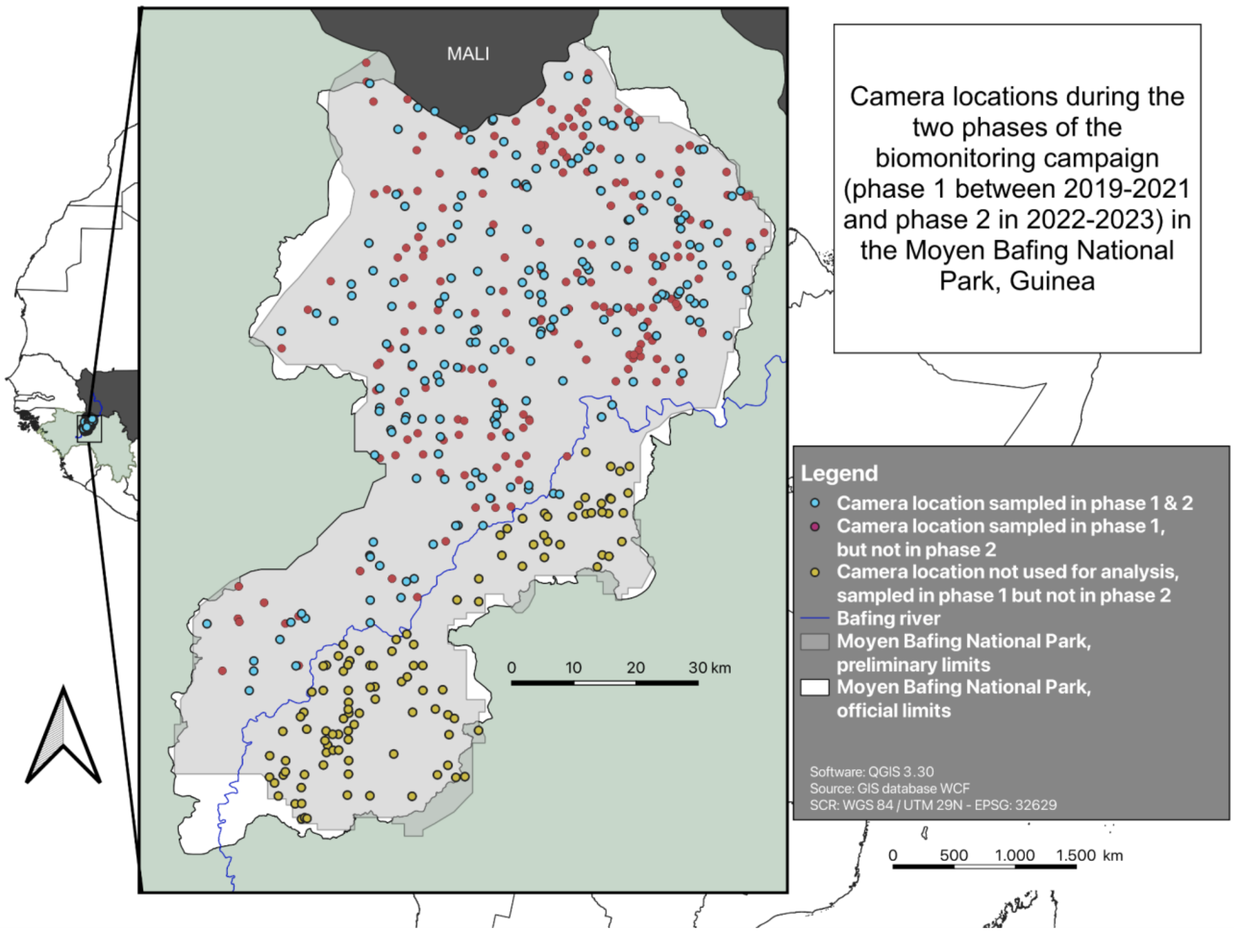


Figure 1: Camera locations used for the biomonitoring in the Moyen Bafing National Park. The yellow, blue and purple points were sampled during phase 1. The camera locations in blue for phase 2, and blue and purple for phase 1 were used in the analysis presented in this report.

Table I. Survey design and effort (CH: Chimpanzees, BU: Bushbucks, RE: Red-flanked duikers, GR: Green monkeys, WA: warthogs).

Strata	Category	Phase 1	Phase 1 using the cameras in the area sampled in Phase 2	Phase 2
TOTAL	Area of suitable habitat surveyed in km² (Area of the whole region in km²)	4373.4 (6428) for CH, BU, RE 3357.1 (4806) for GR, WA	3138.8 (4839) for CH, BU, RE 2122.5 (3239) for GR, WA	3138.8 (4839) for CH, BU, RE 2122.5 (3239) for GR, WA
	Number of cameras set	530	410	253
	Number of cameras used for the analysis	482 for CH, BU, RE 274 for GR, WA	363 for CH, BU, RE 171 for GR 170 for WA	180 for CH, BU, RE 90 for GR, WA
	Temporal survey effort (camera days)	49107 for CH, BU, RE 32764 for GR, 31578 for WA	28914 for CH, BU, RE 14344 for GR 14054 for WA	12384 for CH, BU, RE 4180 for GR, WA
	Start and end of survey	12/9/2018 – 12/4/2021	12/9/2018 – 12/4/2021	5/10/2022 – 11/25/2023
Gallery forest (FG)	Survey area (km²)	646.9 for CH, BU, RE 558.9 for GR, WA	360.8 for CH, BU, RE 272.8 for GR, WA	360.8 for CH, BU, RE 272.8 for GR, WA
	Number of cameras used	137 for CH, BU, RE 77 for GR 74 for WA	100 for CH, BU, RE 48 for GR, WA	75 for CH, BU, RE 35 for GR, WA
Clear forest (FC)	Survey area (km²)	2449 for CH, BU, RE 1915 for GR, WA	1670 for CH, BU, RE 1136 for GR, WA	1670 for CH, BU, RE 1136 for GR, WA
	Number of cameras used	124 for CH, BU, RE 68 for GR and WA	96 for CH, BU, RE 43 for GR, 45 for WA	68 for CH, BU, RE 38 for GR, WA
Bushy savanna (SA)	Survey area (km²)	1278 for CH, BU, RE 883.5 for GR, WA	1108 for CH, BU, RE 713.7 for GR, WA	1108 for CH, BU, RE 713.7 for GR, WA
	Number of cameras used	221 for CH, BU, RE 129 for GR, 125 for WA	167 for CH, BU, RE 80 for GR, 78 for WA	37 for CH, BU, RE 17 for GR, WA

*Note: the area is different depending on the species. For chimpanzees, bushbucks, and red-flanked duikers, the survey area encompasses the Northwest, Northeast, and part of the South. For warthogs and green monkeys, the survey area is not encompassing the Northeast. The distance data were estimated differently to try to diminish the effort (every 10 seconds), but it did not give robust results.

e. Video coding

All videos were coded manually by a team of video analysts. First, all videos were watched, and the timestamp of each video was recorded in an Excel sheet along with the species and the number of individuals present (if any), and information about the camera (location name and UTM coordinates). Second, the videos with the species of interest – chimpanzees (*Pan troglodytes verus*), green monkeys (*Chlorocebus sabaeus*), red-flanked duikers (*Cephalophus rufilatus*), bushbucks (*Tragelaphus scriptus*), and warthogs (*Phacochoerus africanus*) – were set aside and the animal-camera radial distances extracted. Every two seconds (each even second on the videos), the distance of the center of the animal to the camera was estimated using the set of reference videos that were taken during the installation (in phase 1) or the retrieval of the cameras (in phase 2). Reference videos consist of videos of the field team members filming themselves holding a panel showing the distance at which they stand along three lines – one central line and two lines made with decameters going on each side, at an angle not too large so that the person was still visible on the video. They showed the panels on the three lines at each full meter from 0 to 15 meters and then at 17, 20, and 25 meters. The field team members were instructed to touch the trees and the stones around them while showing the panels to assign to those elements a distance that the video analysts will then use as a reference to estimate the animal-camera distances. Alongside these distances, the analysts noted the behavior of the animal each time they recorded a distance, specifically whether the individual reacted to the presence of the camera or not.

f. Relative abundance index

We define the relative abundance index (RAI) for camera traps (Rovero et al., 2014) as:

$$RAI = \frac{Number\ of\ events}{Number\ of\ days\ the\ cameras\ filmed} \times 100$$

We defined two subsequent events as independent that were not triggered by the same individual or group of individuals. We used a threshold of 15 minutes between two consecutive videos showing the same species at the same location to define two videos as independent. If a video, say video 2, was recorded less than 15 minutes from the previous video, say video 1, they are grouped as one event.

If a third video, say video 3, was recorded less than 15 minutes after video 2, the three videos were grouped in one event, even though there might be more than fifteen minutes between video 1 and 3. Using RAI instead of the raw number of videos enables us to compare the capture of cameras that have not necessarily filmed during the same number of days.

g. Distance sampling with camera traps

The method used is an adaptation of the point transect distance sampling method (Buckland et al., 2001) that enables an unbiased estimation of density.

The density is defined as: $D = \frac{N}{A}$

With D being the density and. N the total number of animals in the area A. In practice, we cannot know the total number of animals N in a large area A, because the whole area cannot be surveyed, and some observations of animals can be missed. In distance sampling theory, the general equation for the calculation of the density D is: $D = \frac{E(n)}{a \times P_a}$

with E(n) being the expected number of animals detected in the surveyed area, a the area covered by the survey, and P_a the probability of detection of the animal within this area. A set of points are thus randomly placed in the area A, and the radial distances of the animals detected to the observer are measured. Given the distribution of distances between the observer and the animal, the probability of detection is estimated, which leads to unbiased estimates of density if the main assumptions are met, despite missing some observations. The assumptions are:

(1) The points are placed randomly with respect to the distribution of the animal
(2) Animals at distance 0 from the point are always detected
(3) Distances are measured accurately
(4) Animals are detected at their initial location

The critical concept in distance sampling theory is the detection function, the probability of detection of the animal at a given distance. The detection function needs to have certain properties. At distance 0, the probability of detection needs to be 1, and at small distances, the probability of detections stays close to one. Models for the probability of detection should fall smoothly at middle distance from the point and approach zero at higher distances.

The main models used in distance sampling theory that have those properties are the uniform model, the half-normal model, and the hazard rate model (see Annex 1 for details). Those models are fitted to the observed distances and allow the estimation of P_a.

In camera trap distance sampling, instead of having a human observer recording the distances, a camera trap records a video of animals. The switch from a human observer recording data to a motion detector, recording only in the field of view (FOV) and the way how distances are extracted require some adjustments compared to the traditional point transect formula, especially in the calculation of the effort.

The distances extracted for each animal by the analysts were binned in one-meter intervals from 0 meter to 10 meters (the animal is between 0-1 m, 1-2 m, …, 9-10 m) in phase 1, and from 0 to 8 meters in phase 2. Because precision in the evaluation of the distance is more difficult to assess the further the animal is from the camera, the distances were assigned to the following categories after 10 meters (or 8 meters in phase 2, 8-10m): 10-12 m, 12-15 m, 15-20 m, 20-25 m.

The density of the species of interest was estimated using Distance 7.3 (Thomas et al., 2010) and R software (R Core Team, 2022), using the packages "Distance" and its dependencies. The formula used was the one of Howe (Howe et al., 2017), described by the equation:

$$\widehat{D} = \frac{\sum_{k=1}^{K} n_k}{\pi w^2 \sum_{k=1}^{K} e_k \widehat{P_k}}$$

with the effort,

$$e_k = \frac{\theta T_k}{2\pi t}$$

where k is one location among the set of K total locations, θ is the horizontal angle of view in radians (specificity of the cameras, here 35° meaning 0.611 rad), T_k the time in seconds the camera at location k was filming, w the truncation distance beyond which all distances recorded are discarded, t the interval of time between the extraction of distances in the video – here 2 seconds (Cappelle et al., 2019; Howe et al., 2017), n_k the number of observations of distances of the species of interest at location k, and $\widehat{P_k}$ the estimated probability of obtaining an animal within the truncation distance. $\widehat{P_k}$ is derived from the fit of the detection function to the distance data.

To meet the first assumption that the points are placed randomly with respect to the distribution of the animal, we also needed to ensure that the movements of the animals were independent from the camera. Thus, any reaction to the camera that would lead to a change in the trajectory of the animal should be discarded. Three categories of reactions were recorded and discarded. (1) Stare, when the animal stopped its movement and looked at the camera, (2) move forward, when the animal moved closer to the camera because it sees it and seemingly aims for a closer inspection, and (3) move backward, when the animal seemingly got scared and ran away from the camera.

We opted for a stratified design to reduce variance and improve precision, and hence got an estimate for each stratum of interest (Buckland et al., 2001).

We had 3 strata, defined according to the habitat, that we will refer to as *fg*, *fc*, and *sa*, each with a respective area, A_{fg}, A_{fc}, A_{sa}. The estimated density in each stratum is $\widehat{D_{fg}}$, $\widehat{D_{fc}}$, $\widehat{D_{sa}}$, and thus the estimated abundance $\widehat{N_{stratum}}$ in each stratum is given by:

$$\widehat{N_{stratum}} = \widehat{D_{stratum}} \text{ x } A_{stratum}$$

Total abundance $\hat{N} = \widehat{N_{fg}} + \widehat{N_{fc}} + \widehat{N_{sa}}$

Overall density is thus $\hat{D} = \frac{\hat{N}}{A} = \frac{\widehat{D_{fg}} \times A_{fg} + \widehat{D_{fc}} \times A_{fc} + \widehat{D_{sa}} \times A_{sa}}{A_{fg} + A_{fc} + A_{sa}}$

The coefficient of variation in a stratified design is calculated as follow:

$$CV_{tot} = \sqrt{\frac{(\hat{N}_{fg} CV_{fg})^2 + (\hat{N}_{fc} CV_{fc})^2 + (\hat{N}_{sa} CV_{sa})^2}{\hat{N}^2}}$$

With CV_x being the coefficient of variation of the model in the stratum x. The coefficient of variation and the 95% confidence interval for each stratum is computed from 999 nonparametric bootstrap resamples of data from the different points.

The combined 95% confidence interval for $\hat{D}$ (or $\hat{N}$) – combining the results from the different strata – is computed as follow, assuming that $\hat{D}$ is log-normally distributed (Buckland et al., 2001):

$$(\hat{D}/C, \hat{D} \times C)$$

with $$C = exp\left[1{,}96 \times se(log_e \hat{D})\right]$$

and $$se(log_e\hat{D}) = \sqrt{log_e[1 + (cv(\hat{D})^2]}$$

As repeated distance observations are gathered for the same animal, the data are non-independent. The traditional distance sampling method assumed an independence of the data. Nevertheless, violation of the independence assumption does not cause bias in the estimation of the parameters but introduces overdispersion (Buckland et al., 2001). Thus, the goodness of fit test and an AIC-based selection of models are not reliable. Similarly, model based analytical variance underestimates the actual uncertainty and cannot be used reliably, but bootstrap estimators are not affected. To perform model selection, Howe and collaborators (2019) developed a two steps procedure to identify the best model with over dispersed data. The first step is to compute the QAIC for all the models and compare it between the models with the same detection function. The lowest QAIC models for each key function (hazard rate, half-normal, uniform) are then selected. For the second step, the value of the χ^2 goodness of fit statistic divided by its degrees of freedom is computed across the QAIC selected model ($\hat{c}$) and the model with the smallest value is selected to use for estimation.

h. *Availability of animals to the camera traps*

Animals are not available to camera traps uniformly for 24 hours. The animal is available for detection when active (animals having a certain level of activity that would enable them to trigger the camera) and on the ground (animals within the vertical range of the camera). Additionally, we defined a finite set of snapshot moments at which distances are to be recorded, *t* units of time apart (in this study, *t* is 2 seconds).

Thus, the temporal effort at location k, T_k/t is calculated as follow:

$$T_k/t = (CTdays \times Hours\ of\ the\ day\ active \times activity)/t$$

with *CTdays* being the number of days the camera in location k was operating, removing the days of maintenance. Hours of the day active is the time in seconds between the first hour the animals start to be active to the last hour they are active (the time frame when distances can be taken) in a day. All is multiplied by the estimated activity. To estimate the activity, we fitted a circadian kernel density function to the times of detections to account for the proportion of time the population is active (Rowcliffe et al., 2014). This method relies on the assumption that all individuals are active at the peak of activity, implying a synchronicity between individuals regarding their activities.

The data at times where not all the population is active are considered corrected by the proportion of the population estimated to be active at that time. We fitted kernel distributions with a 1.5 bandwidth and computed 999 bootstraps with replacements to account for variation. We used the R package "*activity*" to fit the kernel distributions to our data sets.

III. Results

In this section, we will present the results of the relative abundance index for all the mammals captured, and the distribution, the abundance and density for the five species of interest, using for phase 1 those cameras that were set in the same area sampled during phase 2. The results for the whole park for phase 1 can be found in the Annex 2. Hence from here on, phase 1 will refer to the cameras set during phase 1 in the same area sampled during phase 2 (blue and purple points in Figure 1, columns 4 and 5 in Table I).

a. Relative abundance index in phase 1 and phase 2

43 different wild mammals' species were recorded with the camera traps in the MBNP. The rarest species were only captured in phase 1, such as the endangered giant pangolin and the vulnerable hippopotamus (only captured in phase 1 in the area not sampled in phase 2). The spotted hyena is also rare in Guinea as it has been chased away and was only captured once in phase 1. The difference between the RAI in phase 1 and phase 2 (Figure 2) shows that most of the species were captured less in phase 2 than in phase 1.

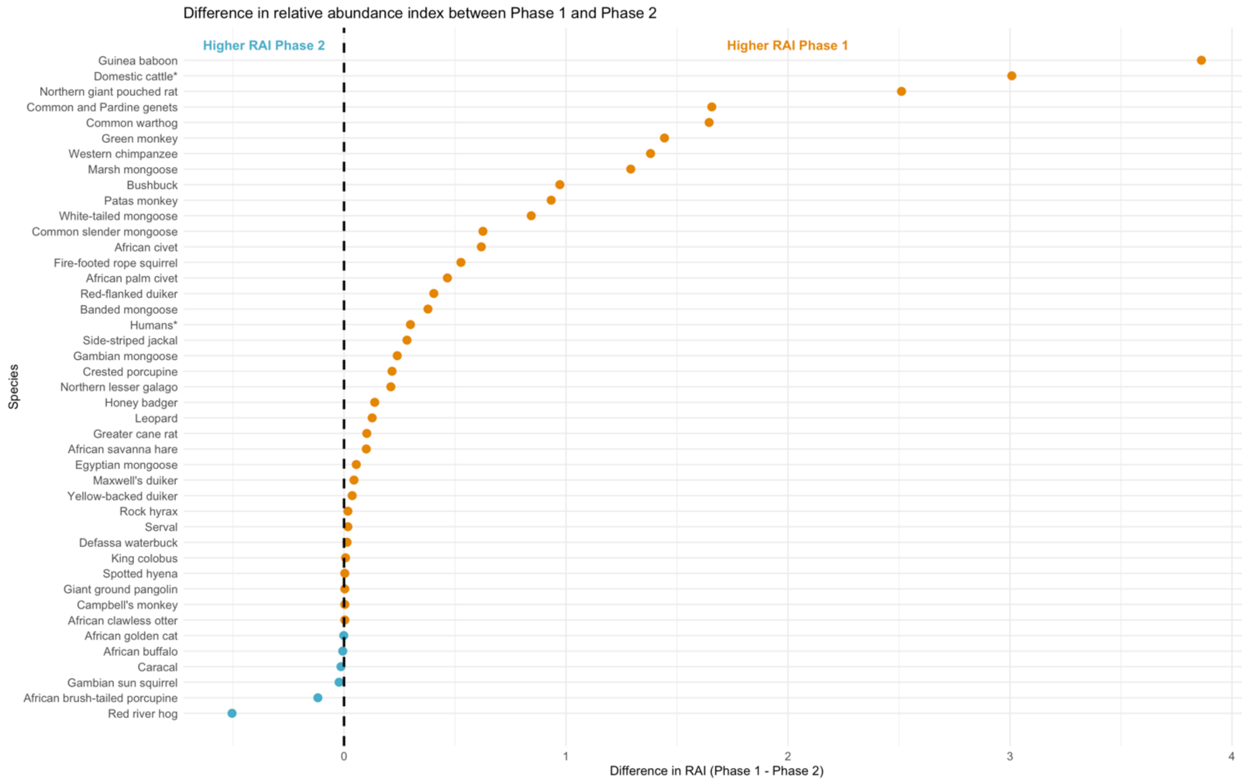


Figure 2. Differences in relative abundance indices (RAI) between phase 1 and phase 2. A positive difference (dots in orange) indicates that the RAI in phase 1 was higher than in phase 2, while a negative difference (dots in blue) indicates that the RAI in phase 2 was higher than in phase 1. The species with a little asterisk (*) are not wild.

Table II. Relative abundance index (RAI) and number of events for each species captured during phase 1 (49107 camera days) and phase 2 (12384 camera days).

Species	Common name	Order	IUCN status	Events (Phase 1)	RAI (Phase 1)	Events (Phase 2)	RAI (Phase 2)
Bos taurus*	Domestic cow*	Artiodactyla	NA	2258	7.809	487	3.932
Capra aegagrus hircus*	Domestic goat*	Artiodactyla	NA	67	0.232	138	1.114
Cephalophus rufilatus	Red-flanked duiker	Artiodactyla	LC	766	2.649	278	2.245
Cephalophus silvicultor	Yellow-backed duiker	Artiodactyla	NT	27	0.093	7	0.057
Hippopotamus amphibius	Hippopotamus	Artiodactyla	VU	0	0.000	0	0.000
Kobus ellipsiprymnus defassa	Defassa waterbuck	Artiodactyla	NT	39	0.135	15	0.121
Ovis aries*	Domestic sheep*	Artiodactyla	NA	4	0.014	0	0.000
Phacochoerus africanus	Common warthog	Artiodactyla	LC	2773	9.591	984	7.946
Philantomba maxwellii	Maxwell's duiker	Artiodactyla	LC	90	0.311	33	0.266
Potamochoerus porcus	Red river hog	Artiodactyla	LC	146	0.505	125	1.009
Syncerus caffer	African buffalo	Artiodactyla	NT	3	0.010	2	0.016
Tragelaphus scriptus	Bushbuck	Artiodactyla	LC	671	2.321	167	1.349
Aonyx capensis	African clawless otter	Carnivora	NT	1	0.003	0	0.000
Atilax paludinosus	Marsh mongoose	Carnivora	LC	726	2.511	151	1.219
Caracal aurata	African golden cat	Carnivora	VU	2	0.007	1	0.008
Caracal caracal	Caracal	Carnivora	LC	10	0.035	6	0.048
Civettictis civetta	African civet	Carnivora	LC	424	1.466	105	0.848
Crocuta crocuta	Spotted hyena	Carnivora	LC	1	0.003	0	0.000
Genetta sp	Common and Pardine genets	Carnivora	LC	1518	5.250	445	3.593
Herpestes ichneumon	Egyptian mongoose	Carnivora	LC	16	0.055	0	0.000
Herpestes sanguineus	Common slender mongoose	Carnivora	LC	279	0.965	42	0.339
Ichneumia albicauda	White-tailed mongoose	Carnivora	LC	468	1.619	96	0.775
Leptailurus serval	Serval	Carnivora	LC	12	0.042	3	0.024
Lupulella adusta	Side-striped jackal	Carnivora	LC	110	0.380	12	0.097

Mellivora capensis	Honey badger	Carnivora	LC	61	0.211	9	0.073
Mungos gambianus	Gambian mongoose	Carnivora	LC	81	0.280	5	0.040
Mungos mungo	Banded mongoose	Carnivora	LC	149	0.515	17	0.137
Nandinia binotata	African palm civet	Carnivora	LC	144	0.498	4	0.032
Panthera pardus	Leopard	Carnivora	VU	60	0.208	10	0.081
Procavia capensis ruficeps	Rock hyrax	Hyracoidea	LC	5	0.017	0	0.000
Smutsia gigantea	Giant ground pangolin	Pholidota	EN	1	0.003	0	0.000
Cercopithecus campbelli	Campbell's monkey	Primates	NT	1	0.003	0	0.000
Chlorocebus sabaeus	Green monkey	Primates	LC	3037	10.504	1122	9.060
Colobus polykomos	King colobus	Primates	EN	2	0.007	0	0.000
Erythrocebus patas	Patas monkey	Primates	NT	536	1.854	114	0.921
Galago senegalensis	Northern lesser galago	Primates	LC	68	0.235	3	0.024
Homo sapiens*	Humans*	Primates	LC	334	1.155	106	0.856
Pan troglodytes verus	Western chimpanzee	Primates	CR	1081	3.739	292	2.358
Papio papio	Guinea baboon	Primates	NT	3636	12.575	1079	8.713
Atherurus africanus	African brush-tailed porcupine	Rodentia	LC	92	0.318	54	0.436
Cricetomys gambianus	Northern giant pouched rat	Rodentia	LC	1590	5.499	370	2.988
Funisciurus pyrropus	Fire-footed rope squirrel	Rodentia	LC	757	2.618	259	2.091
Heliosciurus gambianus	Gambian sun squirrel	Rodentia	LC	192	0.664	85	0.686
Hystrix cristata	Crested porcupine	Rodentia	LC	268	0.927	88	0.711
Lepus victoriae	African savanna hare	Rodentia	LC	29	0.100	0	0.000
Thryonomys swinderianus	Greater cane rat	Rodentia	LC	39	0.135	4	0.032
Varanus sp	Nile and savanna monitor	Squamata	LC	83	0.287	22	0.178

Notes: Species with an asterisk * are not wild species. RAI is the relative abundance index (see section II. f.). IUCN status is taken from the International Union for Conservation of Nature's Red List of Threatened Species which gathers comprehensive information on the global extinction risk status of animal, fungus and plant species (IUCN, 2024). The species are assigned a category according to the degree at which they risk extinction. LC stands for Least concern, where the species is not at risk of extinction. NT is for Nearly threatened, the populations are decreasing but are not yet at risk of extinction. VU, EN, and CR stand for vulnerable, endangered, and critically endangered, respectively, and are used for species having declined by more than 50 to 80% in the past 30 years or that have lost a considerable portion of their occupancy area.

b. Density and abundance estimates

The results of the density and abundance estimates using the camera trap distance sampling method are shown in Figure 3 and 4, respectively. There are no estimates for phase 2 for the green monkey as the distance data were irregular and did not follow the assumptions of the distance sampling method. For phase 1, we estimated the abundance and density in the three strata as defined previously (gallery forest, clear forest, bushy savanna) and combined the results of the three strata to obtain a single value that represents the whole sampled area for chimpanzees, bushbucks, and red-flanked duikers. For the second phase and for the green monkeys and warthogs in the first phase, we combined clear forest and bushy savanna as one stratum and used only two strata for the analysis as there were not enough events in each stratum to fit a separate detection function in the three strata. For all the species, the point estimate is lower in phase 2 than in phase 1, but the 95% confidence intervals overlap between both phases.

