Camera-Trap Survey for Larger Terrestrial Wildlife in the Dja Biosphere Reserve, Cameroon

Diversity & Intactness of the Larger Vertebrate Fauna

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Les éco gardes et personnes d'appui ci-après ont participé à la collecte des données:

Cover page images (ZSL): *Clockwise from top-left:* Central Chimpanzee *Pan troglodytes troglodytes,* Peter's duiker *Cephalophus callipygus* & Fire-crested Alethe *Alethe castanea,* Cameroon cusimanse *Crossarchus platycephalus,* African elephant *Loxodonta africana.*

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Résumé

La grande et moyenne faune terrestre de la partie nord-ouest de la réserve de biosphère de Dja (RBD) a fait l'objet d'une étude à l'aide de pièges photographiques (Camera-trap). Une série de 41 cameras à infrarouge (Bushnell Trophy Cam Aggressor) a été déployée suivant un maillage de 2x2 km pour une évaluation du potentiel faunique. Au total 3725 jours de capture ont été effectués entre fin 2015 et début 2016 pour 7109 évènement de faune enregistrés. La richesse spécifique estimée des espèces a convergé en 148 jours. Cela suggère que la plupart, sinon tous les grands et moyens mammifères terrestres présents dans la zone ont été détectées au cours de cette étude.

Au total, 32 espèces de mammifères ont été détectées, y compris le gorille des plaines de l'Ouest (*Gorilla g. gorilla* – espèces «en danger critique d'extinction» selon les critères de la Liste rouge de l'UICN), le chimpanzé commun (*Pan t. troglodytes* – «en voie d'extinction»), l'éléphant d'Afrique (*Loxodonta africana* – «Vulnérable»), le mandrill (*Mandrillus sphinx* – la première détection de cette espèce dans la Réserve du Dja), le bongo (*Tragelaphus eurycerus* - «Quasi menacée»), le pangolinà écailles tricuspides (*Phataginus tricuspis* - «Vulnérable») et le pangolin géant (*Smutsia gigantea* - «Vulnérable»).

Ce premier déploiement des pièges photographiques pour l'étude des grands et moyens mammifères terrestres de la Réserve de Biosphère de Dja a permis de prouver qu'elle reste une Aire Protégée importante pour la conservation de grands et moyens mammifères terrestres dans le Bassin du Congo. Les données de cette étude contredisent les conclusions des rapports précédents (Steyn 2015). Malgré l'existence d'une chasse omniprésente pour la viande de brousse y compris les grands singes et l'intensification du commerce illégal d'ivoire d'éléphant, d'écaille de pangolin, l'étude a révélé la présence continue de toutes ces espèces dans la petite zone échantillonnée (3-4% de la Réserve entière) située non loin des villages (entre 6 et 19 km). La détection de plusieurs espèces figurant sur la Liste rouge de l'UICN des espèces en voie de disparition souligne la persistance des populations de ces espèces vulnérables dans la Réserve. Ainsi, les Valeurs Universelles Exceptionnelles de la RBD telle que présentées par le site du patrimoine mondial de l'UNESCO (http://whc.unesco.org/en/list/407/), en tant que grand bloc de forêt tropicale contiguë possédant des populations diverses de la faune sauvage restent intactes en 2016 au moins pour la partie couverte par l'étude.

En raison de la taille et de la variabilité des territoires chez les éléphants de forêt, les chimpanzés et de gorilles qui dépassent les 2km^2 de distance inter-pièges utilisés lors de cette étude, on ne peut compter sur la relation positive entre l'occupation (Occupancy) et l'abondance, comme pour les espèces ayant des territoires plus petits, tel que les Céphalophes. L'abondance relative de l'éléphant de forêt tel qu'obtenue lors de cette étude (taux de piégeage) est plus élevée que les données récentes (utilisant les signes) d'inventaires (MINFOF et UICN 2015). Ces différences peuvent être dues, en partie aux effets de déplacements saisonniers de populations d'éléphants alors que l'étude se réalisait a une autre saison.