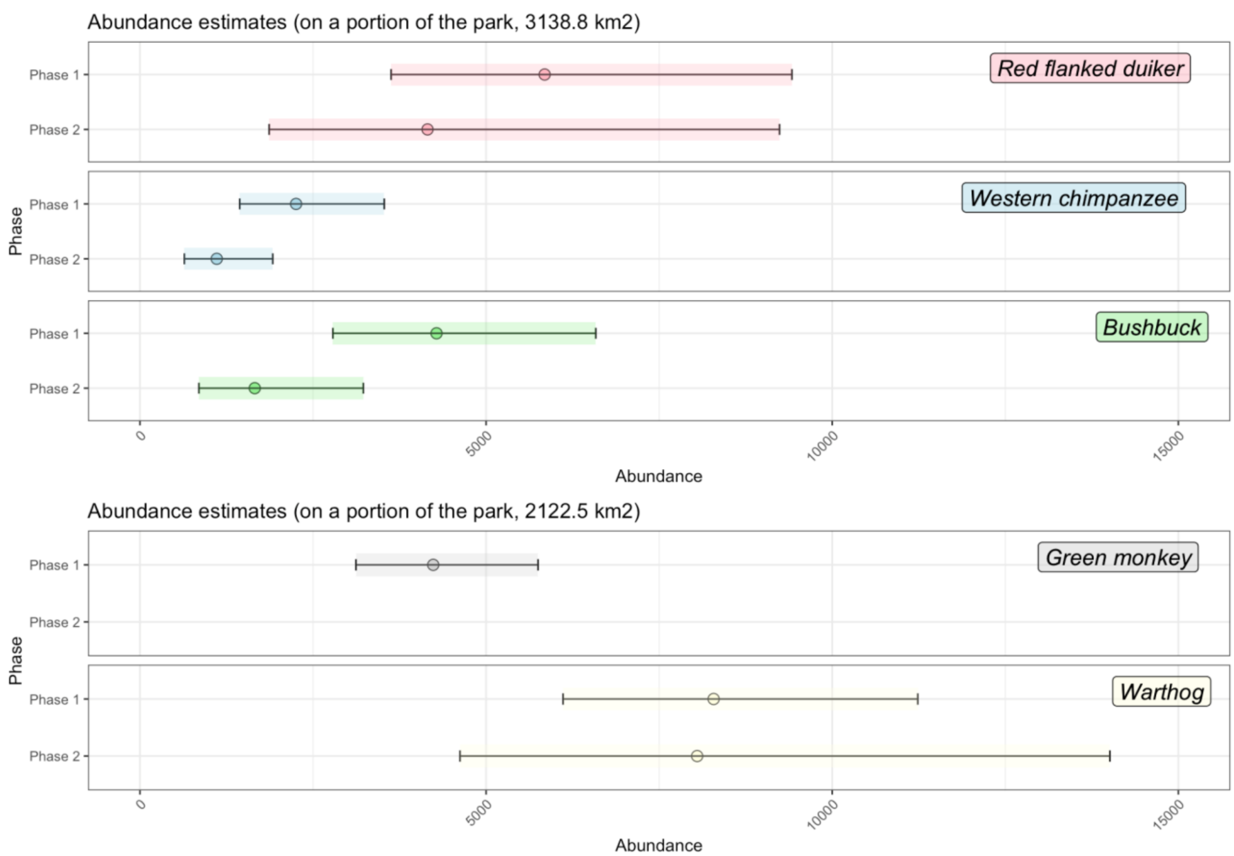


Figure 3: Abundance estimates with 95% confidence intervals of the five species of interest in phase 1 and phase 2. There are no estimates for the phase 2 for the green monkey as the distance data were irregular and did not follow the assumptions of the distance sampling method.

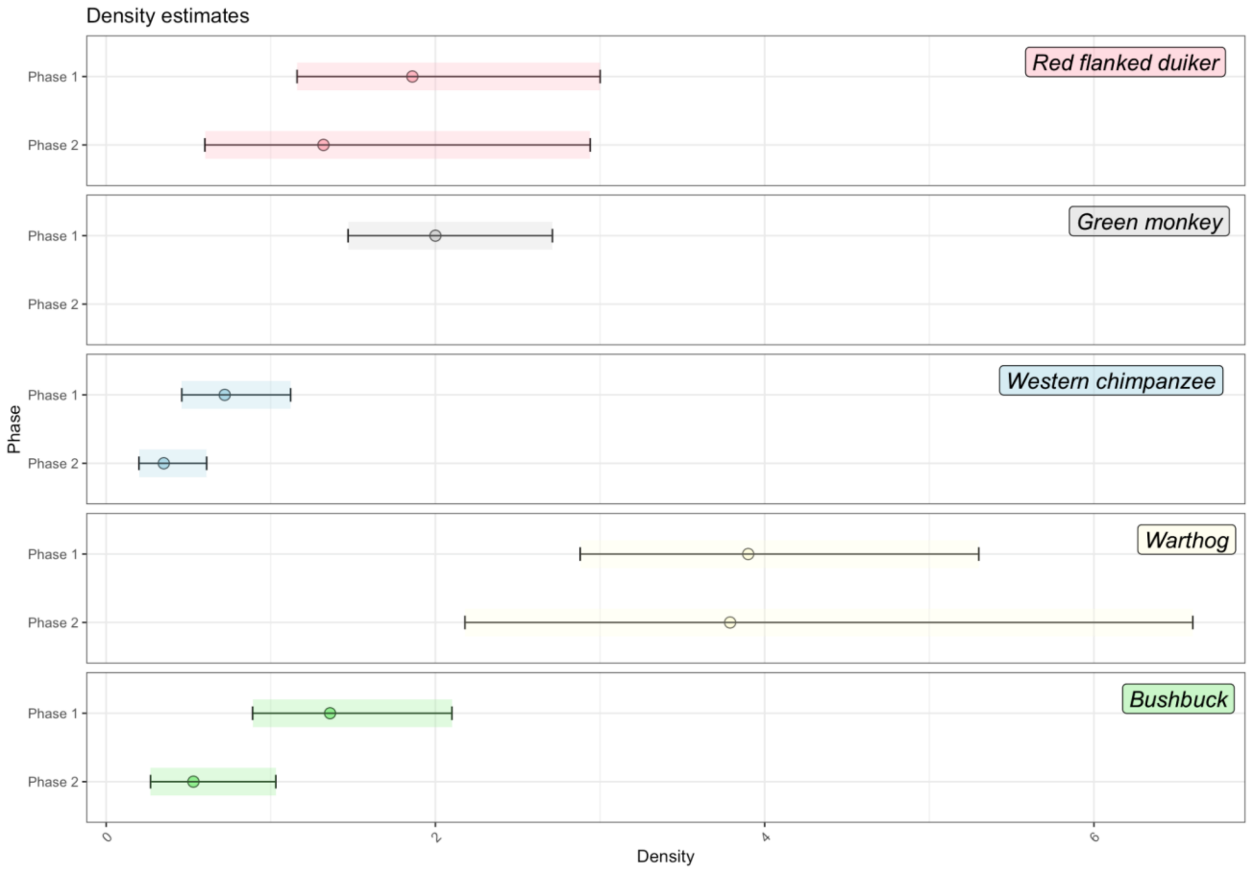


Figure 4: Density estimates with 95% confidence intervals of the five species of interest in phase 1 and phase 2. There are no estimates for the phase 2 for the green monkeys as the distance data were irregular and did not follow the assumptions of the distance sampling method.

c. *Distribution of the five indicator species*

We mapped the RAI per camera for the five species for which we computed density and abundance estimates (Figures 5 to 9). The forest loss is the combined forest loss of the three previous years from the beginning of the phase (2016 to 2018 for phase 1, 2019-2021 for phase 2), extracted from the Hansen tree cover loss database (Hansen et al., 2013). Our analysis of tree cover loss (defined as loss of vegetation taller than 5 meters) based on Hansen's data showed an almost constant rate of forest loss between phases, with about 90 hectares lost in the years 2016 to 2018, and a loss of 82 hectares from 2019 to 2021 in the phase 2 area. The average forest loss per year between 2015 and 2023 was 27.4 ha or 0.3 % of forested area per year.

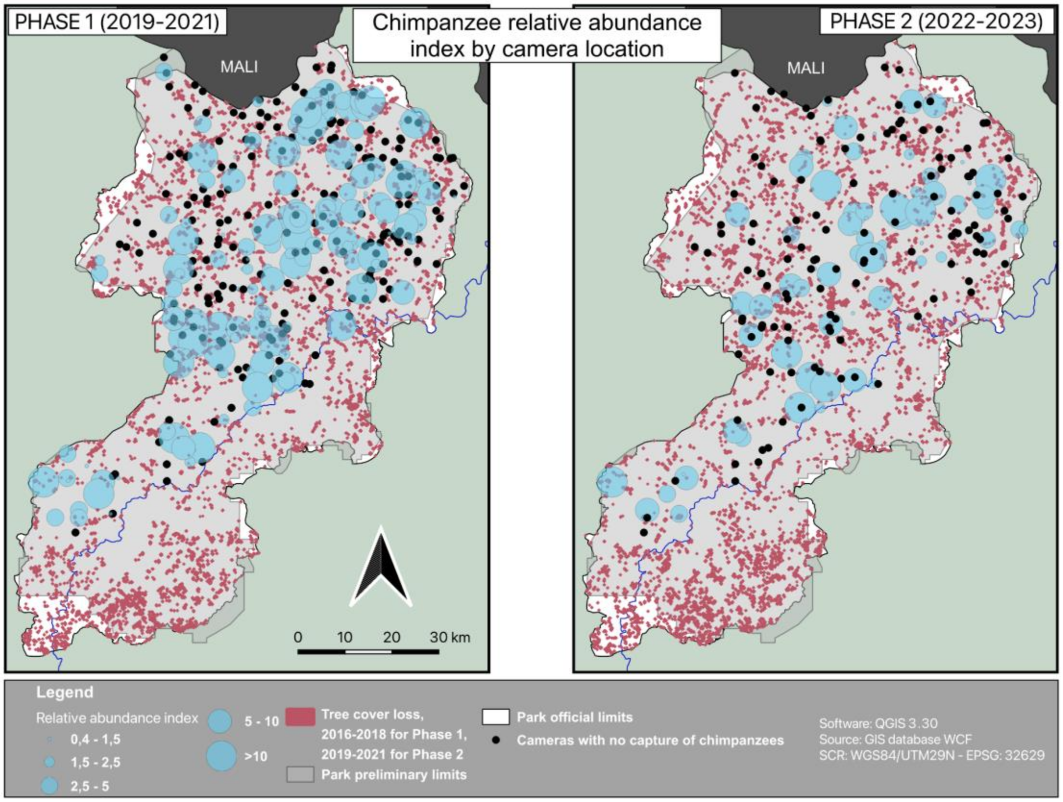
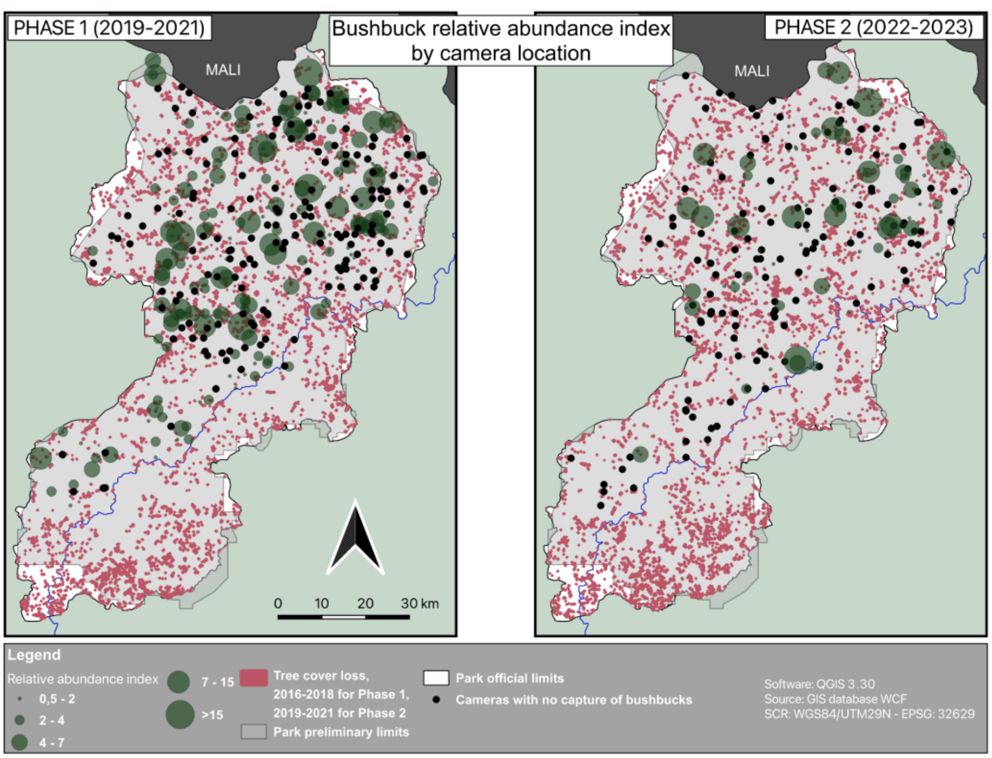
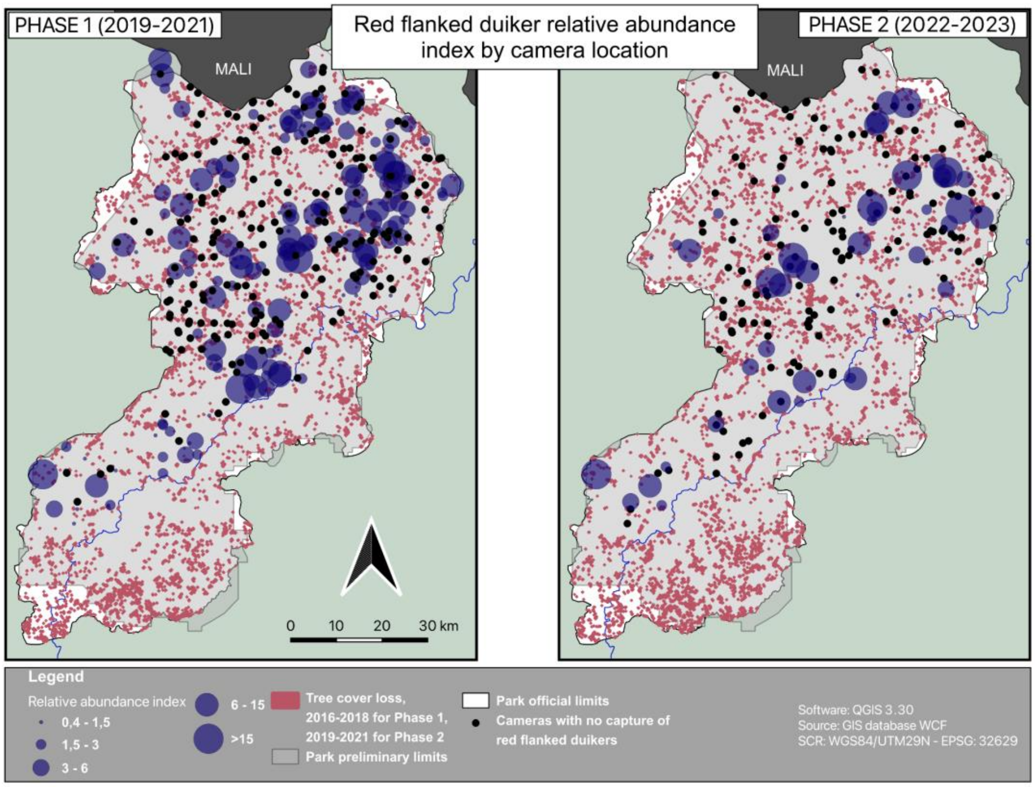
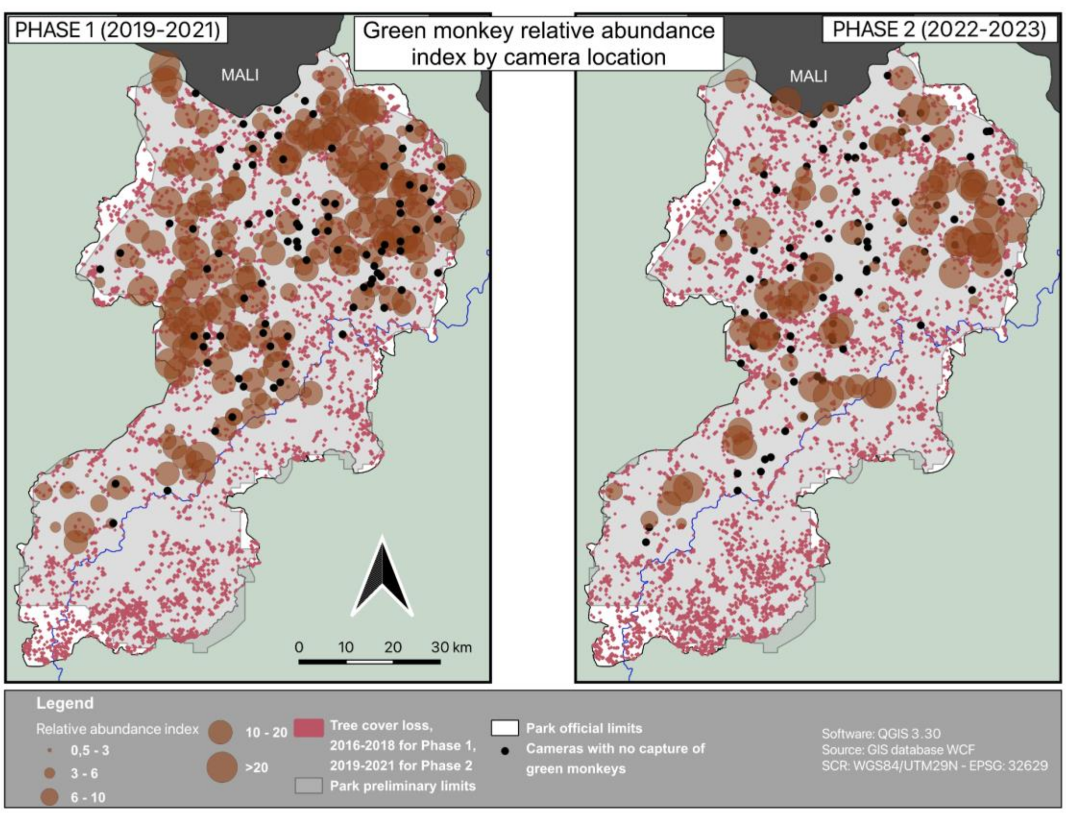


Figure 5 and 6: Relative abundance indices of chimpanzees (Figure 5) and bushbucks (Figure 6) by cameras in phase 1 and phase 2, with the tree cover loss of the three previous years from the start of the survey.





Figures 7 and 8: Relative abundance indices of red-flanked duikers (Figure 7) and green monkeys (Figure 8) in both phases, with the tree cover loss of the three previous years from the start of the survey.



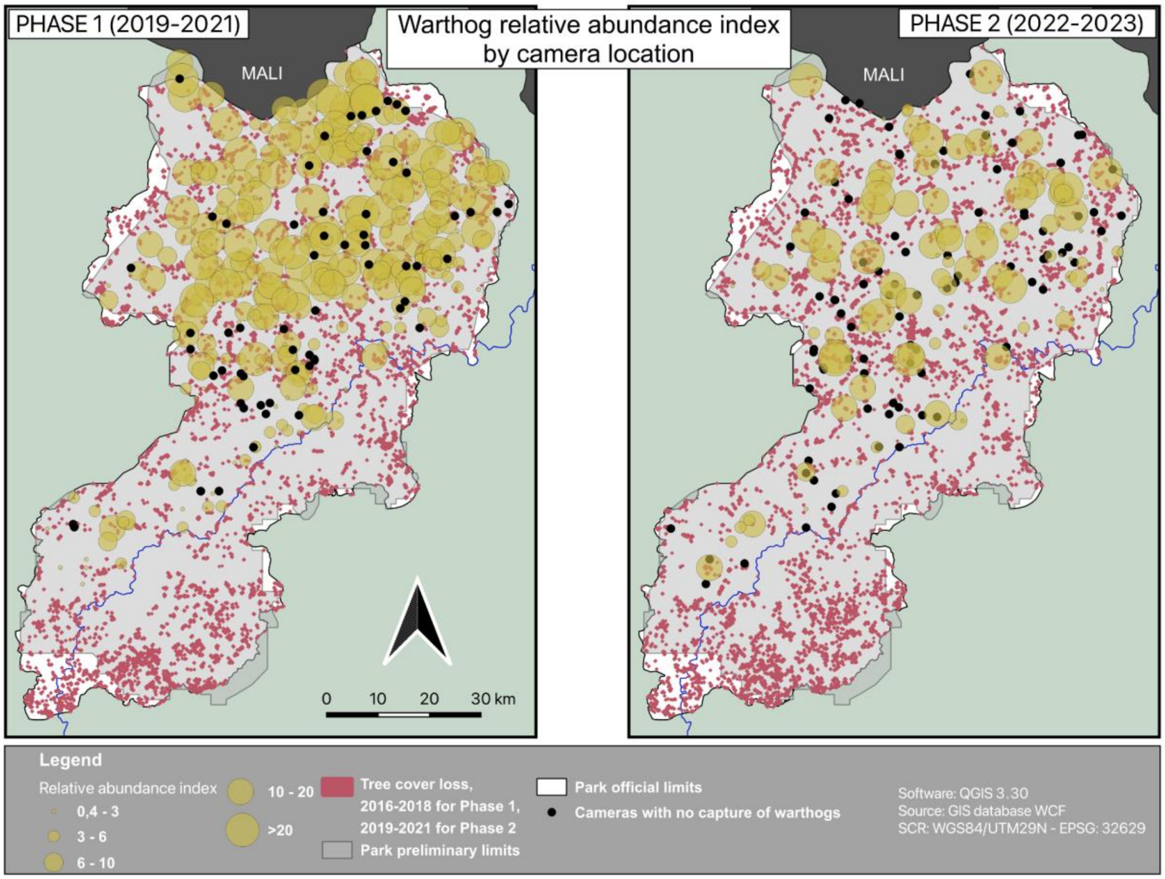


Figure 9: Relative abundance indices of warthogs by camera in phase 1 and phase 2, with the tree cover loss of the three previous years from the start of the survey.

IV. Discussion

We present in this report the results of two phases of biomonitoring with camera traps in the Moyen Bafing National Park between 2019 and 2023, each phase covering the whole park that was accessible at that time. To ensure sufficient data to perform the statistical analyses, the design in the first phase was planned to have a high number of locations (530) with camera traps deployed for a long period (6 to 9 months). In the second phase, the design was reduced to monitor the park in one year, with 253 locations and camera traps deployed for three months. The biomonitoring results show that the MBNP has a high level of biodiversity, with 43 different wild mammal species captured in the area. Among them, three are classified as vulnerable (hippopotamus, African golden cat, and leopard), two endangered (giant pangolins, and king colobus), and the western chimpanzee is critically endangered.

Additionally, six species (defassa waterbuck, African clawless otter, African buffalo, Campbell's monkey, and Patas monkey) are nearly threatened, meaning that their population is decreasing globally. We were able to estimate the density of five species, including the western chimpanzee. This will establish a baseline for comparison with the subsequent monitoring phases, to assess the progress toward achieving the compensation goal.

a. Comparison of the results between the two phases

What is evident while comparing the two phases is that the capture rate of nearly every species decreased between the phases. Additionally, this is reflected in the point estimates of the density and abundance that were also lower in phase 2 for the four species. However, the decrease was still within the confidence intervals of the first phase. We consequently cannot state whether the population decreased or remained stable between the two phases. Nevertheless, the decrease in RAI between the two phases for nearly all species is quite striking and different hypotheses can explain what we observed.

There are different processes at play when trying to estimate animal abundance: the probability of an animal to pass in front of the observer (here the camera) and the ability to detect the animal if it passes in front of the observer. The first probability is linked to the number of individuals present in the sampled area (which allows us to estimate the abundance), to various environmental covariates depending on the species, and to stochastic variation. Consequently, a first obvious hypothesis is that there were, in fact, fewer animals passing in front of the camera. A decrease of population could be caused by diseases, but there were no more carcasses found between phase 1 and 2 and no evidence of a disease that would affect all species. From field experience, there was no increase of poaching either. There was an ongoing almost constant deforestation pressure in the survey area, but this is ongoing now for many years and should not cause a dramatic decrease between the two phases. Besides, species that are not dependent on dense forest, such as the domestic cattle or warthogs also showed a drastic reduction in RAI, which cannot be caused by deforestation. Consequently, the difference in RAI would be more likely due to stochastic variation. Animal movement and use of space is not entirely random but is also impossible to predict. These variations in the probability of detection that cannot be modelled are the reason why it is not possible to give an exact number for an animal population size (unless it is individually counted), and why each point estimate comes with a confidence interval.

It represents the magnitude of uncertainty in the point estimate. By "chance" we could have less animals passing in front of the camera during the second phase, without having in fact less animals in the population available to be captured. In our study, there is no confident evidence of a decrease of population as the confidence intervals between the two phases overlap. Additionally, because we had a smaller effort in the second phase, the results are also more likely to be affected by stochastic variation.

Finally, the difference could be caused by a difference in detectability between the two phases. An animal could be next to the camera, but the camera does not detect it. The distance sampling method is a tool to estimate from the distances of animals to the camera, how often the animals are missed – the further away the more likely they are to be missed. But other parameters than the distance to the camera can influence that ability to detect an animal. A third hypothesis to explain the difference in relative abundance indices (RAI) could be an equipment degradation that would affect the detectability by the cameras. Part of the cameras that were used in phase 2 were old cameras already used in phase 1. No study, to our knowledge, has linked the age of a camera trap to a decrease in detection probability. However, it is not unrealistic to assume that trigger time could increase, and detection range and detection sensitivity could decrease the older the cameras get. Passive infrared (PIR) sensors detect the surface temperature of objects in the detection zone and are triggered when they detect a rapid change in temperature, for example when an animal with a different surface temperature passes in the detection area (Welbourne et al., 2016). The PIR sensors could, with time, misinterpret temperature changes. That would, given an equal effort, decrease the number of distances recorded, either because the camera is not triggered at all, is triggered only when an individual is closer to the camera, or triggers not as fast. By using cameras from a single brand, with the same model, we assumed we could limit the variance due to the quality of the camera itself – even though there is variation in detectability between cameras of a same model (Palencia et al., 2021). However, we did not realize that the intrinsic parameters of the camera might change over time. This could explain why we observed an overall decrease of capture rate: it could be caused by a reduced detection by the cameras, not because less animals pass in front of it. This is a strong hypothesis as nearly all species, including the domestic cows or the warthogs, regardless of their habitat preferences were affected. The few that have a higher RAI in phase 2 are either rare species or nocturnal species that could have by chance be highly present in the vicinity of some cameras during the sampling period in phase 2.

Ultimately, to understand what might have caused the difference in capture rate, at least a third phase of biomonitoring is needed.

b. Necessity of continued biomonitoring, recommendations

A continued biomonitoring is essential, not only to understand the differences observed between the two phases, but most importantly to determine whether there was indeed a downward trend in the surveyed wild mammal population sizes, or whether the lower estimates for phase 2 are simply the result of natural variation or equipment. First, to understand whether there was indeed an aging of the cameras that affected their probability of detecting animals, new cameras should be used for this third phase, ideally from the same brand and model as the two previous phases. Unique camera ID should be tracked thoroughly to be able to compute for each camera how many days it was in the field, how many times it filmed, and how many times it triggered, alongside the time it operated in the rainy and dry season. This could help understand how detection might change with the usage of the camera. Additionally, the number of camera locations should be increased compared to the second phase to collect more data and achieve an effort closer to the first phase. The more data, the more likely they are to follow the distance sampling assumptions. Finally, the objective tied to the creation of the MBNP is the increase of the chimpanzee population. To be able to estimate a population trend, many years (decades) of data collection are required, especially for a species with such a slow life history as chimpanzees. There is also stochasticity in animal population abundance across time, meaning that the overall population trend can be increasing but in the short term the population likely fluctuates and hence can also decrease. It is essential to continue collecting biomonitoring data in the area as firm conclusions can only be drawn with more than two phases.

c. The habitat classification, another source of variation

To increase detection probability and to decrease variation in detection rates between cameras due to the habitat in which they are placed, we opted for a stratified design. It consequently relies on our ability to correctly map the different classes of habitat that are used as strata. It was however common to find discrepancies between the habitat map used (based on a custom classification of satellite images) and the habitat found on the field. Despite the differences in the field, we still used the surface of the habitat computed based on the 2018 habitat map. The error in habitat classification was not considered in the results presented in this report.

For example, if the actual surface of gallery forest – which is the stratum with the highest density of chimpanzee, in the MBNP is smaller than the area predicted using the satellite images, we would overestimate the abundance of chimpanzees.

V. Conclusions

The camera trap distance sampling method is a recently developed promising tool to estimate the abundance and density of terrestrial or semi-arboreal mammals. This report presents for the first time such results collected at a large scale in a savanna mosaic environment. The results of the biomonitoring effort in the MBNP offer a baseline to follow the progress of the conservation efforts in the specific context of the offset project. The comparison of the results between the two phases raises some questions regarding the possible degradation of the equipment and its effects on the animal detectability, and the minimum effort required to obtain robust results in a dryer environment. These avenues are essential topics to improve the understanding of the variations that can affect estimates using the camera trap distance sampling method. At least a third phase of biomonitoring, considering these challenges, would be essential to understand the evolution of the population status in the MBNP, which this report confirmed as an area of high importance for biodiversity and specifically for the critically endangered western chimpanzee. Ideally, this third phase should be built upon the two extensive first phases of biomonitoring conducted in the area and presented in this report, following the established methodology and protocol as closely as possible and implementing changes only to improve performance. This would guarantee the comparability of results over time and build valid and objective data for management and decision processes. Only long-term continuous biomonitoring in the MBNP will permit assessment that the net gain has been achieved.

VI. Acknowledgements

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APPENDIX

ANNEX 1: Models for the detection functions

Three main models (key functions) are used to fit the distance data (Miller, 2016). The function g is the detection function, y is the distance, and w is the truncation distance, meaning the maximum distance considered to which an observer can detect the animal.

A) Uniform model

$$g(y) = 1 \qquad 0 < y < w$$

B) Half normal model

$$g(y) = exp[\frac{-y^2}{2\sigma^2}] \qquad 0 < y < w$$

σ is a scale parameter, that affects how quickly the probability of detection falls with distance from the camera.

C) Hazard rate model

$$g(y) = 1 - exp\left[\left(\frac{-y}{\sigma}\right)^b\right] \qquad 0 < y < w$$

σ is also here a scale parameter, but there is also b a shape parameter, b, that makes the function more flexible

Adjustment terms are added as follow to the key functions:

Key function × (1 + Series)

Series = α1×term1 + α2×term2 + ….. etc.

The αi parameters must be estimated. The adjustment terms we tested in our study to find the best fit to the different distance data were:

- zero, one or two cosine adjustment terms to the half normal key function
- one, two or three cosine adjustment terms to the uniform key function
- zero adjustment term, one or two simple polynomial adjustment terms and one or two cosine adjustment terms to the hazard rate key function

ANNEX 2: Results of the phase 1 using the data from the entire park (column 3 in the Table I)

Table I.A2: Description of the analysis parameters

Species	Strata	Availability	Snapshot moments	Binned intervals	Selected detection function
Chimpanzees	Gallery forest (FG)	0.43	2 seconds	1,2,3,4,5,6,7,8,10,12,15, 20,25	Half normal with 1 cosine adjustment term
	Clear forest (FC)	0.4	2 seconds	1,2,3,5,6,7,9,12,15,20	Hazard rate
	Bushy savanna (SA)	0.33	2 seconds	1,3,5,6,8,10,15,20	Hazard rate
Bushbucks	Gallery forest (FG)	0.39	2 seconds	1,3,4,5,6,7,8,9,10,12,15, 20	Half normal with 2 cosine adjustment terms
	Clear forest (FC)	0.5	2 seconds	1,2,3,4,6,7,8,9,10,12,15, 20	Hazard rate
	Bushy savanna (SA)	0.57	2 seconds	2,3,6,8,9,10,12,15,20	Uniform with 2 cosine adjustment terms
Red-flanked duikers	Gallery forest (FG)	0.32	2 seconds	1,2,3,4,5,6,7,8,9,10,12,1 5,20	Half normal with 1 cosine adjustment terms
	Clear forest (FC)	0.29	2 seconds	1,2,3,4,5,7,8,9,10,12,15, 20	Hazard rate with 1 simple polynomial adjustment
	Bushy savanna (SA)	0.26	2 seconds	1,2,3,4,5,7,8,9,10,12,20	Hazard rate

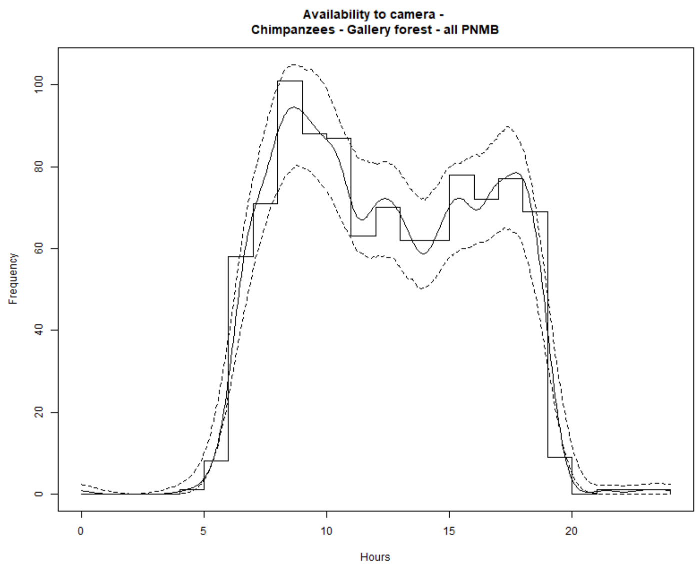
Green monkeys	Gallery forest (FG)	0.39	2 seconds	1,3,4,5,6,7,8,9,10,15,20	Uniform with 1 cosine adjustment term
	Clear forest (FC)	0.35	2 seconds	1,2,3,4,5,6,7,8,9,10,12,20	Hazard rate with no adjustment term
	Bushy savanna (SA)	0.34	2 seconds	1,2,3,4,5,6,9,10,12,15,20	Hazard rate with no adjustment term
Warthogs	Gallery forest (FG)	0.32	2 seconds	1,2,3,4,5,6,7,8,9,10,12,15,20	Uniform with 3 cosine adjustment terms
	Clear forest (FC)	0.38	2 seconds	1,3,4,5,6,7,8,9,10,15,20	Half normal with 2 cosine adjustment terms
	Bushy savanna (SA)	0.4	2 seconds	1,2,3,4,5,6,7,8,9,10,12,15,20	Half normal with 1 cosine adjustment terms

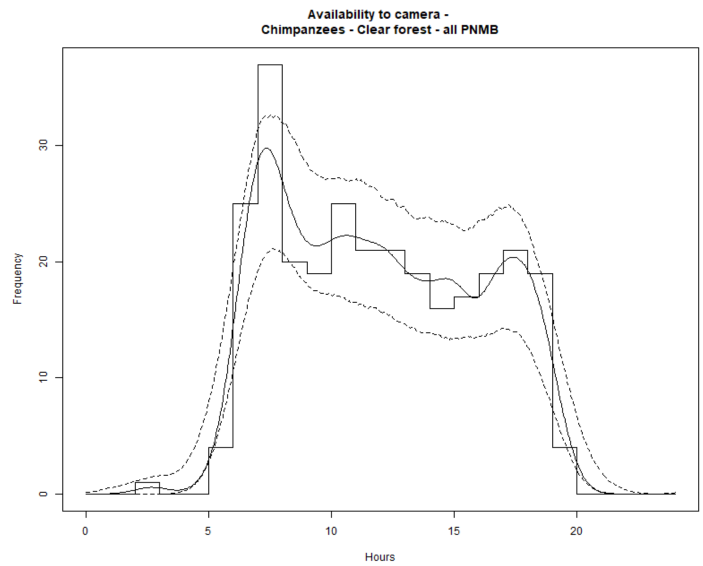
Table II.A2: Results of the camera trap distance analysis

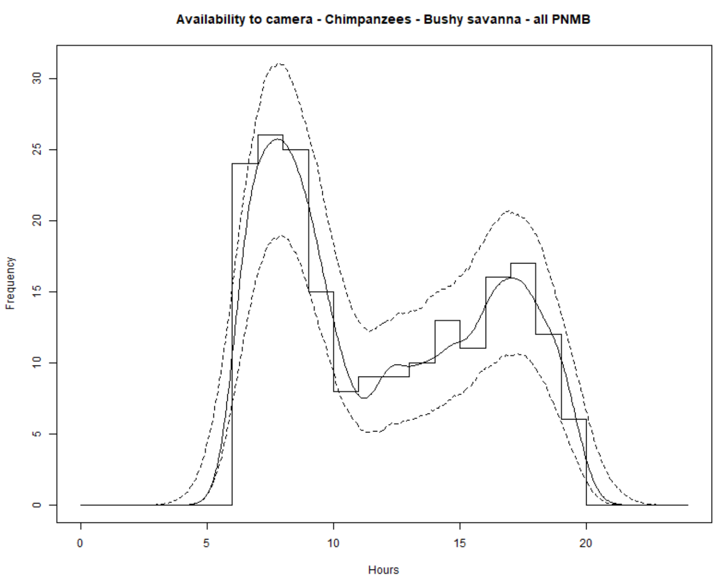
Species	Strata	Total number distances before (after) truncation	Abundance	Density	Coefficient of variation (%)
Chimpanzees	Gallery forest (FG)	27480	1003 (662-1565)	1.5501 (1.0239-2.4190)	22.04
	Clear forest (FC)	7759 (7291)	1441 (747-3191)	0.5885 (0.30505-1.3033)	38.13
	Bushy savanna (SA)	4076 (3481)	256 (113-649)	0.2006 (0.08831-0.5076)	46.72
	TOTAL	39315 (38252)	2700 (1751-4164)	0.62 (0.4-0.95)	22.38
Bushbucks	Gallery forest (FG)	9928 (9863)	1121 (664-2183)	1.7322 (1.0270-3.3747)	30.84
	Clear forest (FC)	6225 (6121)	3213 (2177-5798)	1.3121 (0.889-2.368)	25.21
	Bushy savanna (SA)	6074 (5908)	591 (405-979)	0.4928 (0.3170-0.7661)	22.71
	TOTAL	22227 (21892)	4925 (3465-7001)	1.13 (0.79-1.6)	18.09
Red-flanked duikers	Gallery forest (FG)	5864 (5786)	1151 (750-1879)	1.7793 (1.1594-2.9045)	23.64
	Clear forest (FC)	4005 (3973)	3503 (1458-9265)	1.4305 (0.5953-3.7836)	49.61
	Bushy savanna (SA)	3746 (3605)	1495 (791-3107)	1.1696 (0.6187-2.4311)	35.82
	TOTAL	13615 (13364)	6149 (3465 - 10912)	1.41 (0.79-2.5)	29.9

Green monkeys	Gallery forest (FG)	19440 (18113)	1287 (722-2480)	2.3 (1.2919-4.4378)	31.75
	Clear forest (FC)	7217 (6941)	1709 (1136-2938)	0.8926 (0.59328-1.5344)	24.2
	Bushy savanna (SA)	10123 (9692)	815 (559-1359)	0.9223 (0.63289-1.538)	22.77
	TOTAL	36780 (34746)	3811 (2790-5206)	1.14 (0.83-1.55)	16.01
Warthogs	Gallery forest (FG)	10186 (9844)	1587 (882-2803)	2.84 (1.5789-5.0159)	29.66
	Clear forest (FC)	11938 (11561)	5024 (2931-9536)	2.6237 (1.5306-4.9805)	30.76
	Bushy savanna (SA)	14769 (14205)	2350 (1564-3740)	2.6601 (1.77-4.23)	22.33
	TOTAL	36893 (35610)	8961 (6201-12950)	2.67 (1.85-3.86)	19

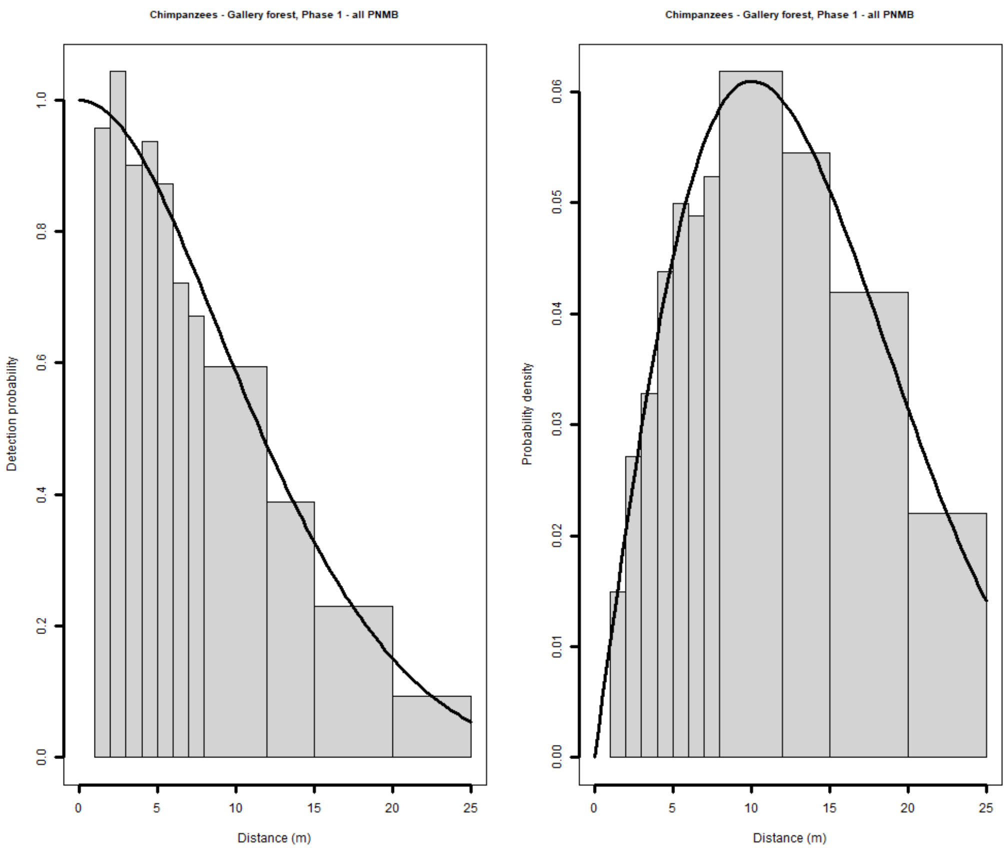
Activity patterns of the chimpanzees using the data from the whole park, Phase 1



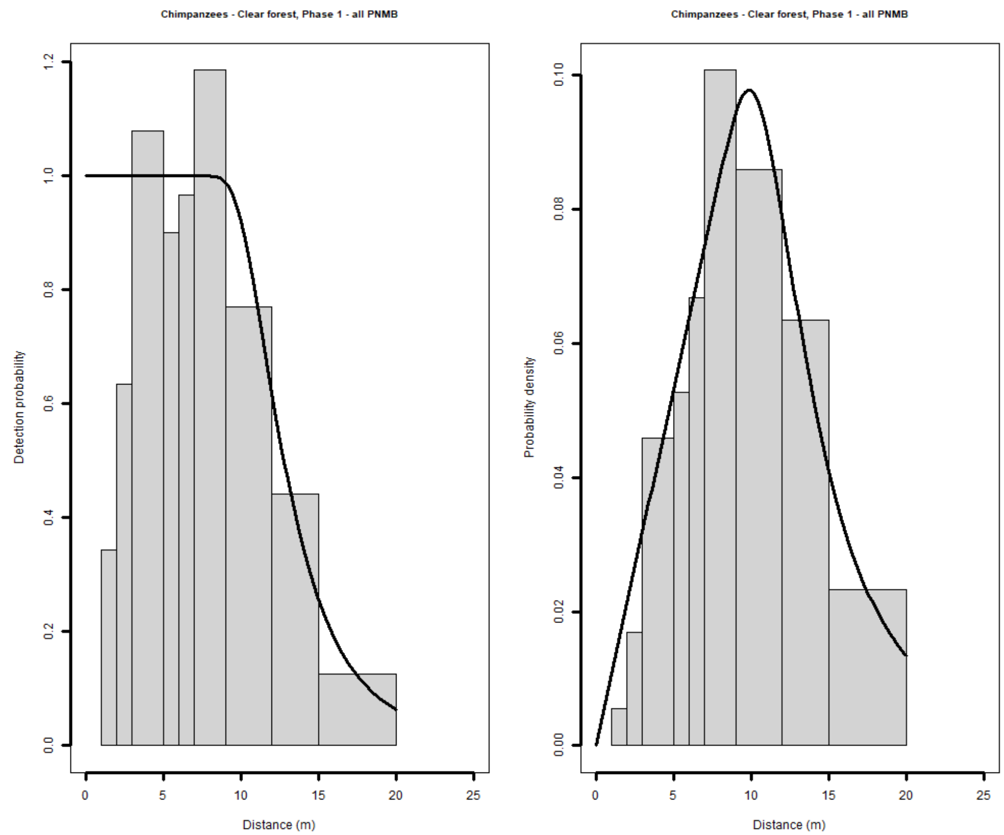




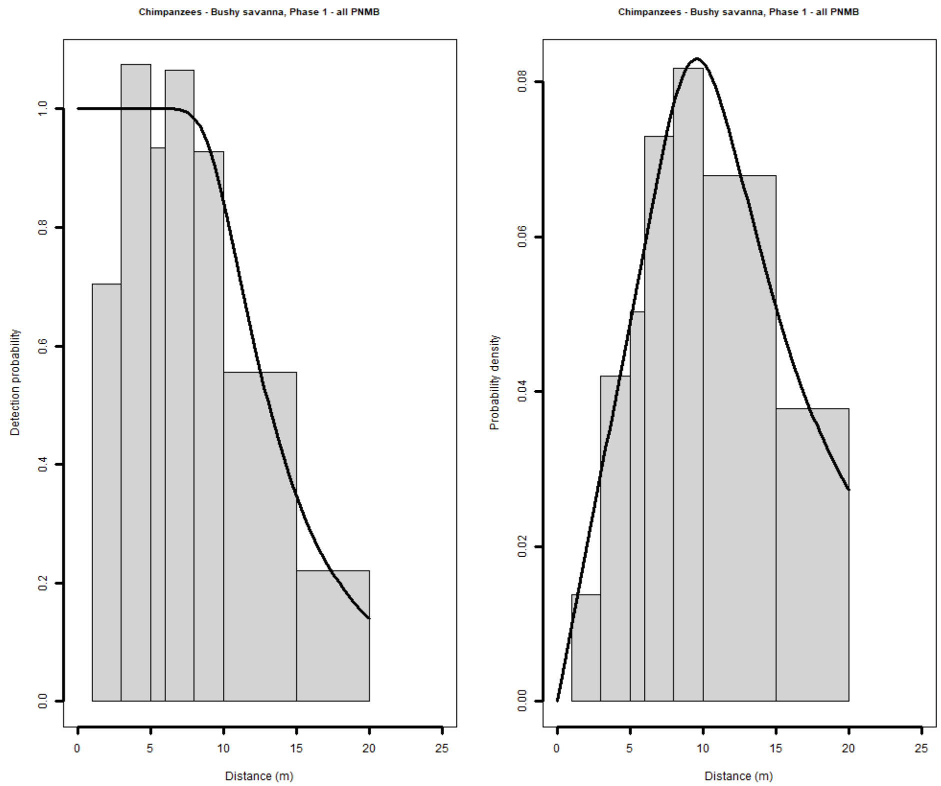
CHIMPANZEES



Fitted detection function, gallery forest, chimpanzees

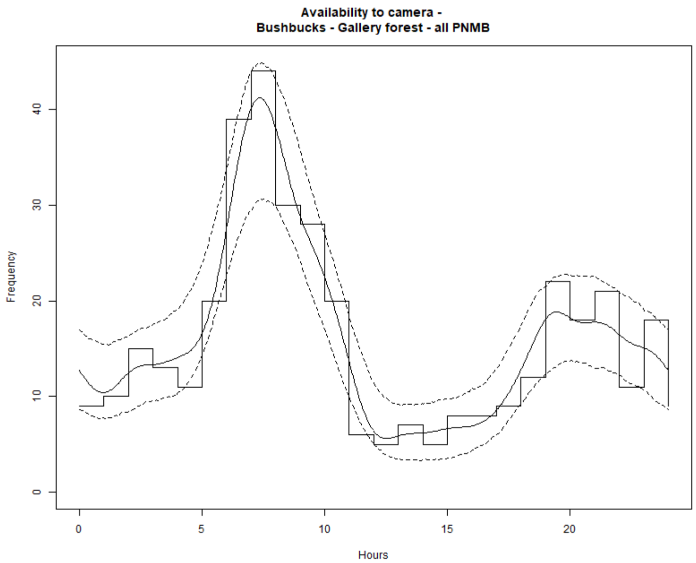


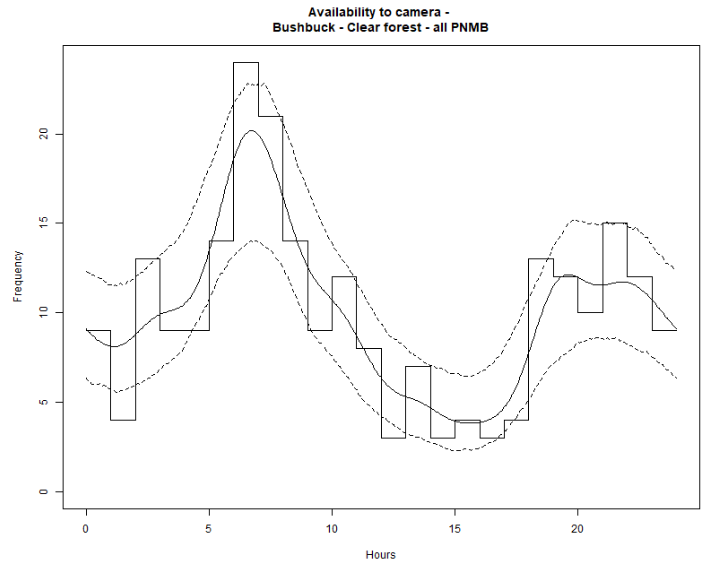
Fitted detection function, clear forest, chimpanzees