Sur la base des données recueillies lors de cette étude Camera-trap dans la zone Nord-Ouest, nous pensons que le statut de la grande et moyenne faune de la Réserve de Biosphère du Dja correspond très probablement à la catégorie « Faune diminué » (troisième niveau d'un continuum faunique d'intactivité qui va d'un état intact, relativement intact, diminué, épuisé, à un etat de «forêt vide»). Toute la grande et moyenne faune, à l'exception peut-être des felidae sauvages, se trouvent encore dans la Réserve du Dja, bien que probablement en abondance réduite. La présence de grands céphalophes soutient également cette catégorisation, car ils sont souvent rares ou absents sous l'effet du braconnage.

Les études à l'aide de pièges photographiquessont complémentaires des inventaires classiques avec transects linéaires et/ou Recce pour le suivi des espèces cibles. Les Cameras pièges enregistrent une proportion plus grande de la moyenne et grande faune que ne le font les inventaires avec les méthodes classiques (Linéaires/Recce) qui elles sont efficaces pour les oiseaux et primates arboricoles ainsi que pour les espèces qui laissent des traces visibles au sol comme les nids, les crottes, les traces d'alimentation. Ainsi, le statut «Intact» de la mégafaune terrestre dans une zone protégée peut être mieux estimé à l'aide des études Camera-trap. Toutefois, les données obtenues par les méthodes Recce et transects linéaires permettent des estimations d'abondance plus fiables et une plus grande capacité à détecter les changements de populations de gorilles, de chimpanzés et d'éléphants de forêt dont l'âge des signes (crottes et nids) peut être évalué. Les études à l'aide

de pièges photographiques sont probablement plus fiables que les méthodes par Transect linéaires ou Recce pour détecter ces espèces lorsque leur nombre est faible.

Afin de compléter les données recueillies à partir des inventaires par Recce ou transects linéaires, nous recommandons le déploiement de pièges photographiques suivant un maillage (grille) d'après la méthode standard ZSL / MINFOF. Le déploiement de ces pièges photographiques devra se faire dans chaque secteur au moins une fois tous les deux ans, à la même saison pour chaque grille, dans la mesure du possible. Les grilles devraient principalement prendre en compte l'habitat principal, c'est-à-dire qu'elles ne devraient pas être trop proches des limites de la réserve. Chaque secteur devrait également disposer de 10 caméras en permanence placées dans des sites à haute valeur (bais (clairières naturelles), flaques d'eaux, pistes d'animaux pour suivre la présence ou l'absence d'espèces vulnérables (éléphant de forêt, grands singes, Pangolin géant, bongo, etc.) au fil du temps. Une méthodologie standard d'étude utilisant la méthodologie piégeage photographique est recommandée. Le coût de démarrage estimé pour l'étude de 2017 est d'environ $7 780. Chaque déploiement et analyses additionnels coûtent environ $ 9 430.

EXECUTIVE SUMMARY

The medium- to larger-bodied terrestrial fauna of the northwest portion of the Dja Biosphere Reserve (DBR) was surveyed using camera-traps. An array of 41 infrared-triggered trail cameras (Bushnell Trophy Cam Aggressor), each roughly 2 km apart in a square grid pattern, was placed for a combined c. 3,725 operational days for a wildlife survey in late 2015 and early 2016 with 7,109 wildlife events recorded. The estimated species richness converged at 148 days. This suggests that most, if not all, medium-to-large (≥0.5 kg) terrestrial mammals species present in the area were detected during the survey.

A total of 32 mammal species were detected, including Western lowland gorilla (*Gorilla gorilla gorilla* – Critically Endangered species under IUCN Red List criteria), the Endangered central chimpanzee (*Pan troglodytes troglodytes*), African forest elephant (*Loxodonta africana* – Vulnerable), mandrill (*Mandrillus sphinx* - the first record of this large species in the reserve), bongo (*Tragelaphus eurycerus* – Near Threatened), white-bellied pangolin (*Phataginus tricuspis* – Vulnerable), and giant pangolin (*Smutsia gigantea* – Vulnerable).