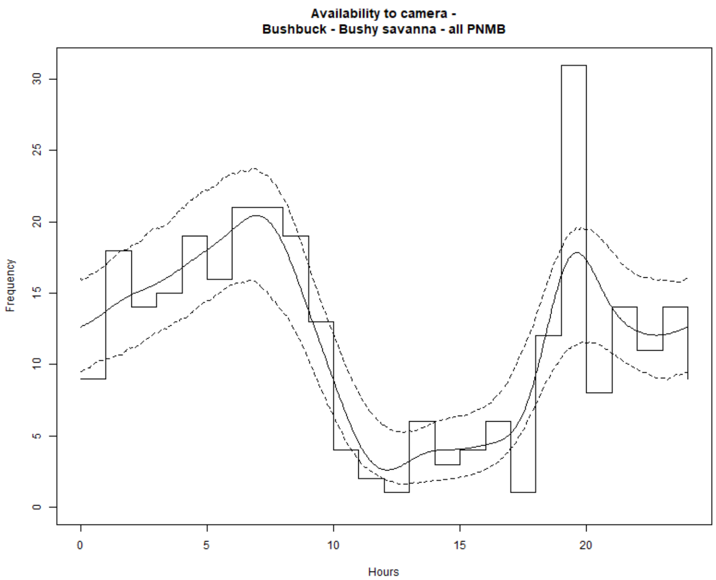


Fitted detection function, bushy savanna, chimpanzee

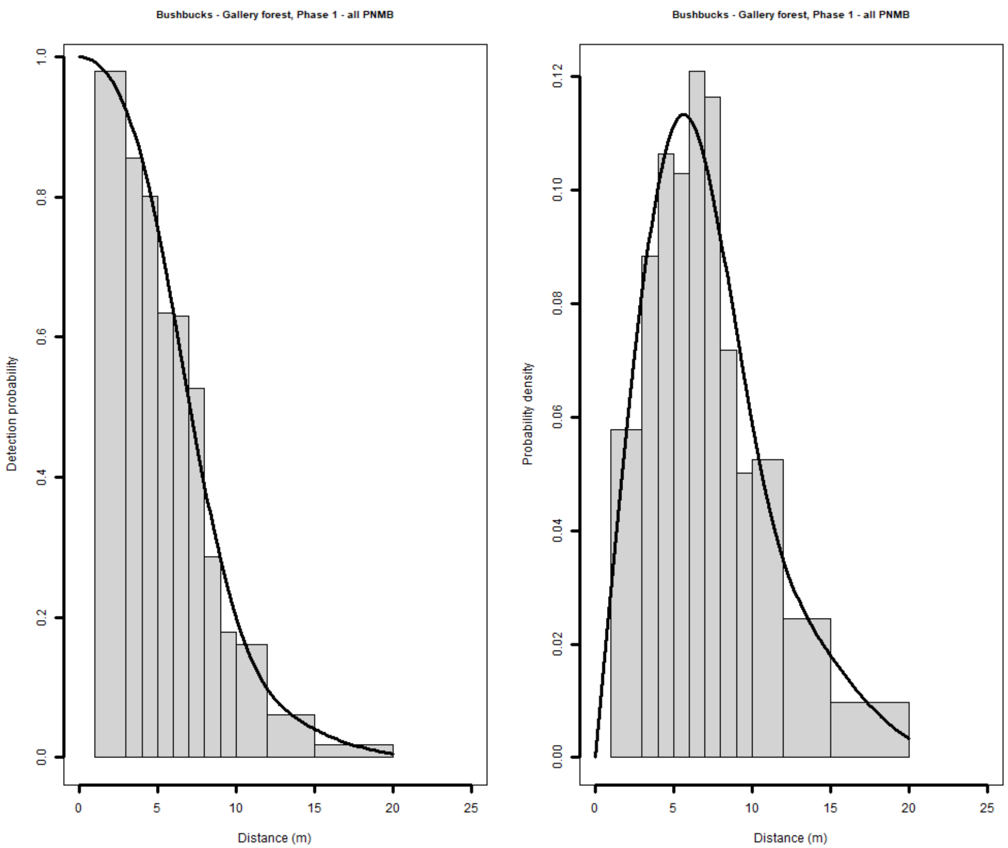
Activity patterns of the bushbucks using the data from the whole park, Phase 1



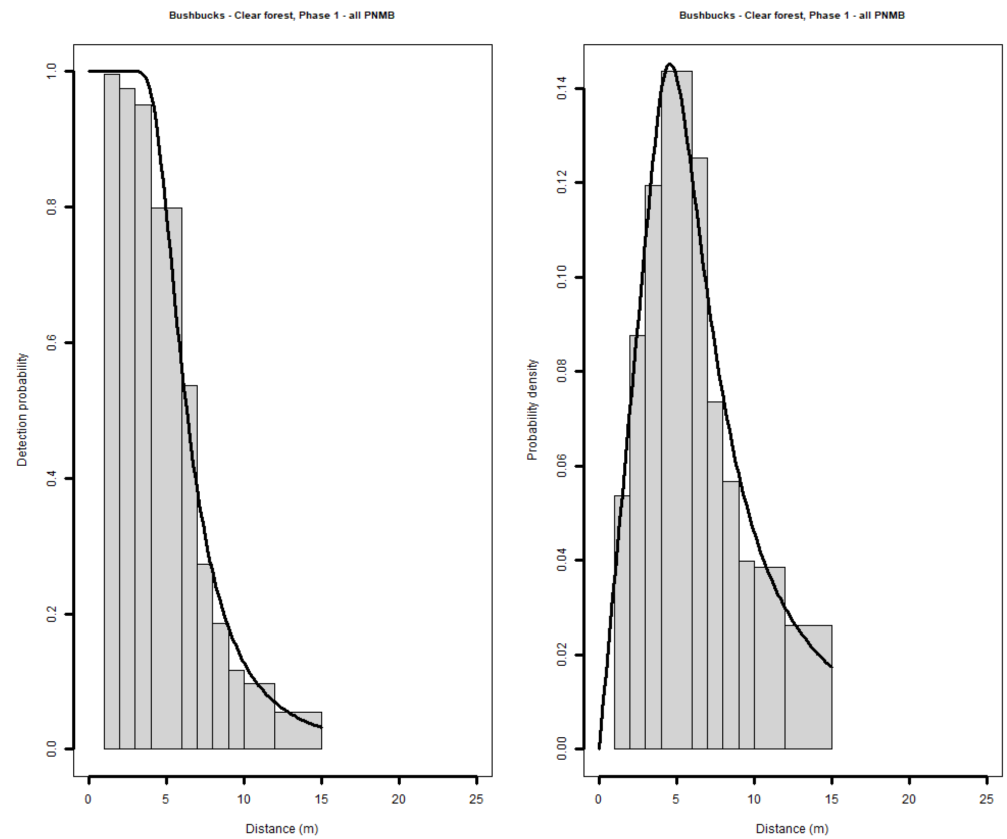




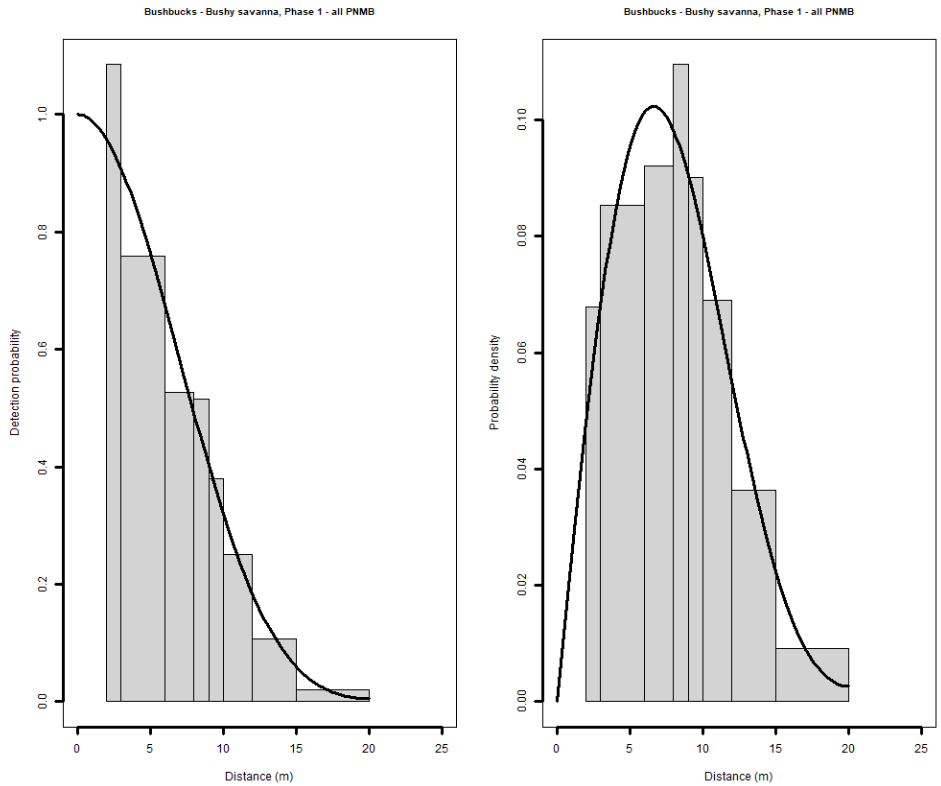
BUSHBUCKS



Fitted detection function, gallery forest, bushbucks

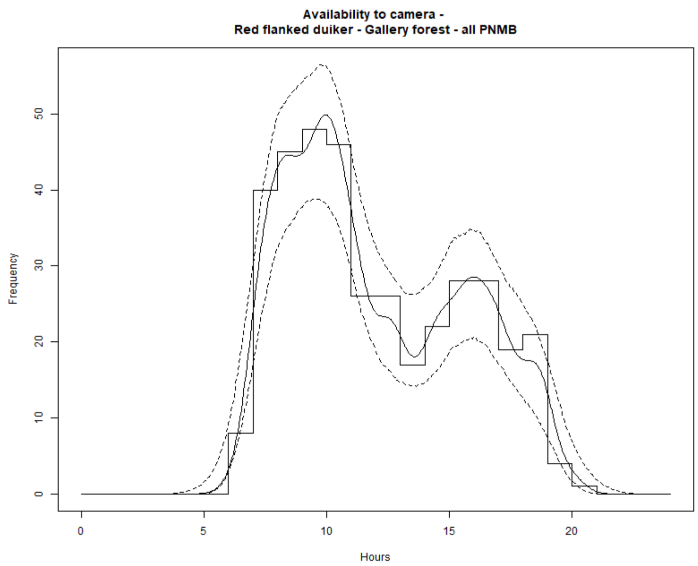


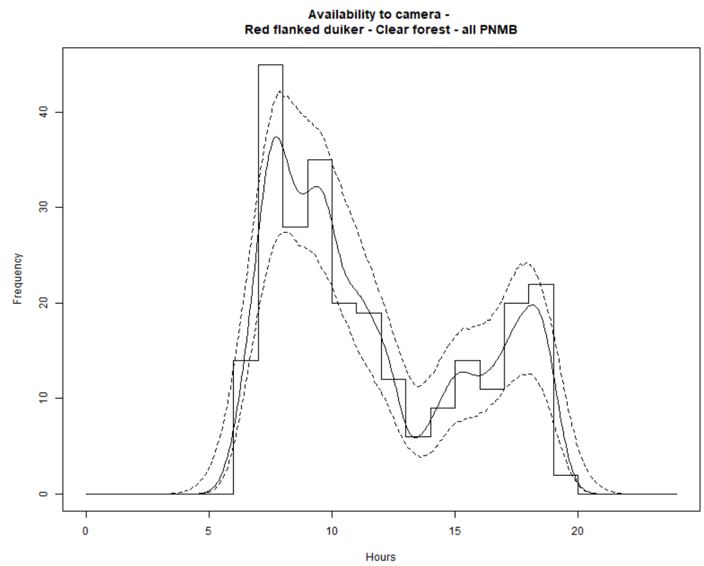
Fitted detection function, clear forest, bushbucks

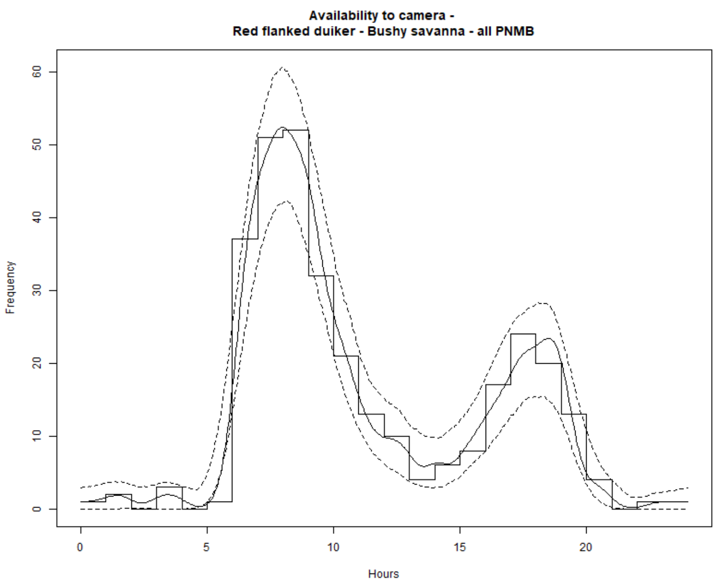


Fitted detection function, bushy savanna, bushbucks

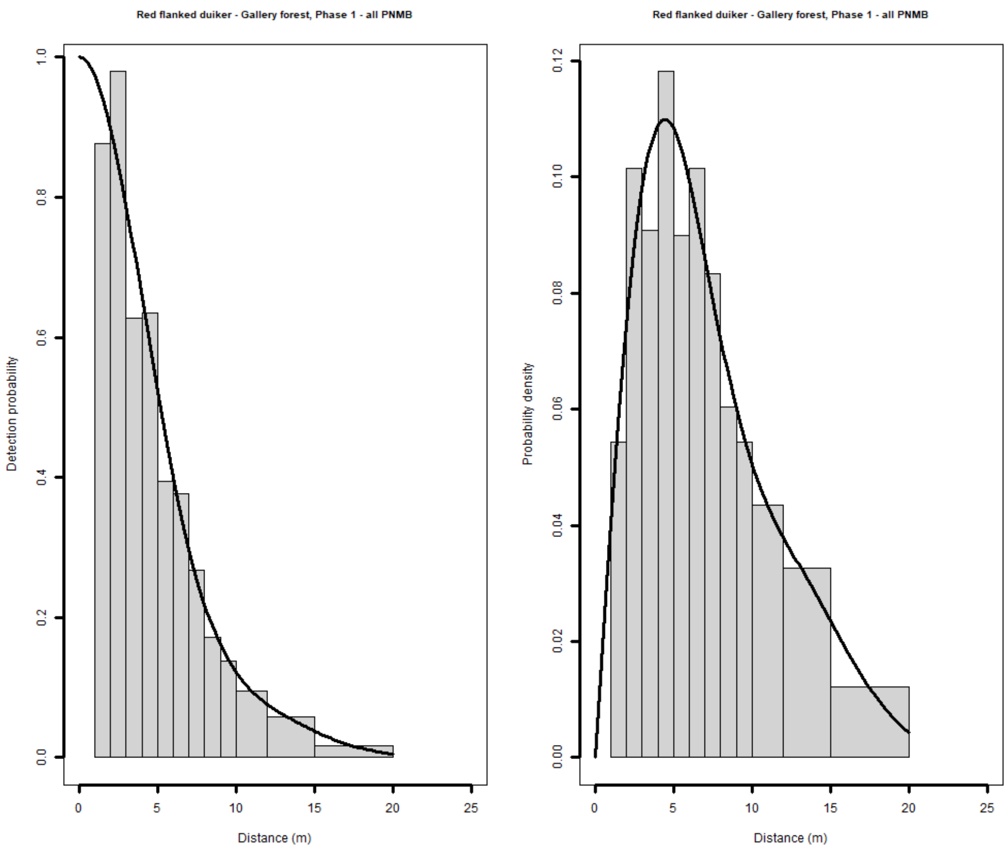
Activity patterns of the red-flanked duikers using the data from the whole park, Phase 1



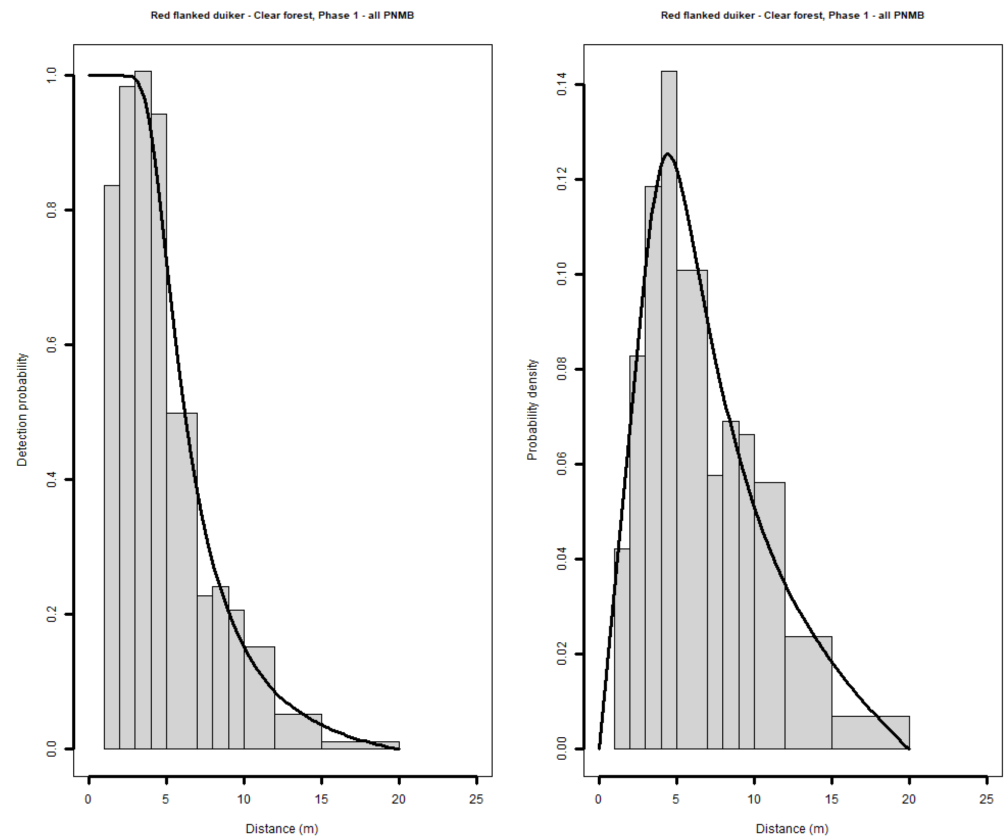




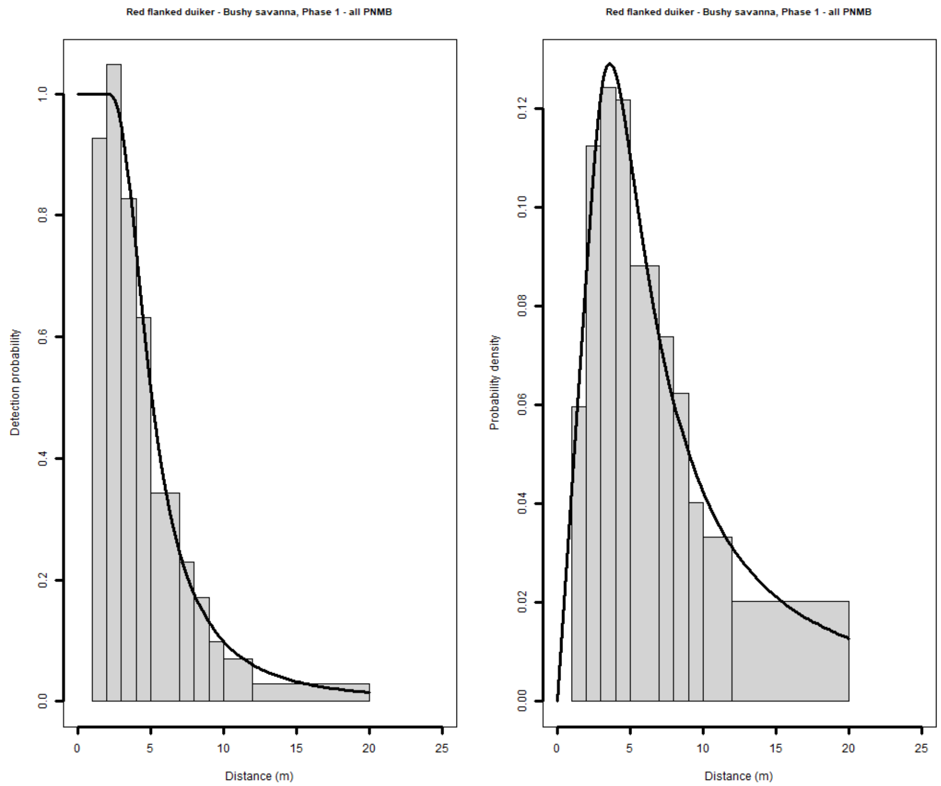
RED-FLANKED DUIKERS



Fitted detection function, gallery forest, red-flanked duikers

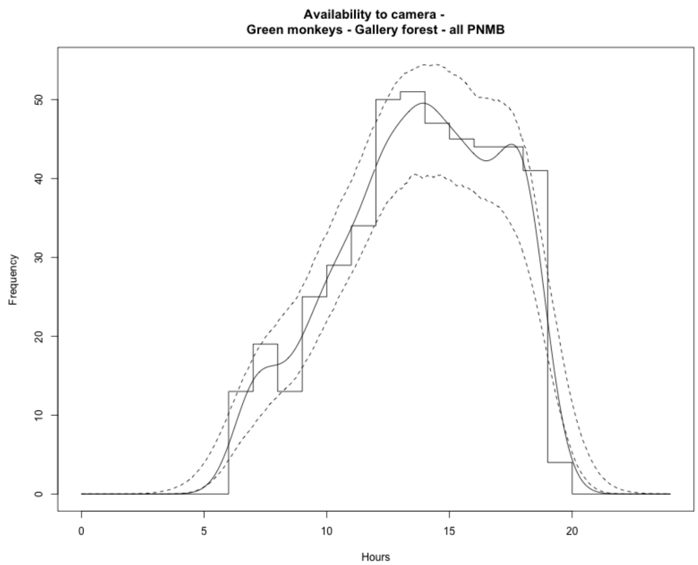


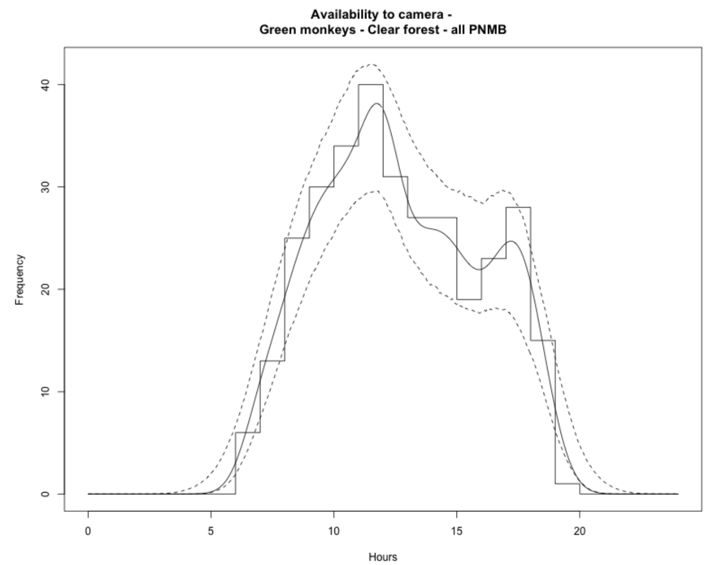
Fitted detection function, clear forest, red-flanked duikers

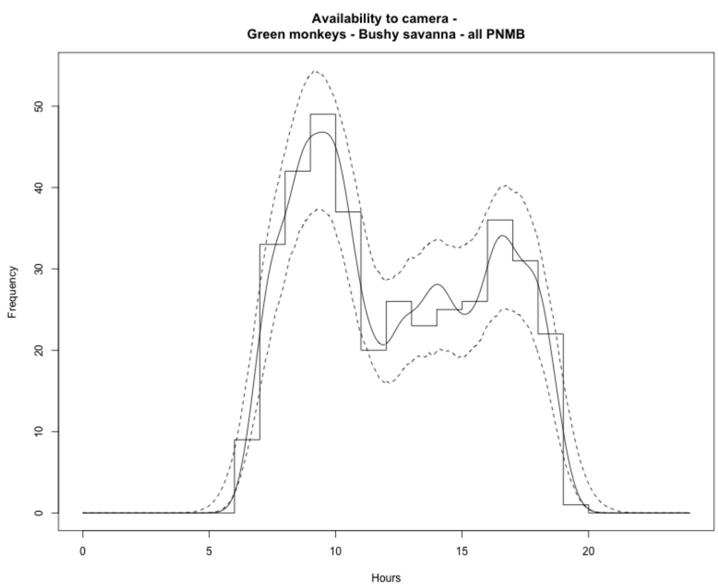


Fitted detection function, bushy savanna, red-flanked duikers

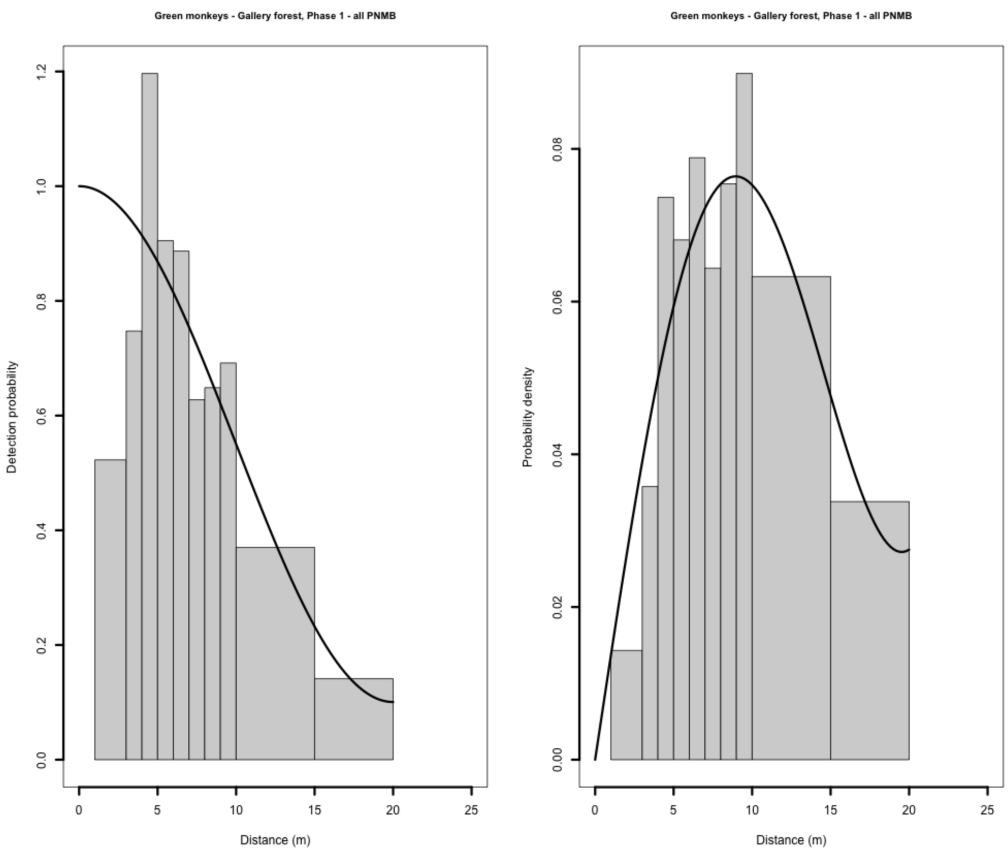
Activity patterns of the green monkeys using the data from the whole park, Phase 1



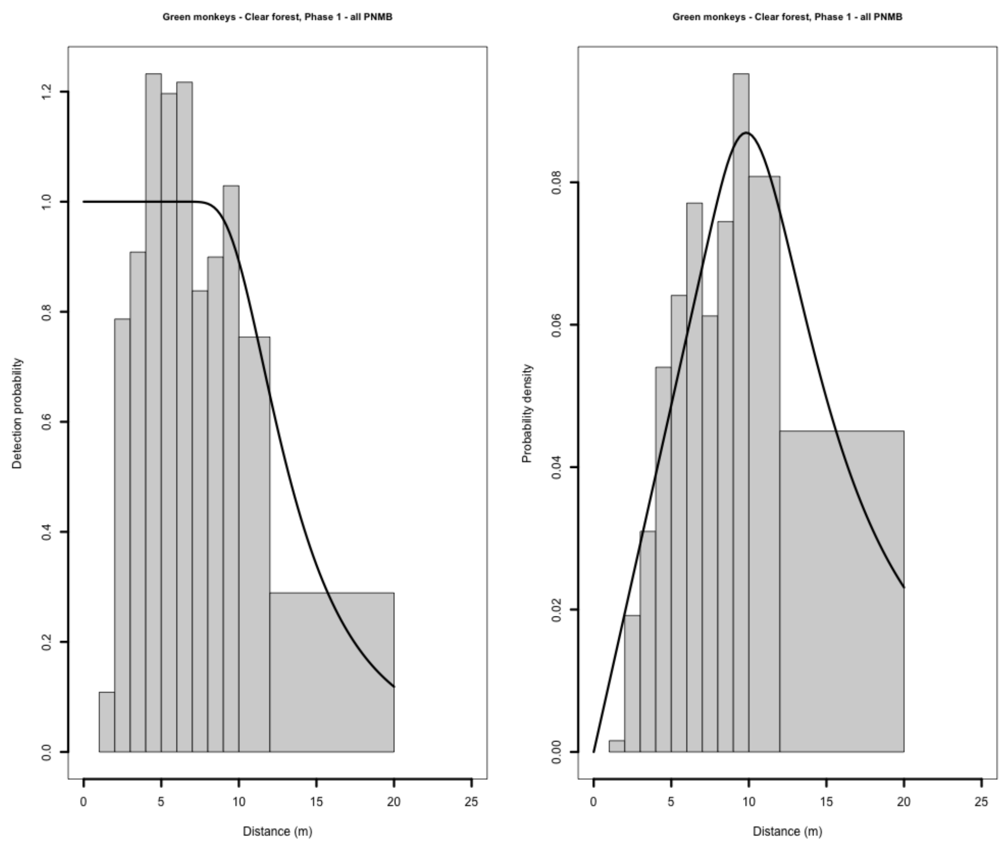




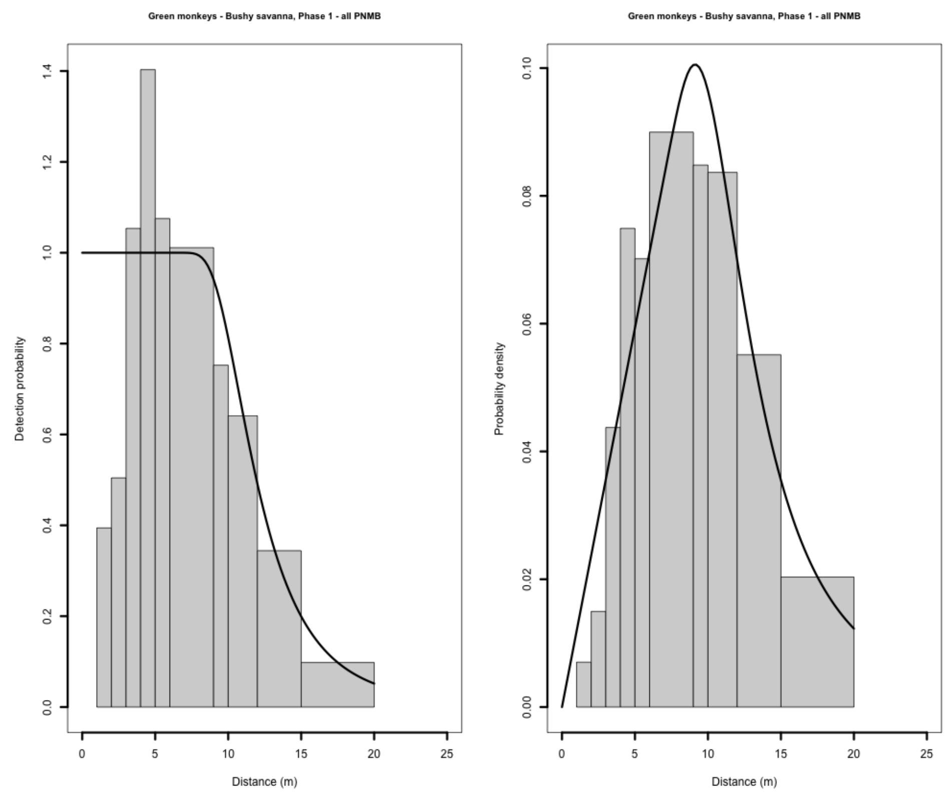
GREEN MONKEYS



Fitted detection function, gallery forest, green monkeys

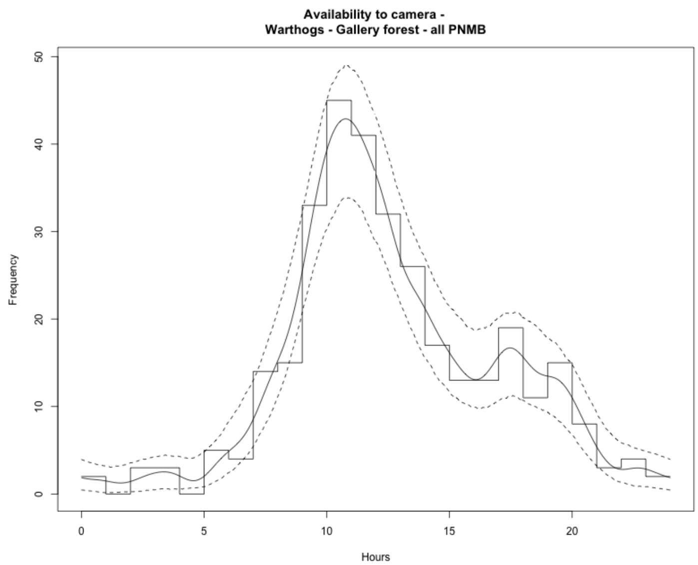


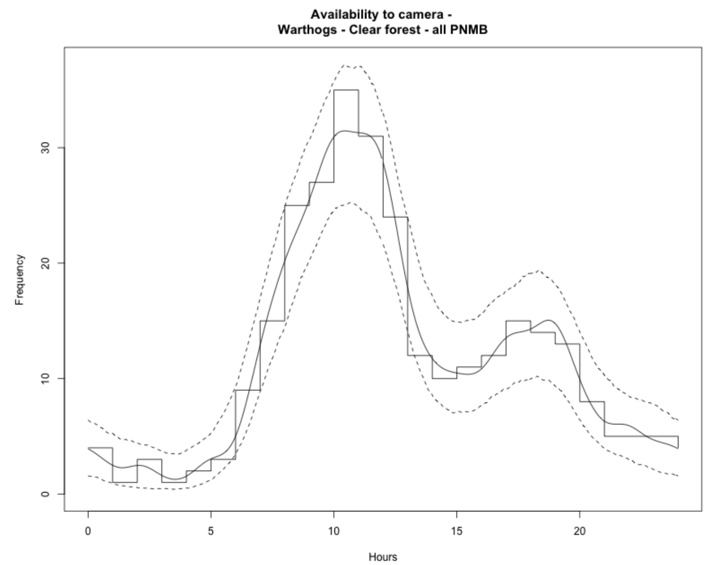
Fitted detection function, clear forest, green monkeys

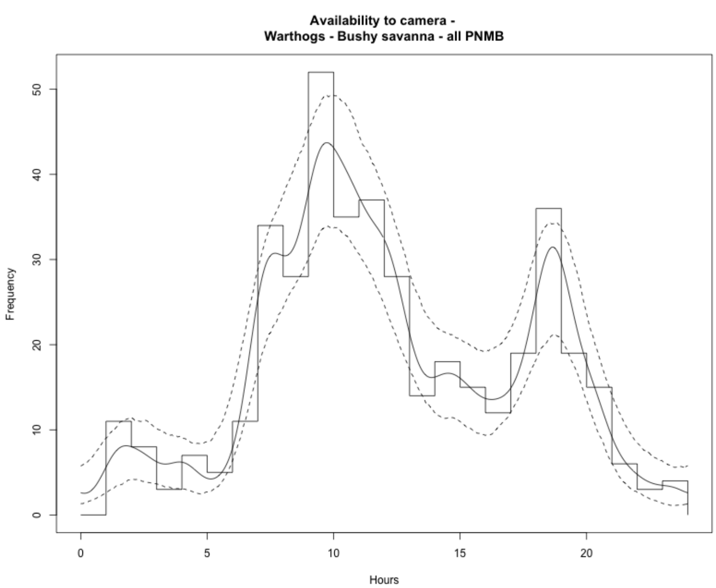


Fitted detection function, bushy savanna, green monkeys

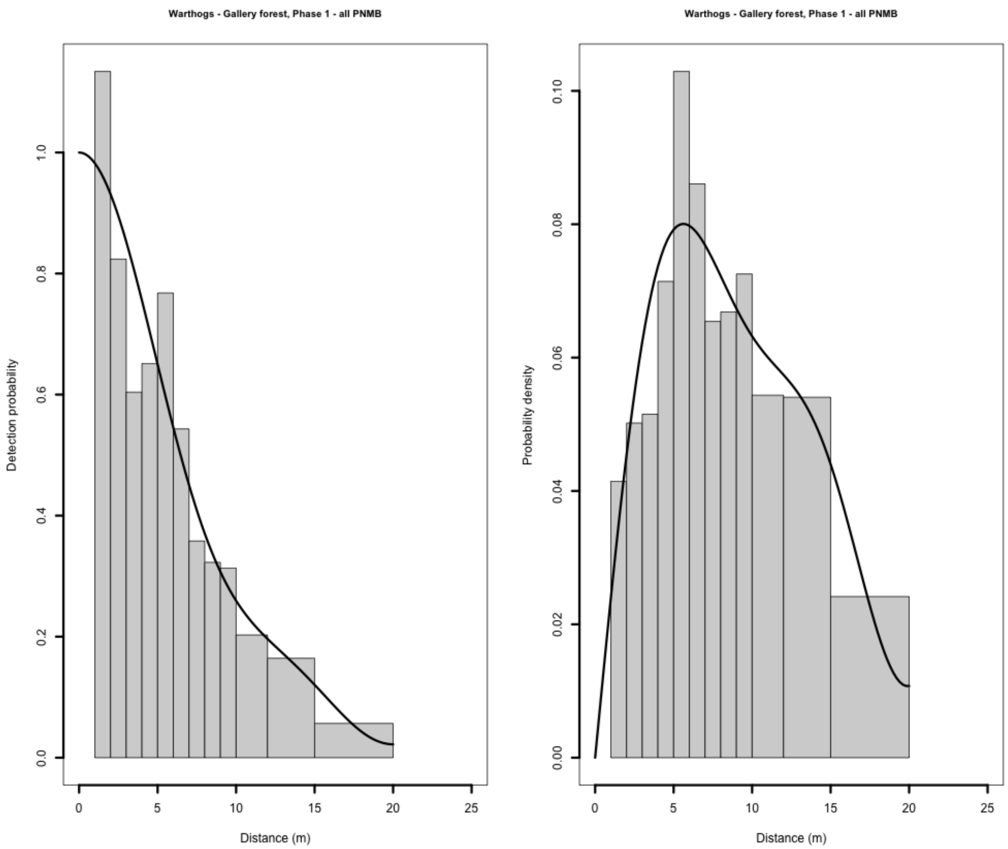
Activity patterns of the warthogs using the data from the whole park, Phase 1



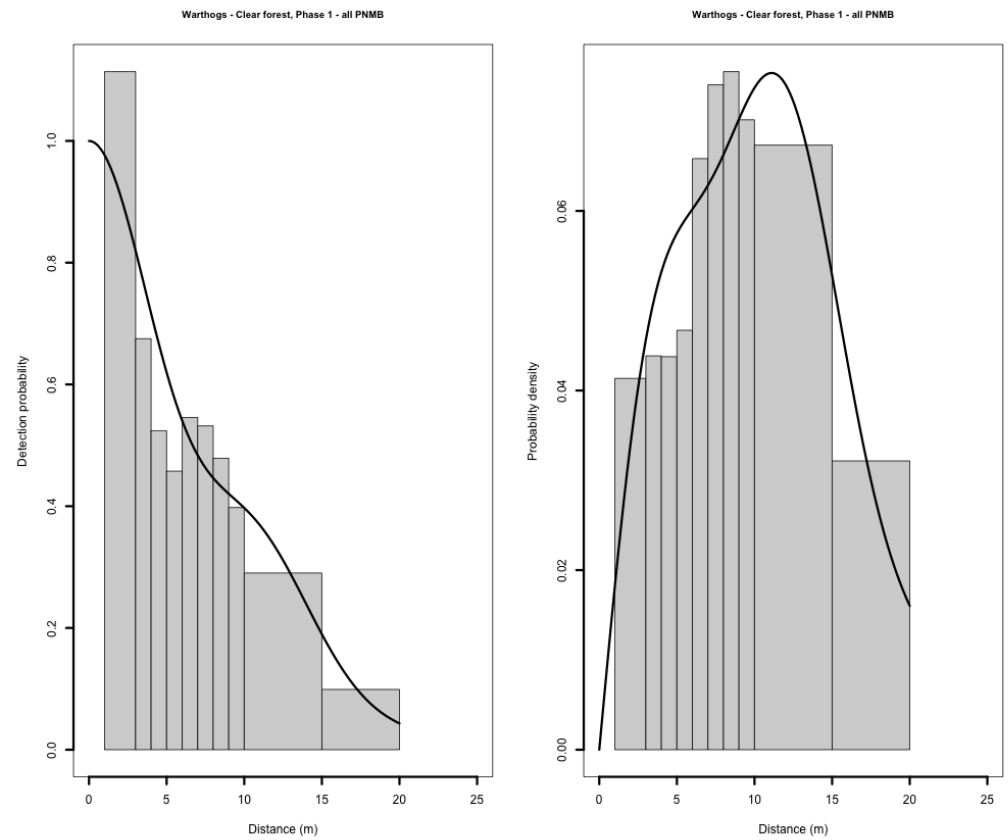




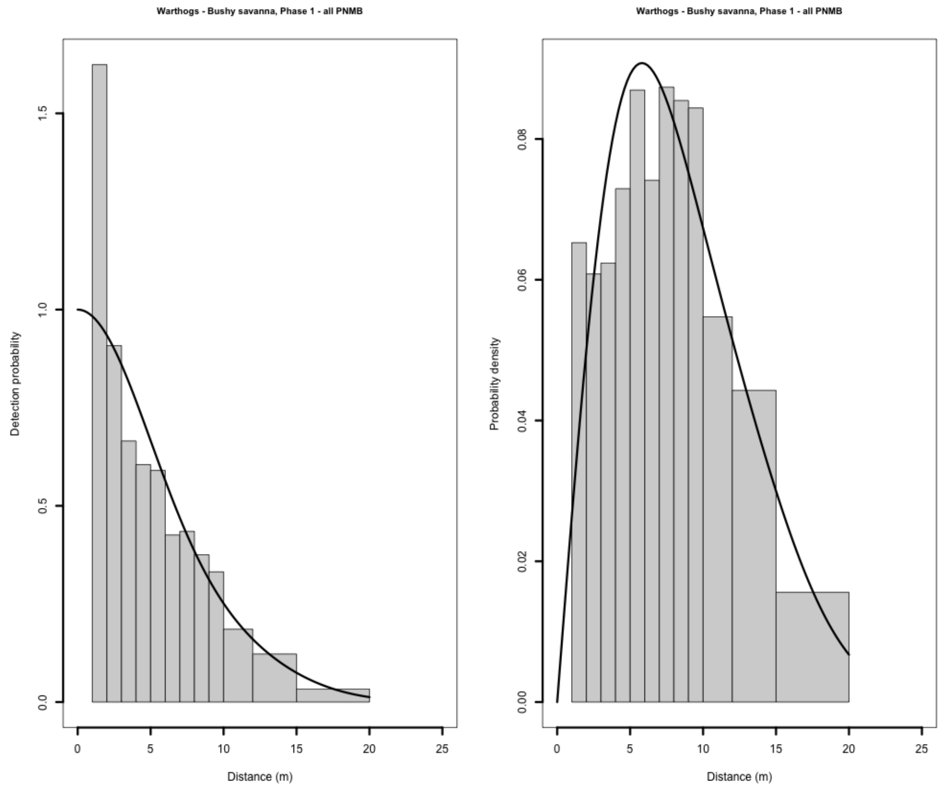
WARTHOGS



Fitted detection function, gallery forest, warthogs



Fitted detection function, clear forest, warthogs



Fitted detection function, bushy savanna, warthogs

ANNEX 3: Results of the phase 1 using the data sampled in the same area as phase 2 (column 4 in the Table I, results presented as phase 1 in the report)

Table I.A3: Description of the analysis parameters

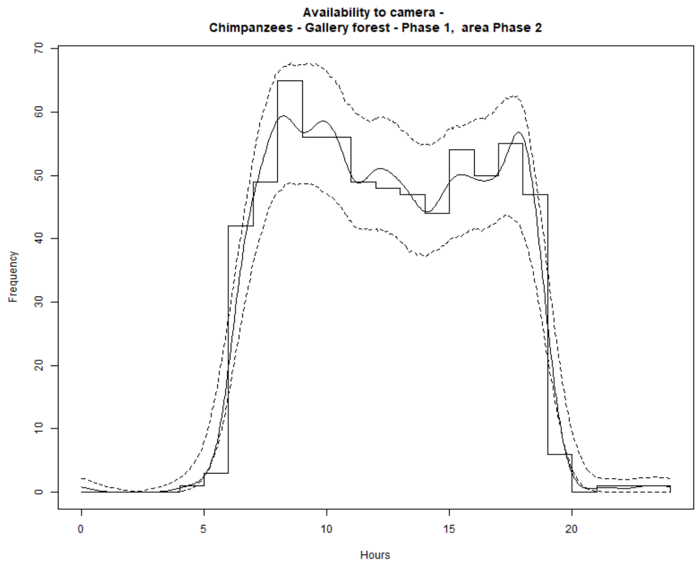
Species	Strata	Availability	Snapshot moments	Binned intervals	Selected detection function
Chimpanzees	Gallery forest (FG)	0.47	2 seconds	1,2,4,5,6,7,8,9,10,12,15,20,25	Hazard rate with 1 simple polynomial adjustment term
	Clear forest (FC) & Bushy savanna (SA)	0.37	2 seconds	1,2,3,6,7,9,10,12,15,20	Hazard rate with no adjustment term
Bushbucks	Gallery forest (FG)	0.39	2 seconds	1,3,4,5,6,8,9,10,12,15,20	Hazard rate with no adjustment term
	Clear forest (FC) & Bushy savanna (SA)	0.55	2 seconds	1,2,3,5,6,8,9,10,12,15,20	Hazard rate with 2 cosine adjustment terms
Red-flanked duikers	Gallery forest (FG)	0.35	2 seconds	1,3,4,5,6,7,8,9,10,12,15,20	Hazard rate with 1 simple polynomial adjustment term
	Clear forest (FC) & Bushy savanna (SA)	0.27	2 seconds	1,2,3,4,5,7,9,10,12,15,20	Hazard rate with 2 simple polynomial adjustment
Green monkeys	Gallery forest (FG)	0.4	2 seconds	1,2,3,5,6,7,10,12,15,20	Half normal with no adjustment term
	Clear forest (FC) & Bushy savanna (SA)	0.4	2 seconds	1,2,3,4,5,6,7,9,10,12,15,20	Uniform with 2 cosine adjustment terms
Warthogs	Gallery forest (FG)	0.32	2 seconds	1,2,3,5,6,7,10,12,15,20	Uniform with 3 cosine adjustment terms
	Clear forest (FC) & Bushy savanna (SA)	0.4	2 seconds	2,3,4,5,6,7,9,10,12,15,20	Half normal with no adjustment term

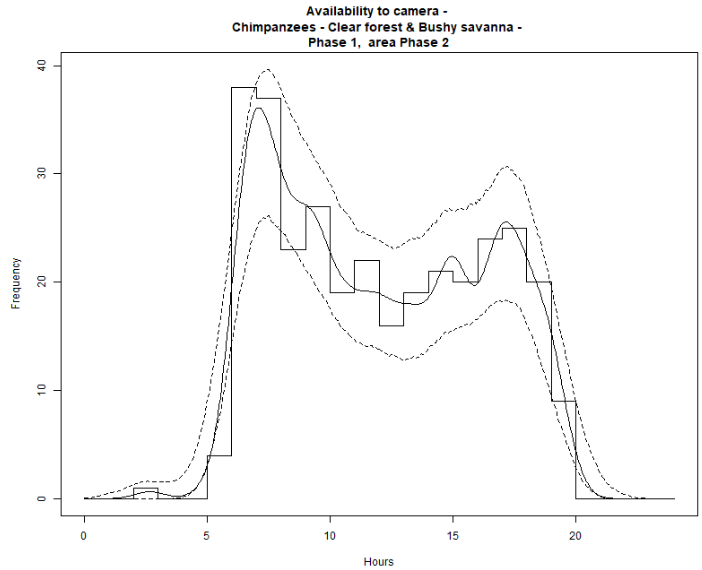
Table II.A3: Results of the camera trap distance analysis

Species	Strata	Total number distances before (after truncation)	Abundance	Density	Coefficient of variation (%)
Chimpanzees	Gallery forest (FG)	24195	717 (490-1232)	1.99 (1.36-3.41)	23.59
	Clear forest (FC) & Bushy savanna (SA)	9282 (8870)	1538 (876-2965)	0.55 (0.32-1.07)	31.75
	TOTAL	33477 (33065)	2255 (1441-3526)	0.72 (0.46-1.12)	23.13
Bushbucks	Gallery forest (FG)	7443 (7418)	695 (372-1441)	1.93 (1.03-3.99)	35.3
	Clear forest (FC)& Bushy savanna (SA)	8260 (8184)	3589 (2248-6049)	1.29 (0.81-2.18)	25.6
	TOTAL	15703 (15602)	4284 (2787-6785)	1.36 (0.89-2.1)	22.2
Red-flanked duikers	Gallery forest (FG)	4181 (4115)	659 (413-1317)	1.86 (1.14-3.65)	30.06
	Clear forest (FC) & Bushy savanna (SA)	6315 (6172)	5187 (3279-9499)	1.87 (1.18-3.21)	27.56
	TOTAL	10496 (10287)	5846 (3629 - 9417)	1.86 (1.16-3)	24.69
Green monkeys	Gallery forest (FG)	17881 (16684)	1236 (695-2699)	4.53 (2.55-9.89)	34.75
	Clear forest (FC) & Bushy savanna (SA)	14319 (13950)	3000 (2375-4606)	1.62 (1.28-2.49)	16.9

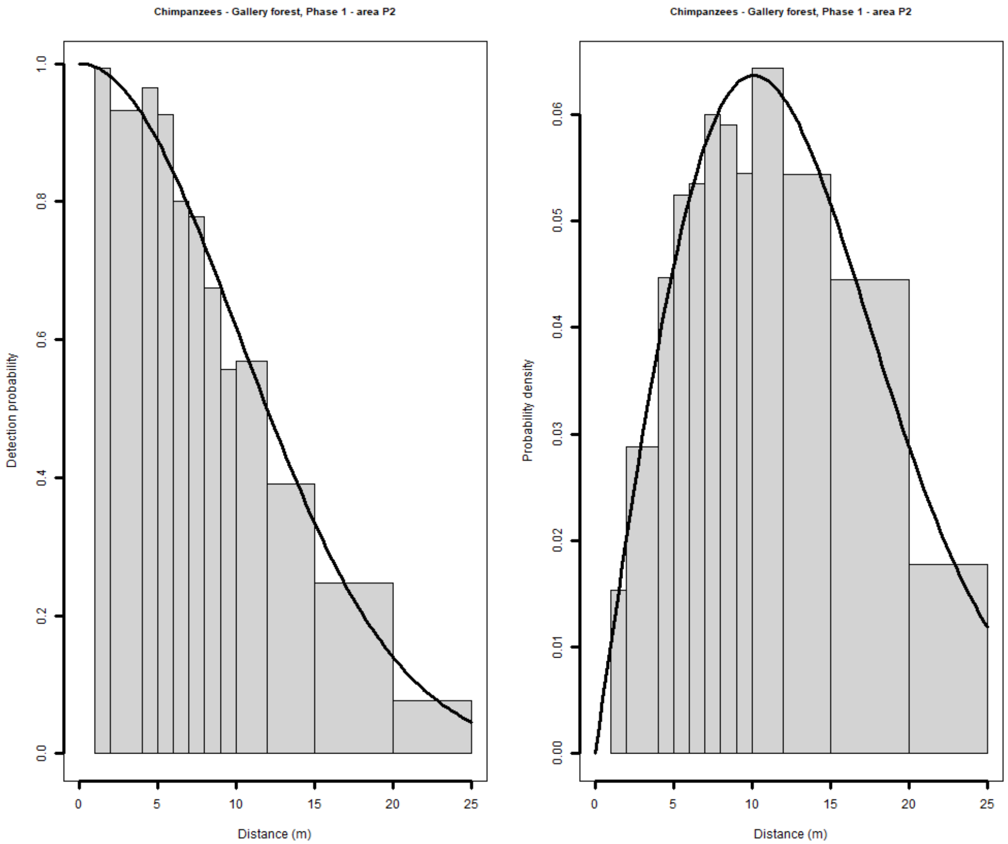
	TOTAL	32200 (30634)	4236 (3121-5750)	2 (1.47-2.71)	15.67
Warthogs	Gallery forest (FG)	9258 (8931)	1644 (979-2925)	6.03 (3.59-10.72)	27.82
	Clear forest (FC) & Bushy savanna (SA)	20915 (20345)	6643 (4784-9775)	3.59 (2.59-5.28)	18.23
	TOTAL	30173 (29276)	8287 (6113-11235)	3.9 (2.88-5.29)	15.62