This first systematic camera-trap survey for medium-to-large terrestrial mammals in the Dja Biosphere Reserve has provided evidence that it remains an important protected area for the conservation of medium-to-large terrestrial mammals in the Congo Basin. This contradicts previous reports (Steyn 2015). Despite pervasive bushmeat hunting and intensifying illegal trade in elephant ivory, pangolin scale, and great apes, the survey has documented continued presence of all these species in a small sample area (3-4% of the greater reserve) located relatively close to permanent settlement (that is, from 6 to 19 km). The detection of several species on the IUCN Red List of Endangered Species highlights the persistence of populations of these vulnerable species within the reserve. Thus, the Outstanding Universal Values of the DBR as highlighted by the UNESCO World Heritage Site Designation (http://whc.unesco.org/en/list/407/), that is, the large block of contiguous rainforest and diverse wildlife populations, at least for the sector surveyed, remain intact as of 2016.

Due to the large, variable home ranges of forest elephant, chimpanzee, and gorilla that exceed this survey's inter-trap distances of 2 km, the positive relationship between occupancy and abundance cannot be relied upon as with species with smaller home ranges, such as the duiker species. The relative abundance of forest elephant as measured by trapping rate was higher in the camera-trap survey area than those recently found by sign surveys (MINFOF & IUCN 2015). This observation may be due, in part, to forest elephants moving seasonally within the forest as the MINFOF & IUCN and this survey were conducted in a different season.

From the data gathered in this camera trap survey, we believe that the status of the larger terrestrial vertebrate fauna of the Dja Biosphere Reserve falls, most likely and within the zone of the camera trap grid, in the Diminished Fauna category (the third-level of a faunal intactness continuum that ranges from intact, relatively intact, diminished, depleted, to an 'empty forest' status). All the larger vertebrates, except for wild felids, perhaps, still occur within the Dja Reserve, albeit likely at diminished abundances. The presence of larger-bodied duikers also supports this categorization as they often are rare or extirpated under intensive hunting.

Camera-trap surveys are complementary to line transect distance sampling surveys, recce encounter data, and patrol-based direct encounter data for monitoring target wildlife populations. Camera-trap surveys record a much greater proportion of the larger vertebrate fauna than do line transect and recce surveys that are best-suited for gathering data (direct observations and sign) for larger-bodied species that leave noticeable sign, such as nests and dung, and for arboreal primates and birds. Thus, the overall 'intactness' status of the larger cursorial vertebrate fauna (that is, the terrestrial

megafauna) within a protected area can be better estimated using camera-trap surveys. However, the distance sampling data obtained through line transect and recce encounter rate surveys allows for more reliable abundance estimates and greater sensitivity to changes in populations for gorilla, chimpanzee, and forest elephant whose sign (dung and nests) can be dated. Camera-trap surveys are likely more reliable than distance and encounter rate sampling at detecting these species when their numbers are low.

In order to complement data gathered from line transect and recces surveys, we recommend that ZSL/MINFOF standard-camera trap surveys be deployed on permanently established grids in each sector at least once every two years, during the same season for each grid, wherever possible. The grids should encompass primarily core habitat, that is, they should not be too close to the reserve boundary. Each sector should also have 10 permanently running cameras placed in favourable sites in the core habitat (for example, bais [natural clearings], waterholes, and game trails to track presence or absence of vulnerable species (for example, forest elephant, great apes, giant pangolin, bongo) over time. A standard camera-trap survey methodology is recommended. The 2017 estimated start-up costs for a standard survey is roughly $7,780. Each subsequent camera-trap grid deployment and analysis is roughly $9,430.