Activity patterns of the chimpanzees

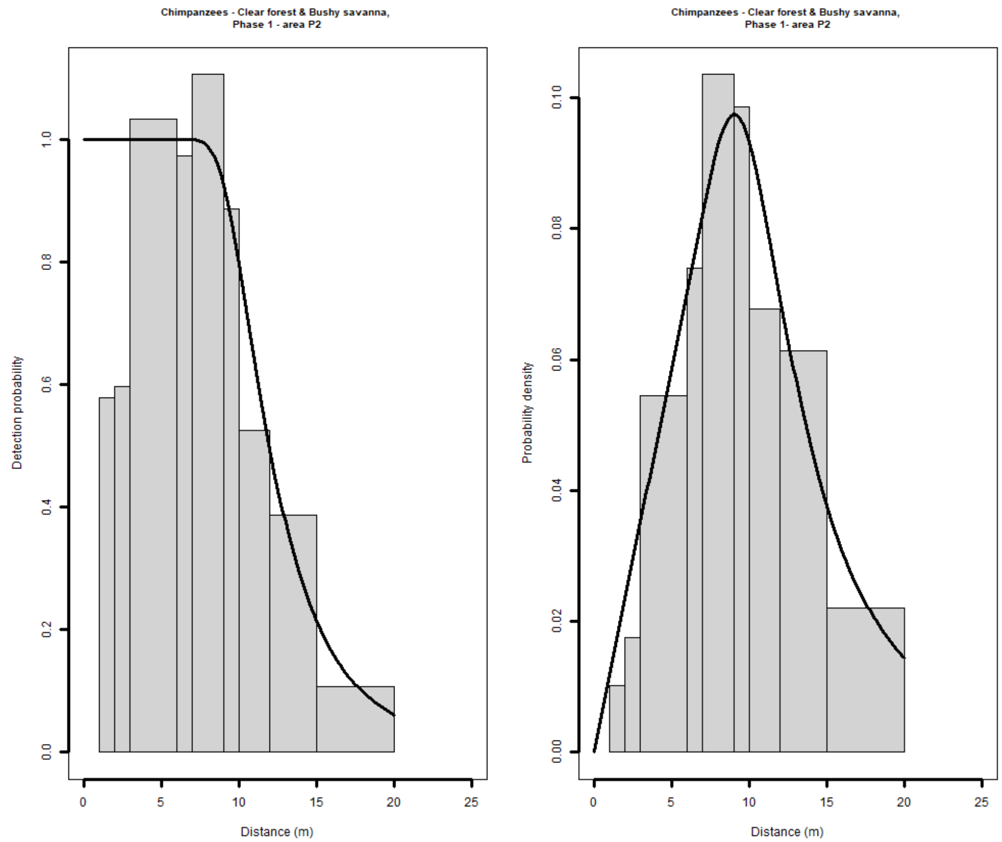




CHIMPANZEES

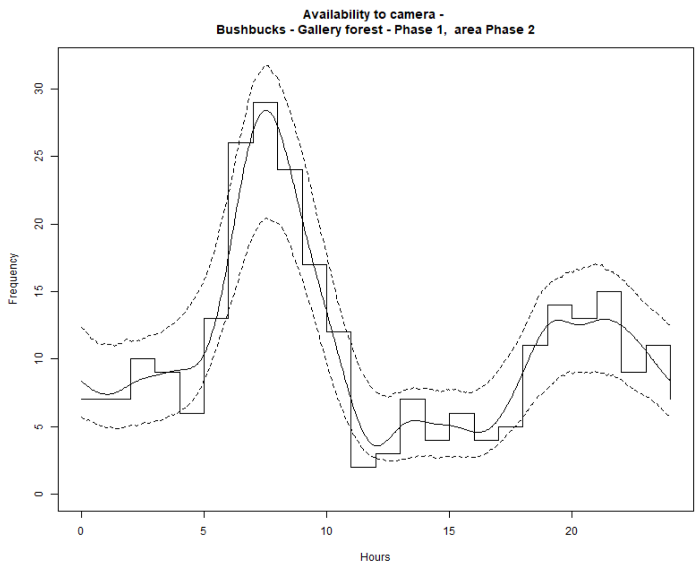


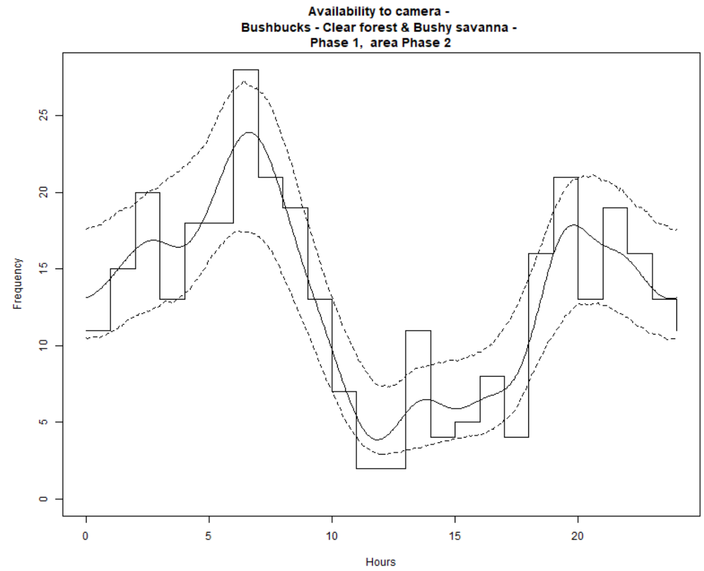
Fitted detection function, gallery forest



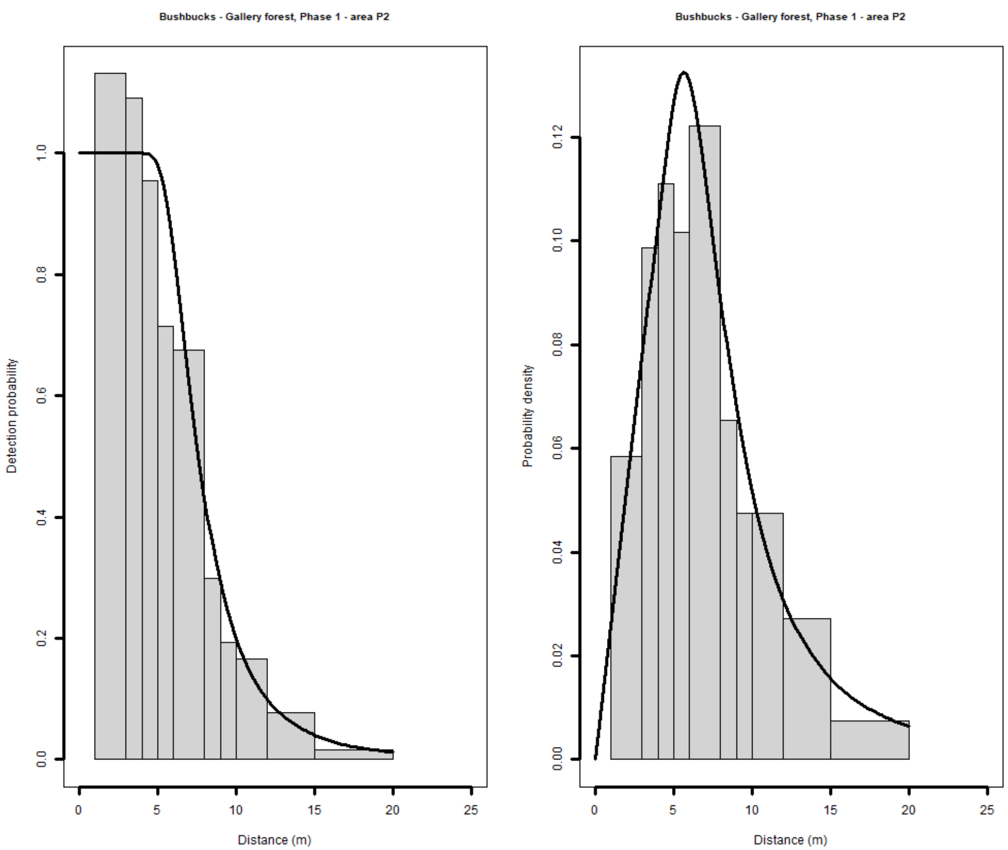
Fitted detection function, clear forest & bushy savanna

Activity patterns of the bushbucks

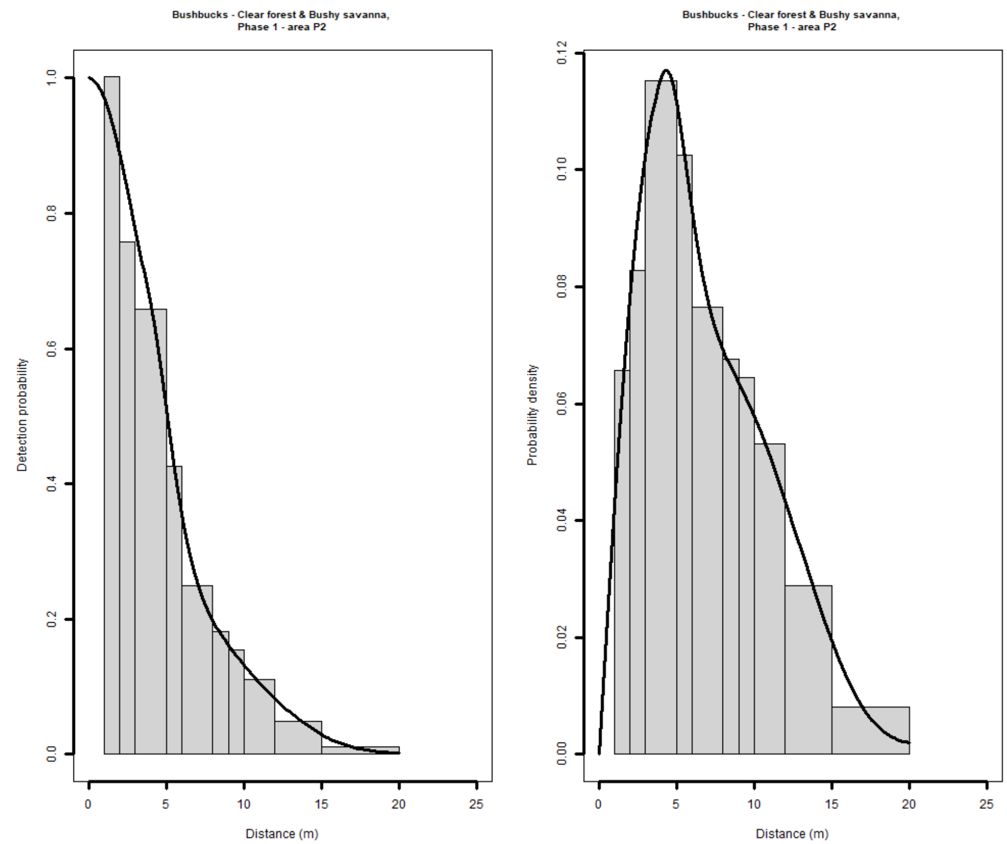




BUSHBUCKS

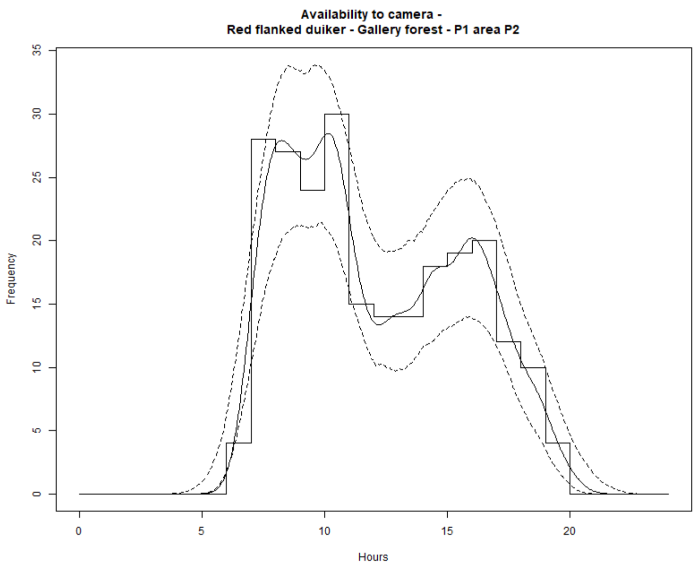


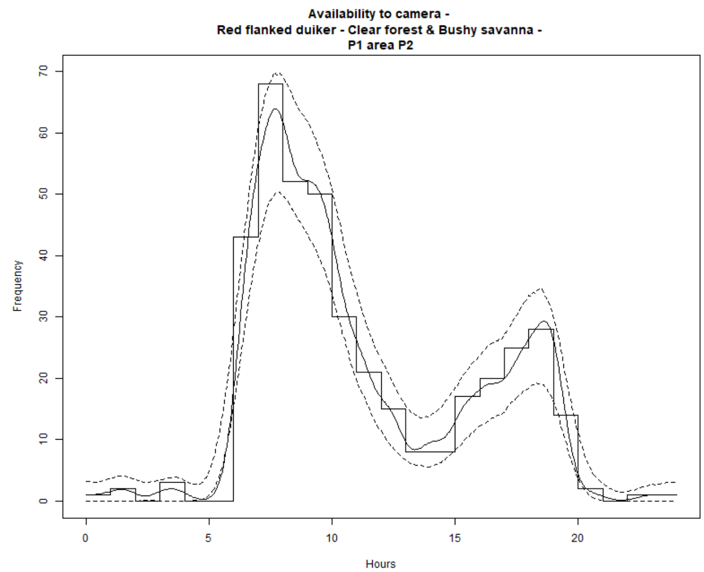
Fitted detection function, gallery forest



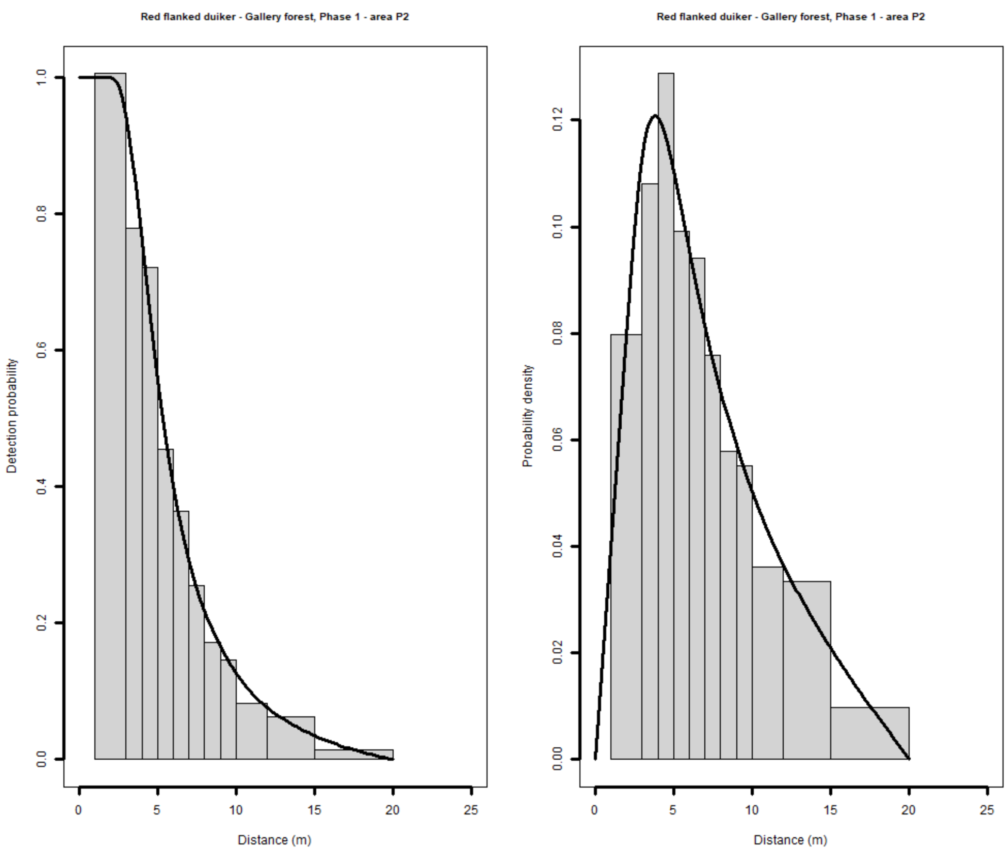
Fitted detection function, clear forest & bushy savanna

Activity patterns of the red-flanked duikers

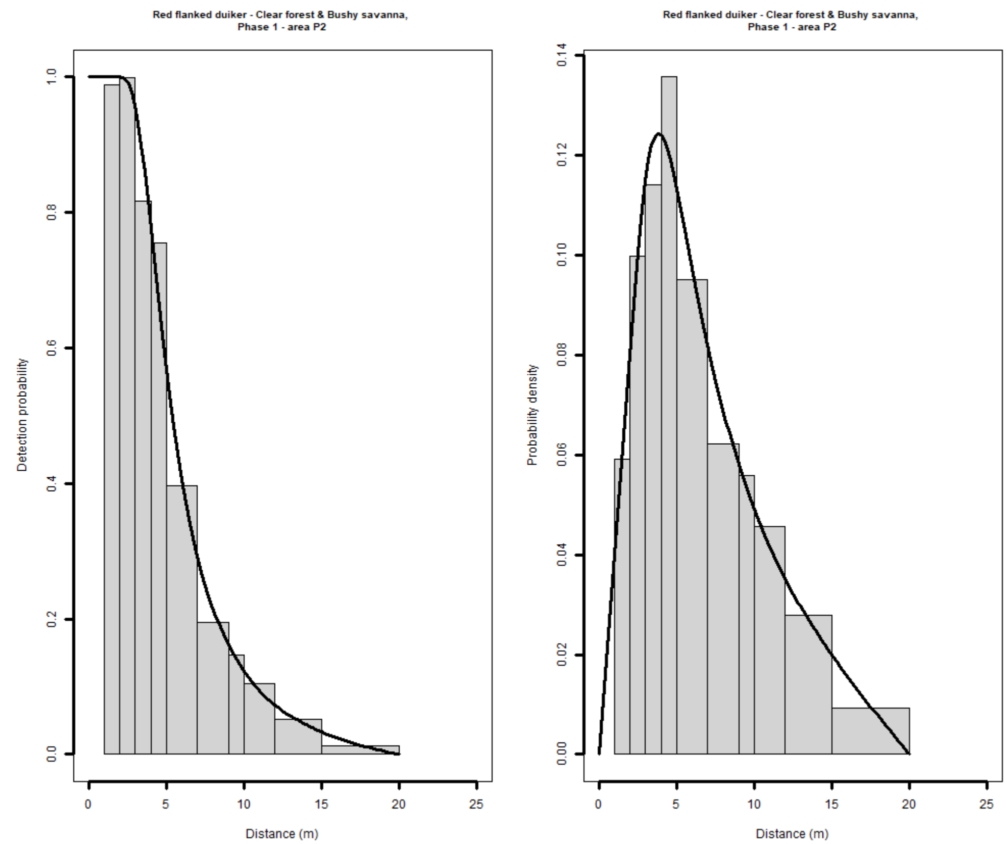




RED-FLANKED DUIKERS

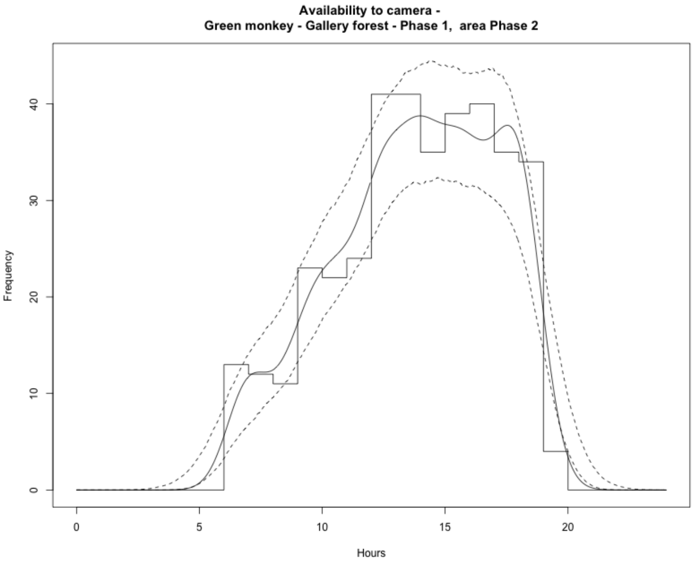


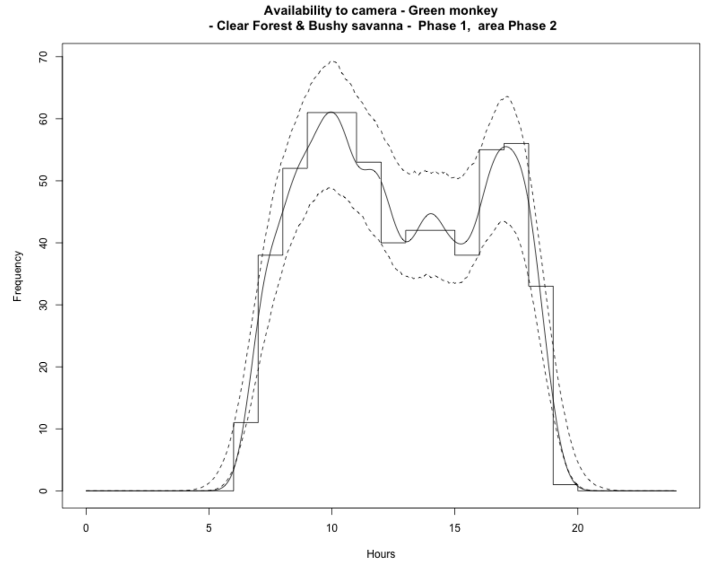
Fitted detection function, gallery forest



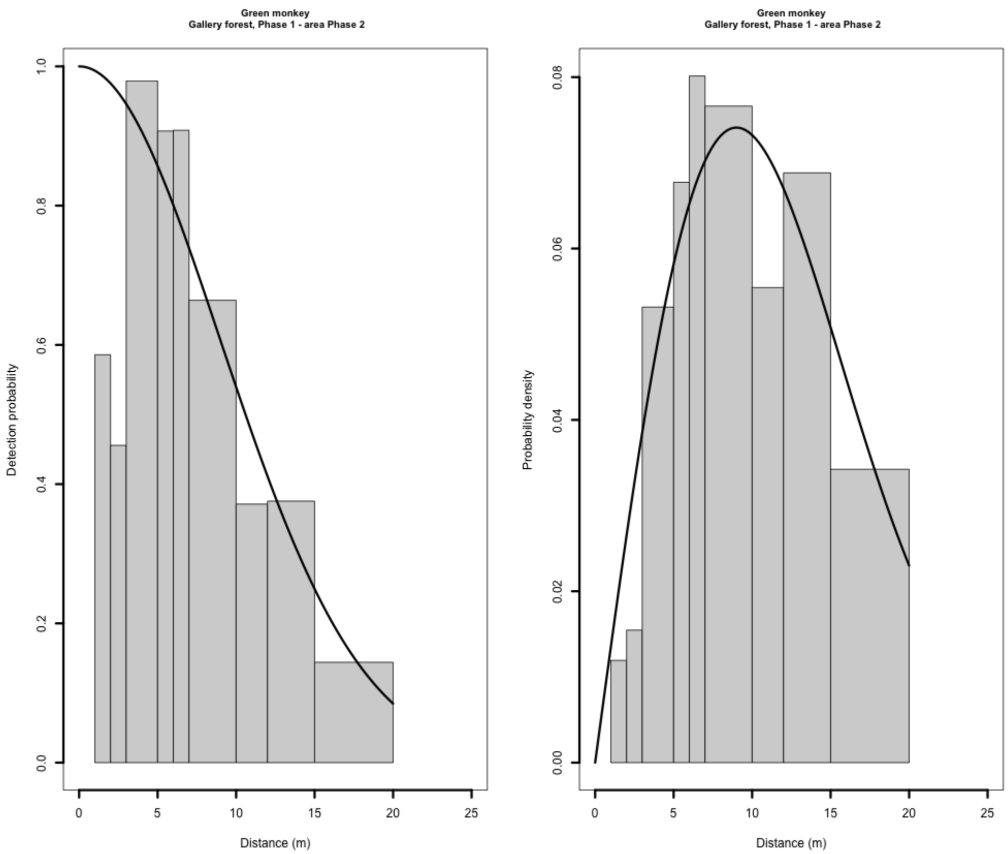
Fitted detection function, clear forest & bushy savanna

Activity patterns of the green monkeys

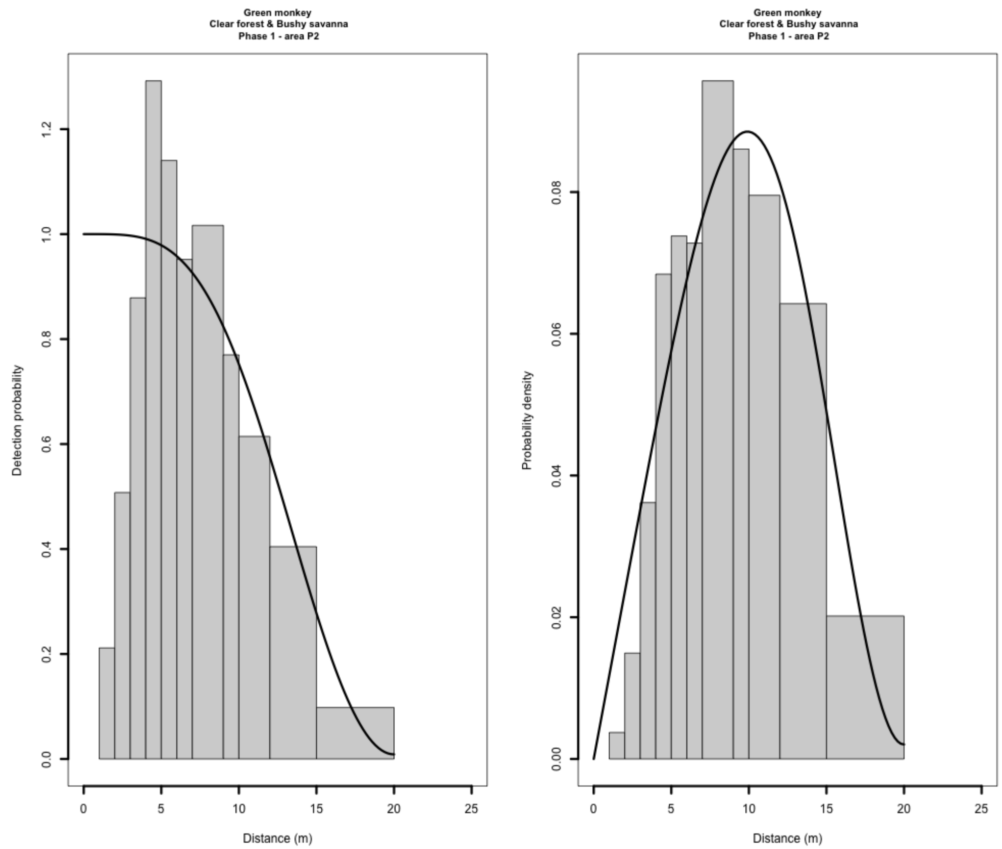




GREEN MONKEYS

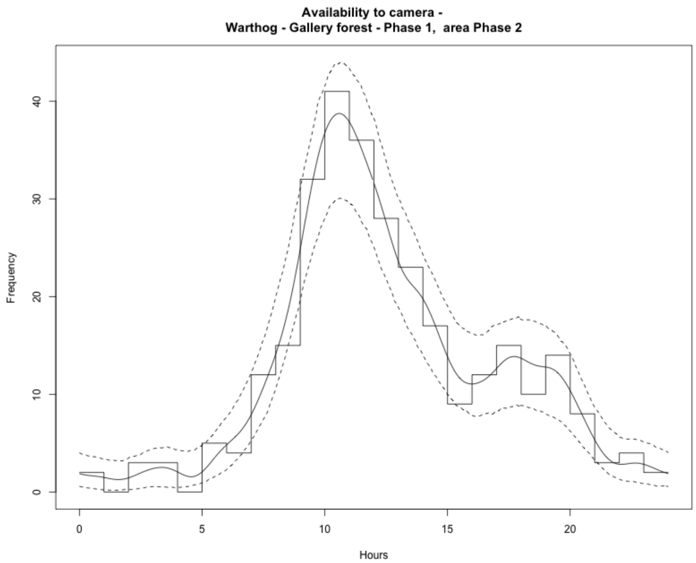


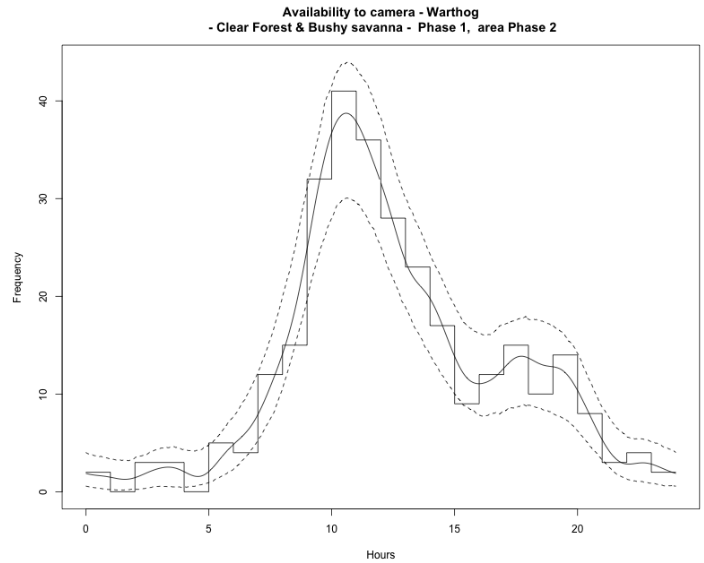
Fitted detection function, gallery forest



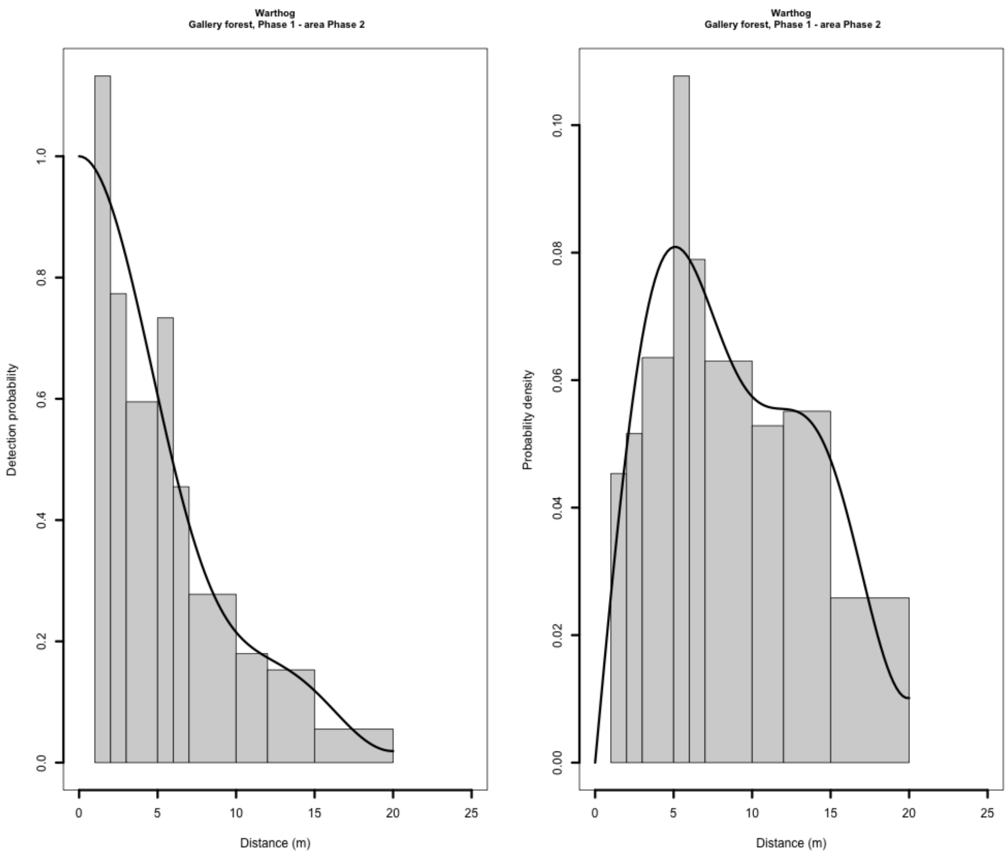
Fitted detection function, clear forest & bushy savanna

Activity patterns of the warthogs

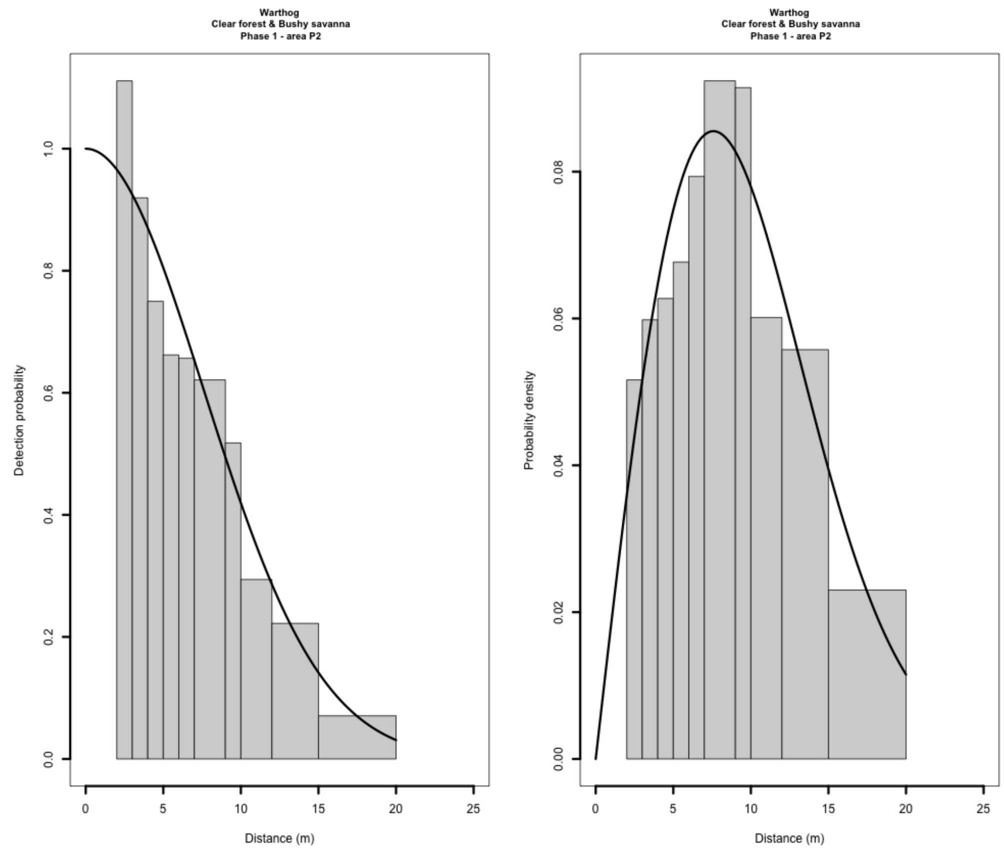




WARTHOGS



Fitted detection function, gallery forest



Fitted detection function, clear forest & bushy savanna

ANNEX 4: Results of the phase 2 (column 5 in the Table I, results presented as phase 2 in the report)

Table I.A4: Description of the analysis parameters

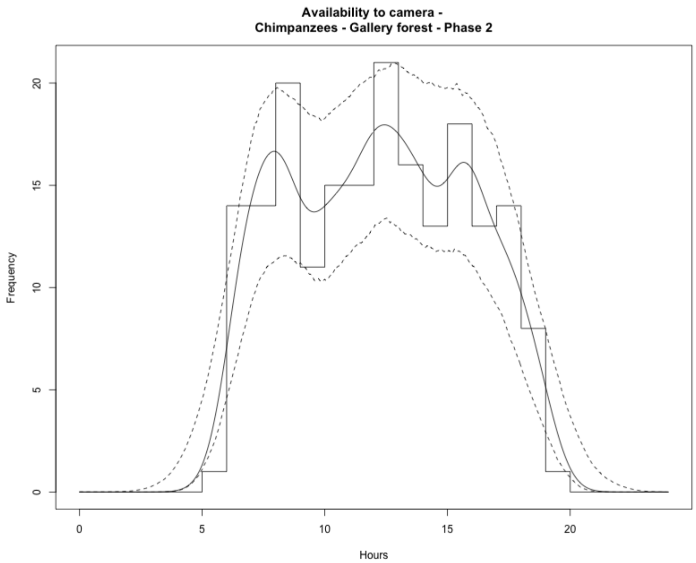
Species	Strata	Availability	Snapshot moments	Binned intervals	Selected detection function
Chimpanzees	Gallery forest (FG)	0.45	2 seconds	2,3,5,6,7,10,12,15,20,25	Hazard rate with 2 cosines adjustment terms
	Clear forest (FC) & Bushy savanna (SA)	0.55	2 seconds	1,2,4,5,6,7,8,10,12,20,25	Hazard rate with 1 simple polynomial adjustment term
Bushbucks	Gallery forest (FG)	0.46	2 seconds	2,3,5,6,7,8,10,12,15	Uniform with 2 cosine adjustment terms
	Clear forest (FC) & Bushy savanna (SA)	0.59	2 seconds	1,2,3,4,6,7,8,10,12,15	Half normal with 2 cosine adjustment terms
Red-flanked duikers	Gallery forest (FG)	0.28	2 seconds	1,3,4,5,6,7,10,12,15,20	Half normal with 1 cosine adjustment term
	Clear forest (FC)& Bushy savanna (SA)	0.39	2 seconds	1,2,4,6,7,8,12,15	Half normal with 1 cosine adjustment term
Green monkeys	Gallery forest (FG)	0.32	2 seconds	-	NA
	Clear forest (FC) & Bushy savanna (SA)	0.36	2 seconds	-	NA
Warthogs	Gallery forest (FG)	0.46	2 seconds	1,3,5,7,8,10,12,15	Half normal with 1 cosine adjustment
	Clear forest (FC) & Bushy savanna (SA)	0.5	2 seconds	1,2,3,5,7,10,15,20	Half normal with 1 cosine adjustment

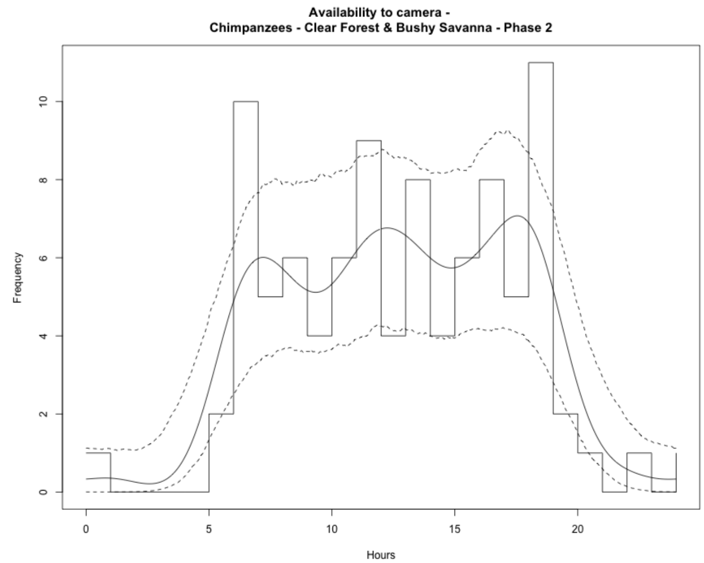
Table II.A4: Results of the camera trap distance analysis

Species	Strata	Total number distances before (after truncation)	Abundance	Density	Coefficient of variation (%)
Chimpanzees	Gallery forest (FG)	6038 (5713)	324 (202-663)	0.9 (0.56-1.84)	30.59
	Clear forest (FC) & Bushy savanna (SA)	3132	785 (454-1961)	0.28 (0.16-0.71)	38.19
	TOTAL	9170 (8845)	1109 (641-1917)	0.35 (0.2-0.61)	23.13
Bushbucks	Gallery forest (FG)	2233 (1797)	154 (100-507)	0.43 (0.28-1.41)	42.52
	Clear forest (FC)& Bushy savanna (SA)	1122 (1100)	1504 (781-3332)	0.54 (0.28-1.2)	38.3
	TOTAL	3355 (2897)	1658 (852-3226)	0.53 (0.27-1.03)	35
Red-flanked duikers	Gallery forest (FG)	2953 (2888)	1079 (471-2781)	2.99 (1.31-7.71)	46.96
	Clear forest (FC) & Bushy savanna (SA)	1273 (1129)	3075 (1177-9026)	1.11 (0.42-3.25)	55.05
	TOTAL	4226 (4017)	4154 (1868 - 9239)	1.32 (0.6-2.94)	42.54
Green monkeys	Gallery forest (FG)	11466 (10042)	-	-	-
	Clear forest (FC) & Bushy savanna (SA)	10303 (8743)	-	-	-

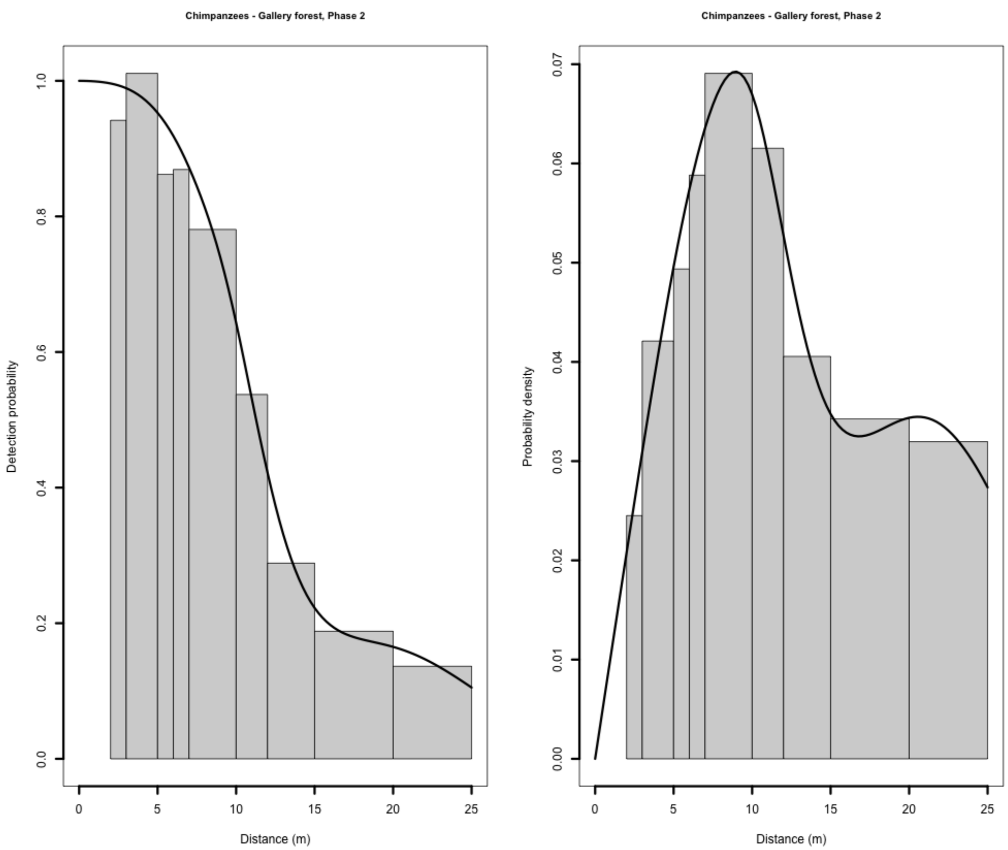
	TOTAL	21769 (18785)	-	-	-
Warthogs	Gallery forest (FG)	2742 (2541)	1519 (819-3422)	5.57 (3-12.54)	36.42
	Clear forest (FC) & Bushy savanna (SA)	8793 (7871)	6530 (3302-12619)	3.53 (1.79-6.82)	34.54
	TOTAL	11535 (10412)	8049 (4624-14010)	3.79 (2.18-6.6)	28.84

Activity patterns of the chimpanzees

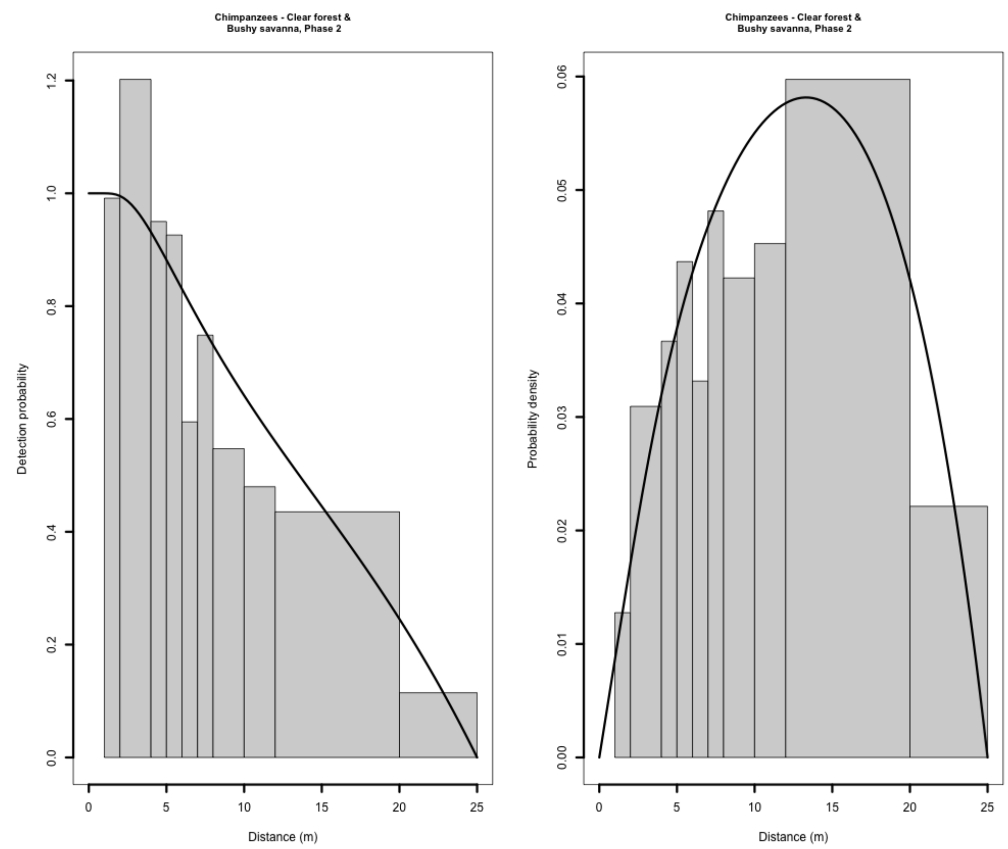




CHIMPANZEES

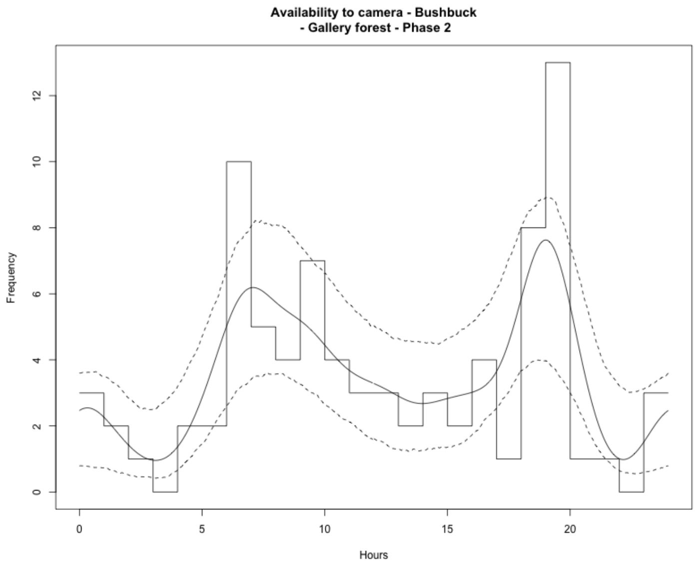


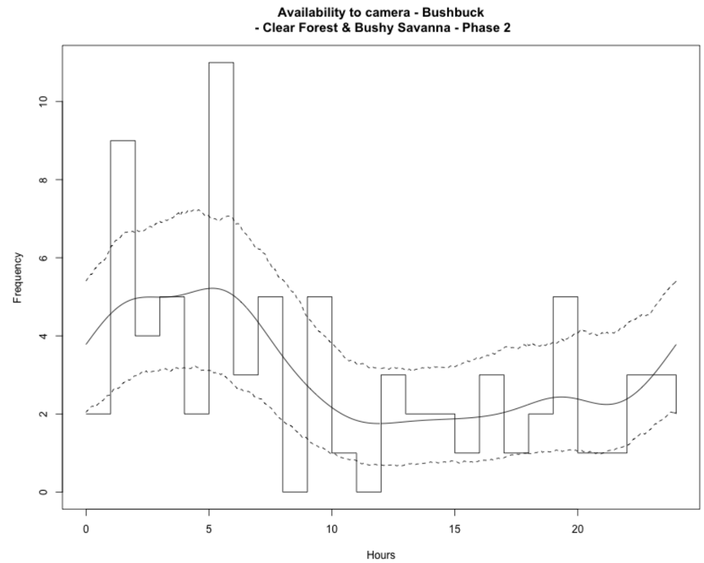
Fitted detection function, gallery forest



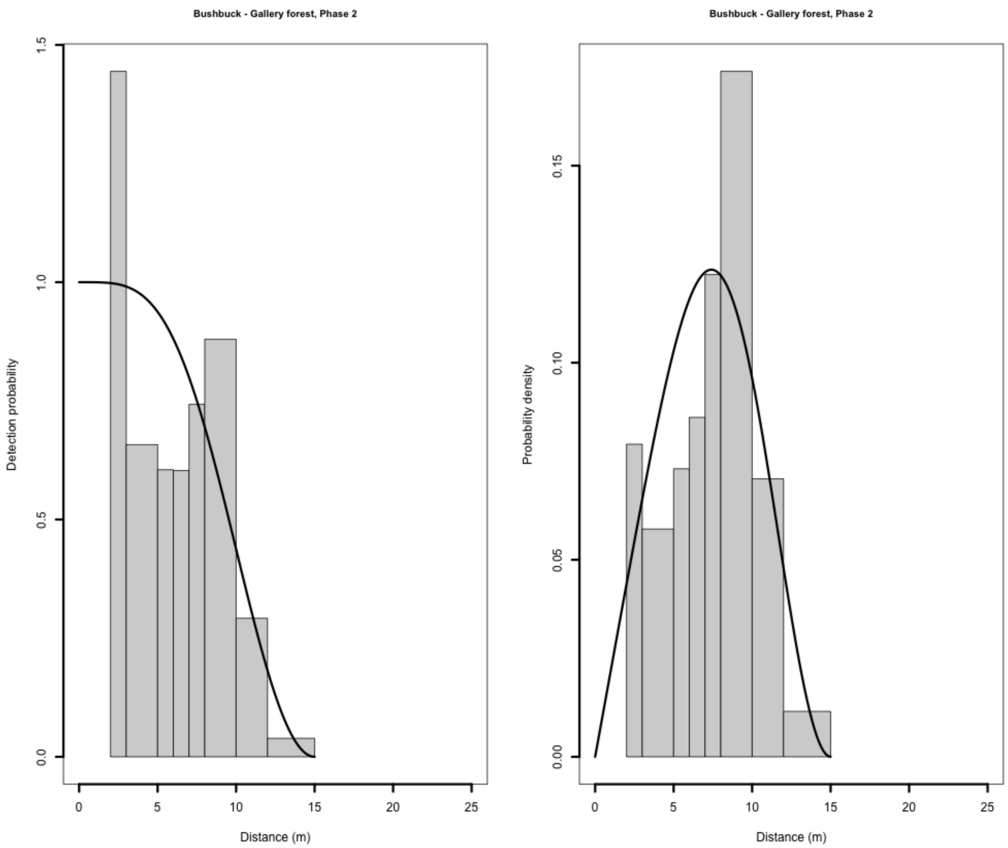
Fitted detection function, clear forest & bushy savanna