Camera-Trap Survey for Larger Terrestrial Wildlife in the Dja Biosphere Reserve, Cameroon

The Dja Biosphere Reserve (DBR) is one of the largest tracts of contiguous rainforest in Africa (Djuikouo et al. 2010), as 90% of the habitat is still considered undisturbed (UNESCO 2011). The DBR is also recognized as a World Heritage Site for this reason, as well as its exceptional biota. The reserve has high levels of both floristic and faunal diversity containing 109 species of mammal and is recognised as one of the 15 critical zones for the conservation of African biodiversity by the IUCN (UNESCO 2011). Resident wildlife include rare and endangered species, such as Western lowland gorilla (*Gorilla gorilla gorilla* – IUCN status: Critically Endangered), central chimpanzee (*Pan troglodytes troglodytes* – IUCN status: Endangered) and African forest elephant (*Loxodonta africana* – IUCN status: Vulnerable). However, due to the dense vegetation within the forest, previous surveys to estimate abundance and presence of these mammals have often been limited to using animal sign, such as dung, footprints, and nests (Latour 2010, UNESCO 2011, MINFOF & IUCN 2015). This report summarises camera-trap results from the first systematic camera-trap survey conducted in the Northern Sector of the Dja Biosphere Reserve (DBR). Camera-trapping is a particularly suitable technique for longer-term monitoring of medium-sized to large mammals in forest habitats (Silveira et al. 2003, Gompper et al. 2006, Lyra-Jorge et al. 2008, Walker 2010, Roberts 2011, Rovero et al. 2014, Amin et al. 2015, Nakashima 2015).

The survey has several objectives:

1) **A Baseline for Megafauna** – To establish baseline data on the diversity, status, distribution and behaviour of medium-to-large terrestrial mammals within the Northern Sector of the Dja Biosphere Reserve (DBR).
2) **Contribution of Camera-Trap Data** – To better understand how data from camera-trap surveys can be used to complement and confirm that derived from distance sampling of line transect and recce encounter rate surveys (Buckland et al. 2001, 2004, MINFOF & IUCN 2015) and patrol-based direct encounter or sign data (ZSL & MINFOF 2016).
3) **Estimate the Intactness of the DBR Megafauna** – To provide data that can be used, along with other information, to more accurately estimate the intactness (that is, the status) of the larger terrestrial vertebrate fauna in the DBR as of early 2016, and help monitor this Outstanding Universal Value of concern for the DBR's UNESCO World Heritage Site status (http://whc.unesco.org/en/list/407/).
4) **Identify Refugia Areas** – To better understand if camera-trap surveys can be used by protected areas managers to identify areas within the DBR that act as spatial refugia for wildlife or deserve increased conservation action.
5) **Assess Cost-Effectiveness of Camera Surv**eys – To assess the cost-effectiveness of systematic camera-trap surveys for wildlife monitoring in the DBR, particularly in terms of overall cost, time and staff requirements, and approaches that are useful to sensitize local communities and reduce camera-trap loss and failure.

METHODS

Survey Location

The Dja Faunal Reserve was established in 1950 and was reclassified as a Biosphere Reserve in 1981 and further upgraded to a World Heritage Site in 1987 (Muchaal & Ngandjui 1999). The reserve is located 243 km southeast of the capital Yaoundé in southern Cameroon (Fig. 1). It covers an area of approximately 5,260 km^2, extending between latitudes 2˚49'-3˚23'N and longitudes 12˚25-13˚35'E (UNESCO 2011). Approximately 80% of the reserve is surrounded by the Dja River. This provides a