Activity patterns of the bushbucks

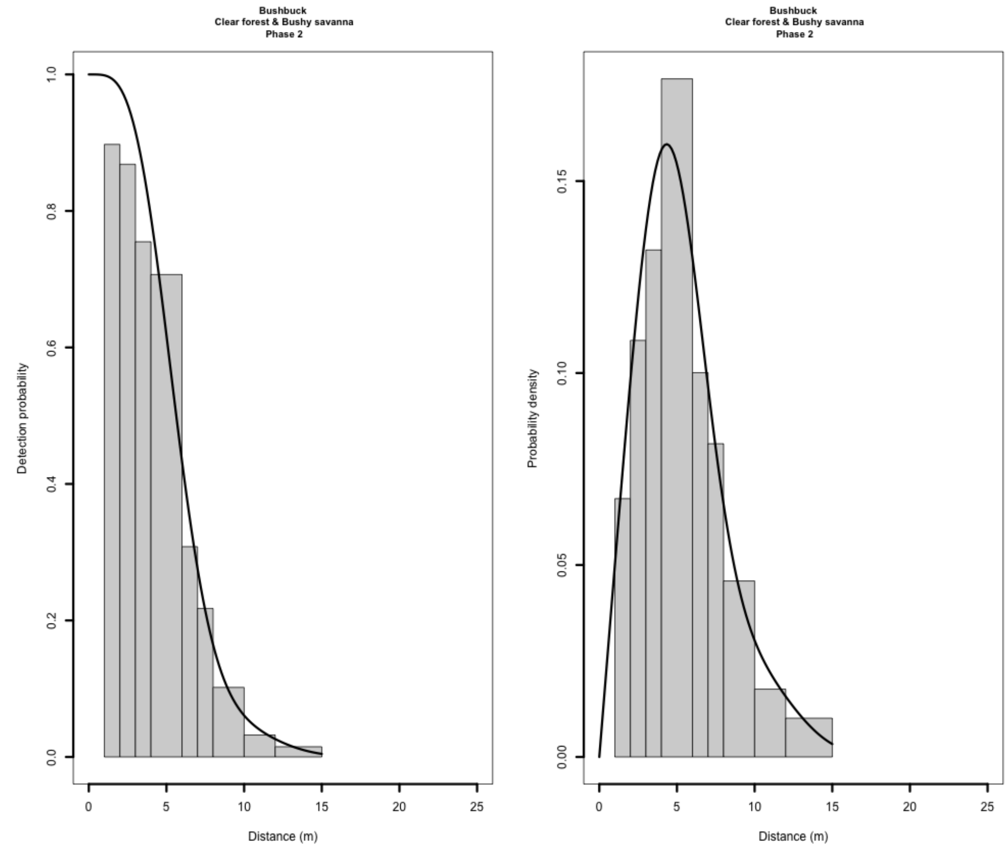




BUSHBUCKS

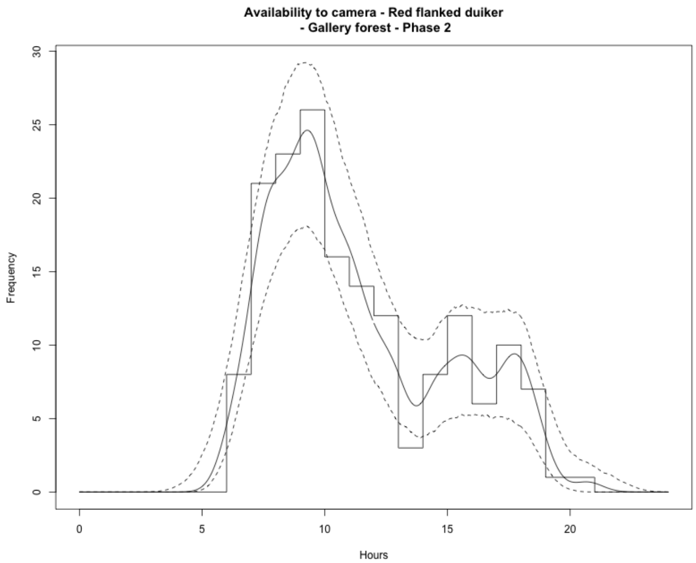


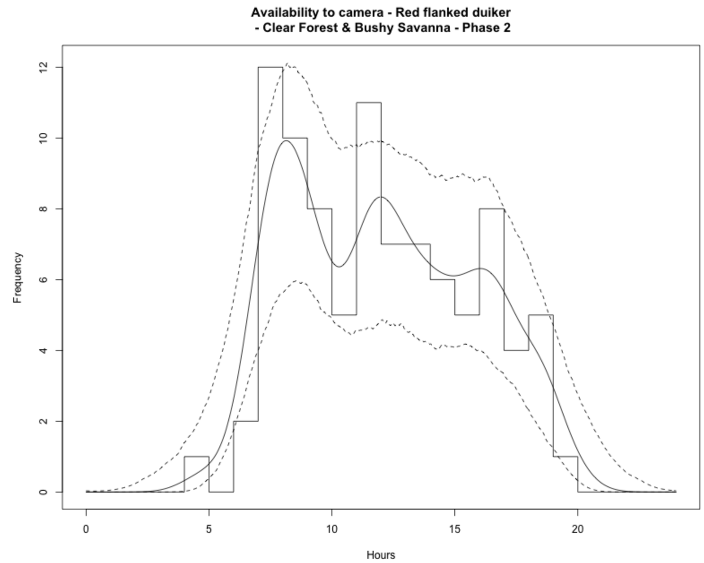
Fitted detection function, gallery forest



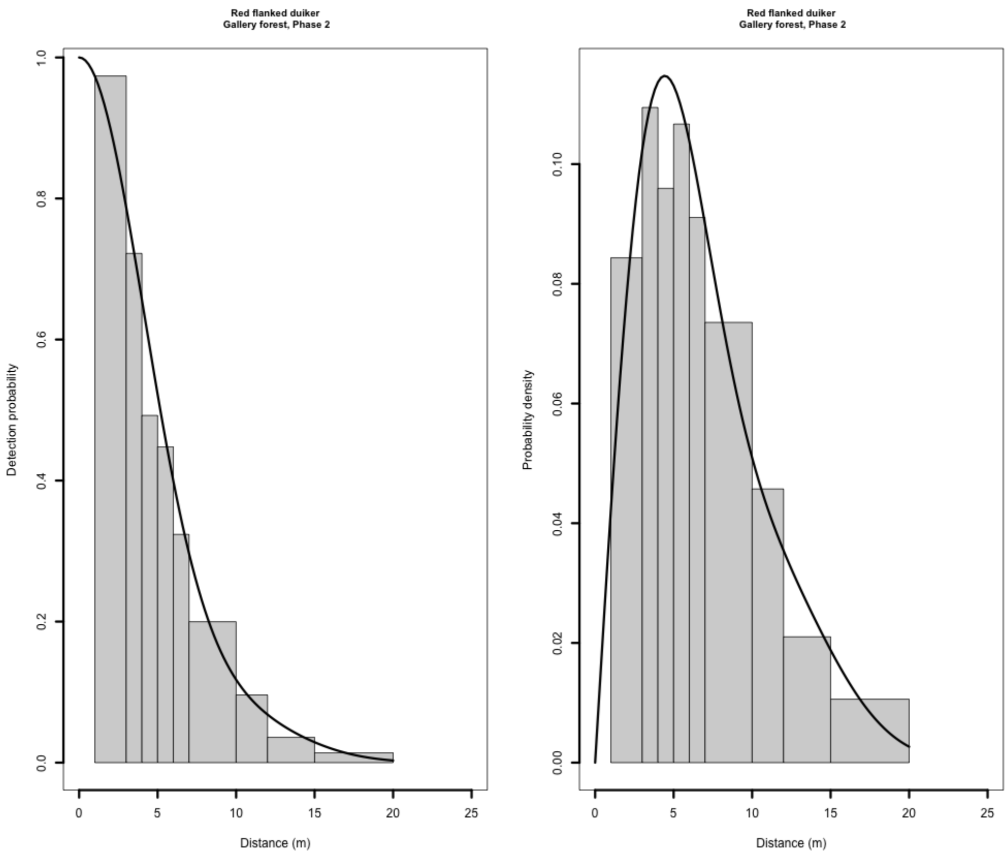
Fitted detection function, clear forest & bushy savanna

Activity patterns of the red-flanked duikers

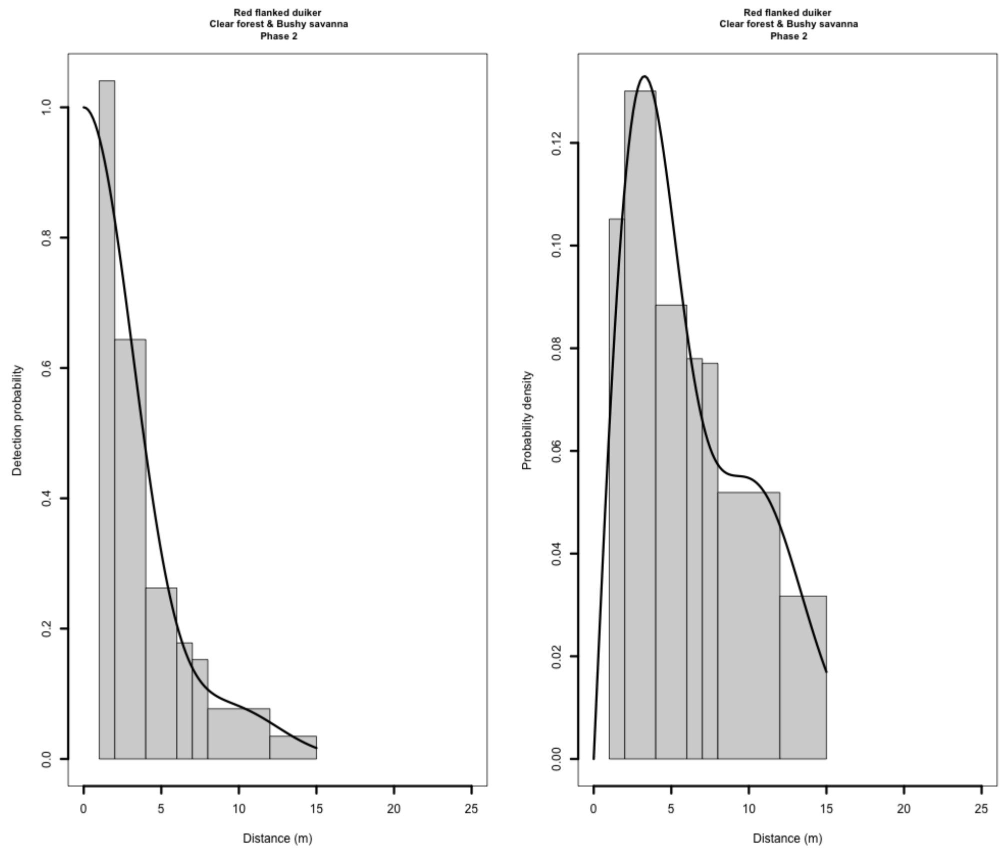




RED-FLANKED DUIKERS

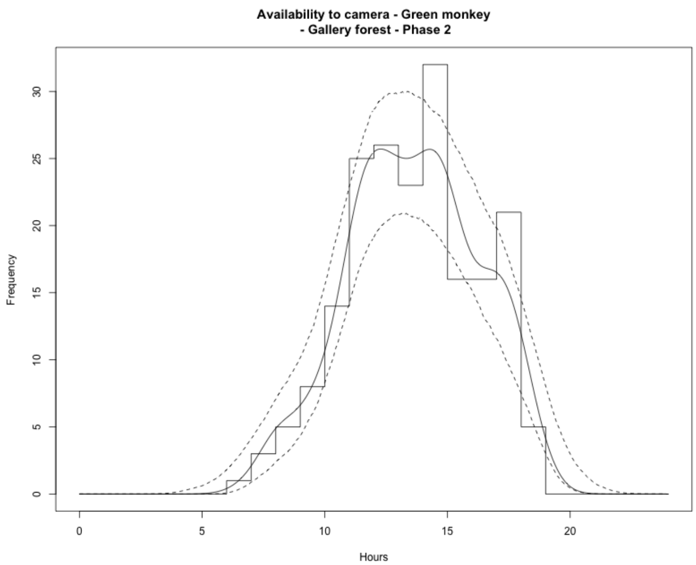


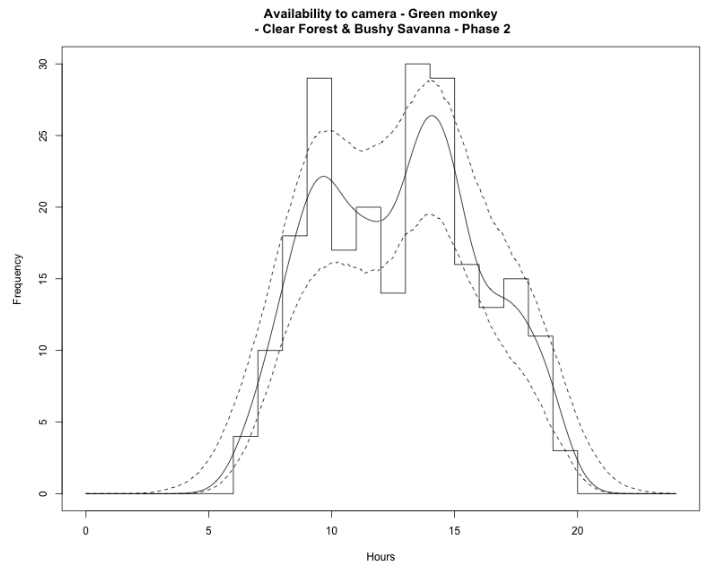
Fitted detection function, gallery forest



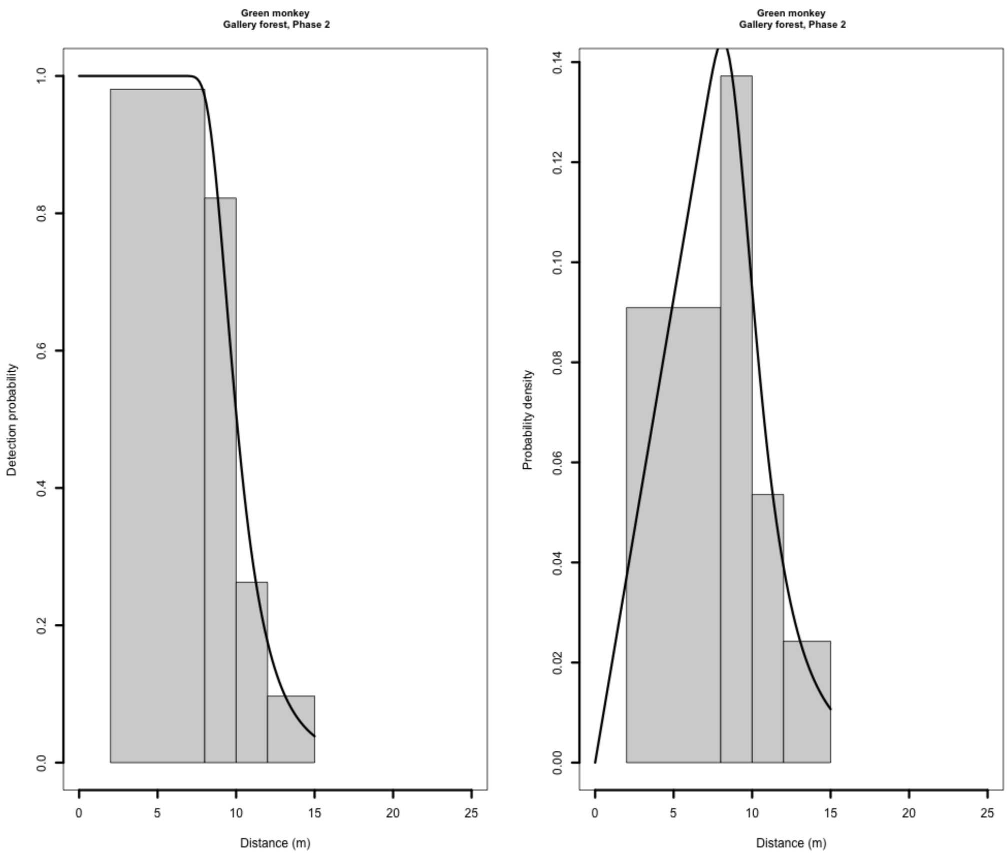
Fitted detection function, clear forest & bushy savanna

Activity patterns of the green monkeys

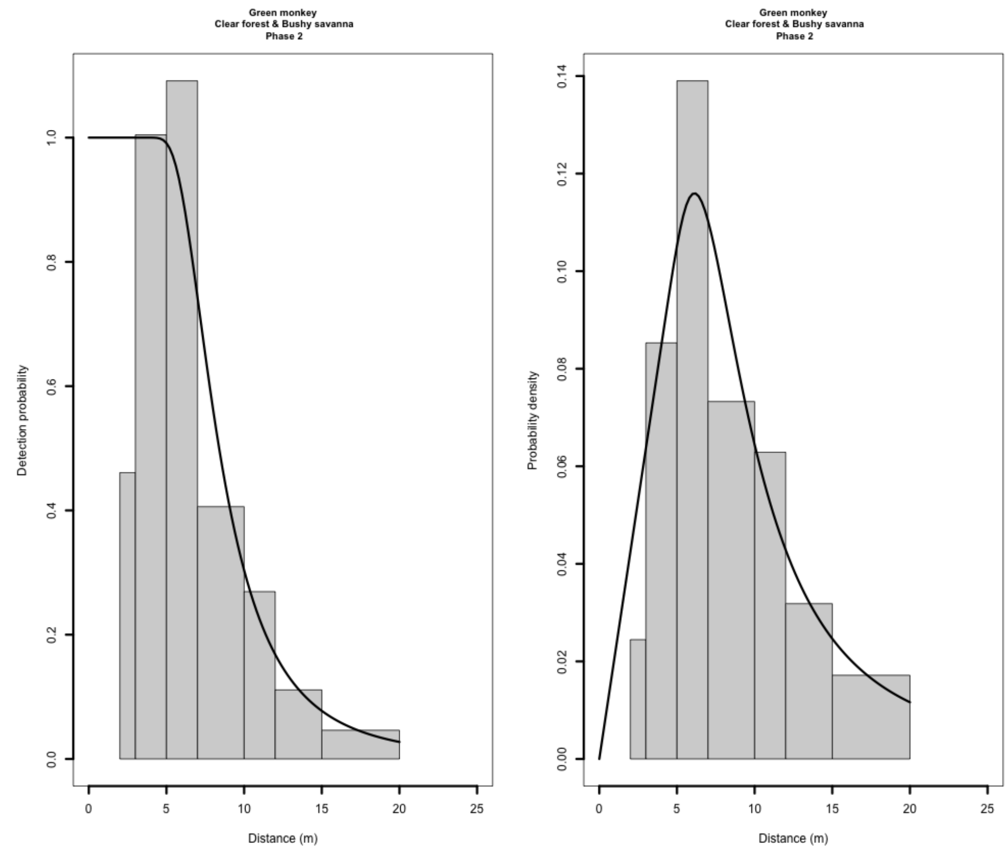




GREEN MONKEYS

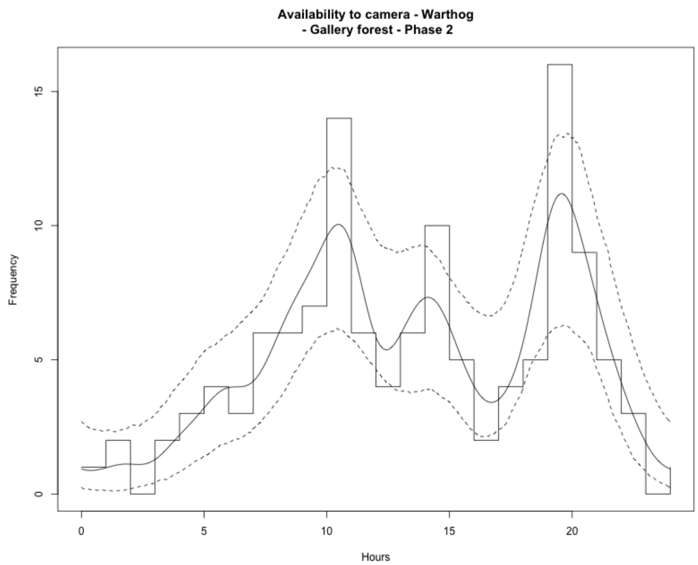


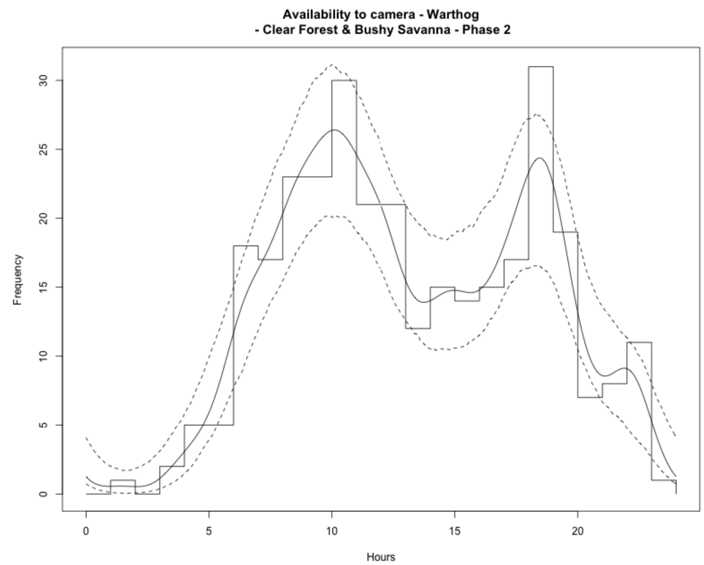
Fitted detection function, gallery forest



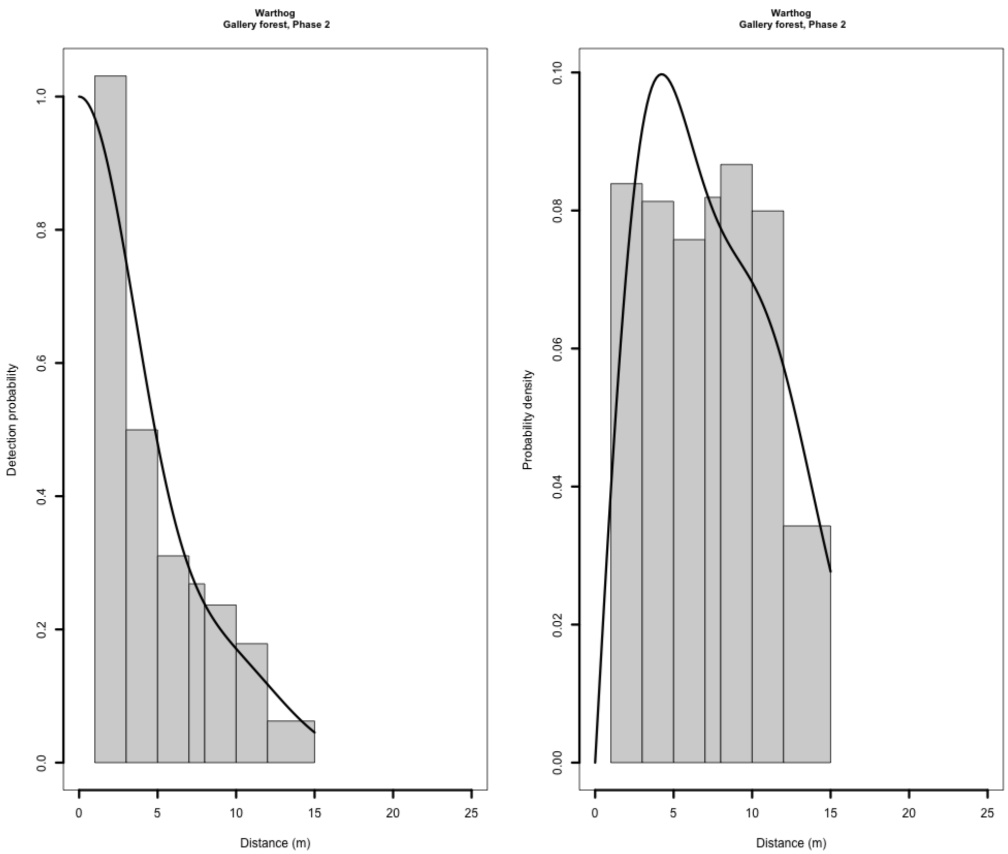
Fitted detection function, clear forest & bushy savanna

Activity patterns of the warthogs

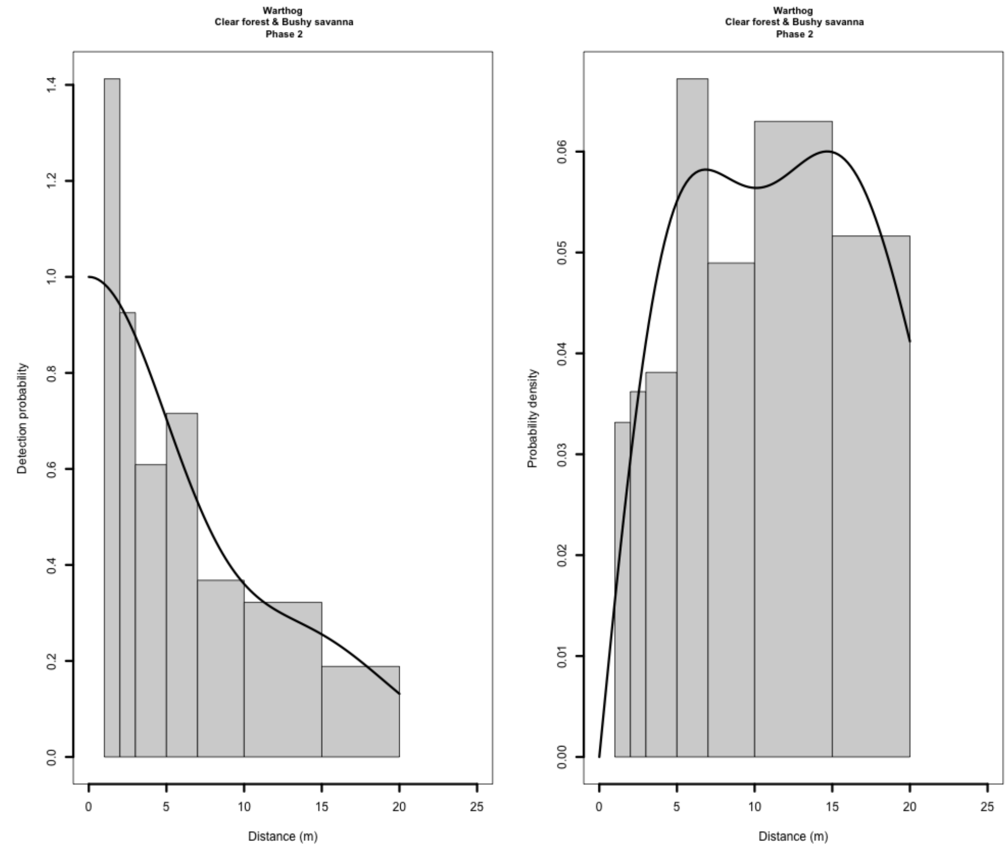




WARTHOGS



Fitted detection function, gallery forest



Fitted detection function, clear forest & bushy savanna