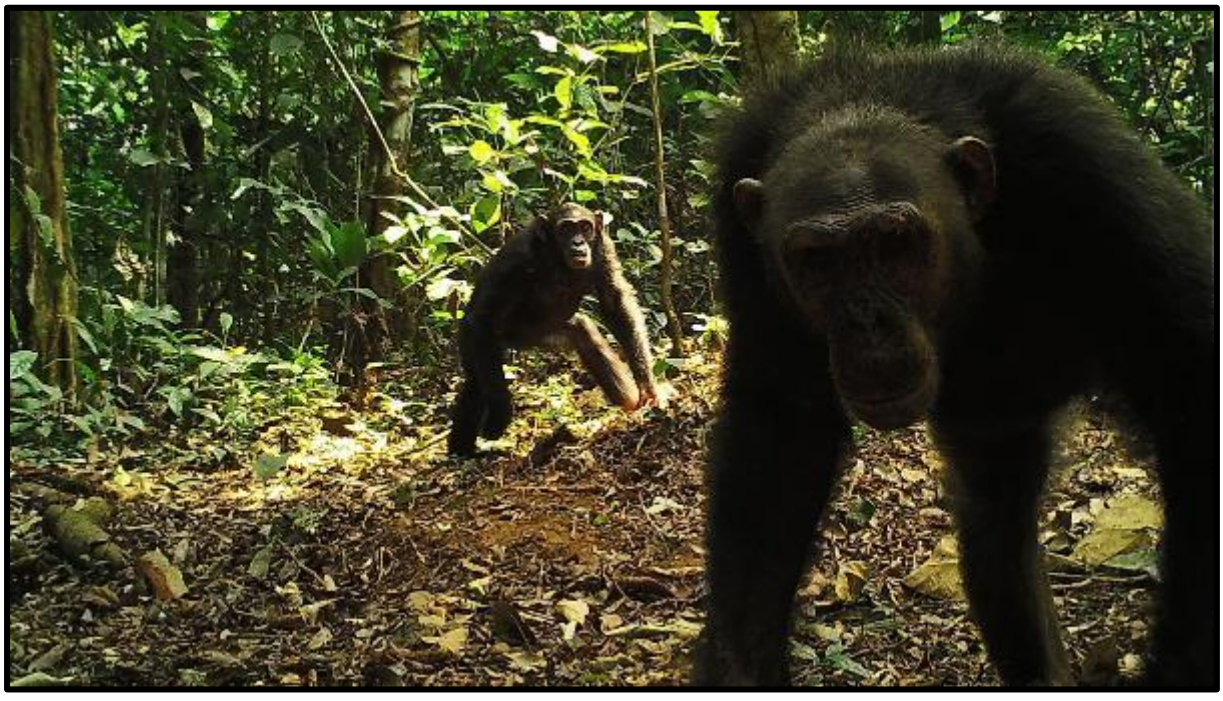
natural barrier and some limited protection to the reserve (Nguiffo 2001), though crossing in canoes is common. The density of human populations around the reserve is low, estimated in 2001 at 1.5 people per km^2, with many small villages surrounding the reserve (Nguiffo 2001). The settlement and transport corridors to the south and east of the reserve are rapidly clearing natural forest.

The reserve is a relatively flat plateau of round-topped hills (UNESCO 2011) and ranges in altitude from 600-800 masl (MINFOF & IUCN 2015). The topography is mainly shallow valleys on either side of a ridgeline that cuts through the reserve east to west (MINFOF & IUCN 2015). In the floors of the valleys swamp habitat becomes more common and tributaries throughout the reserve flow into the Dja River (UNESCO 2011, MINFOF & IUCN 2015). The three major types of forest in the reserve are mixed species forest, monodominant forest where *Gilbertiodendron dewevrei* is the most abundant species, and periodically flooded forest (Djuikouo et al. 2010).

There are four main seasons: the long rains (August-November), the dry season (November-March), the small rains (March-May) and a shorter dry season (June-July) (MINFOF & IUCN 2015). During the dry season there is on average <100 mm of rainfall and a mean annual rainfall of approximately 1,570 mm (UNESCO 2011). The mean annual temperature is 23.5˚C–24.5˚C (Sonké 1998). The maximum temperature is reached in February and the minimum in July (MINFOF & IUCN 2015).

Within and around the reserve, large-scale poaching both for subsistence, commercial and illegal wildlife trade is widespread. Around the reserve significant threats include mining, logging, agricultural clearance, and the construction of hydroelectric dams (Muchaal & Ngandjui 1995, 1999, MINFOF & IUCN 2015).

The Ministry of Forests and Fauna (MINFOF) is responsible for the management of the reserve. To ensure that the reserve receives adequate protection it has been split into four sectors with a base responsible for each sector in the nearest town; Lomié (East Sector), Djoum (South Sector), Meyomessala (West Sector) and Somalomo (North Sector). The camera-trap study was undertaken in the North Sector of the reserve (Fig. 1).



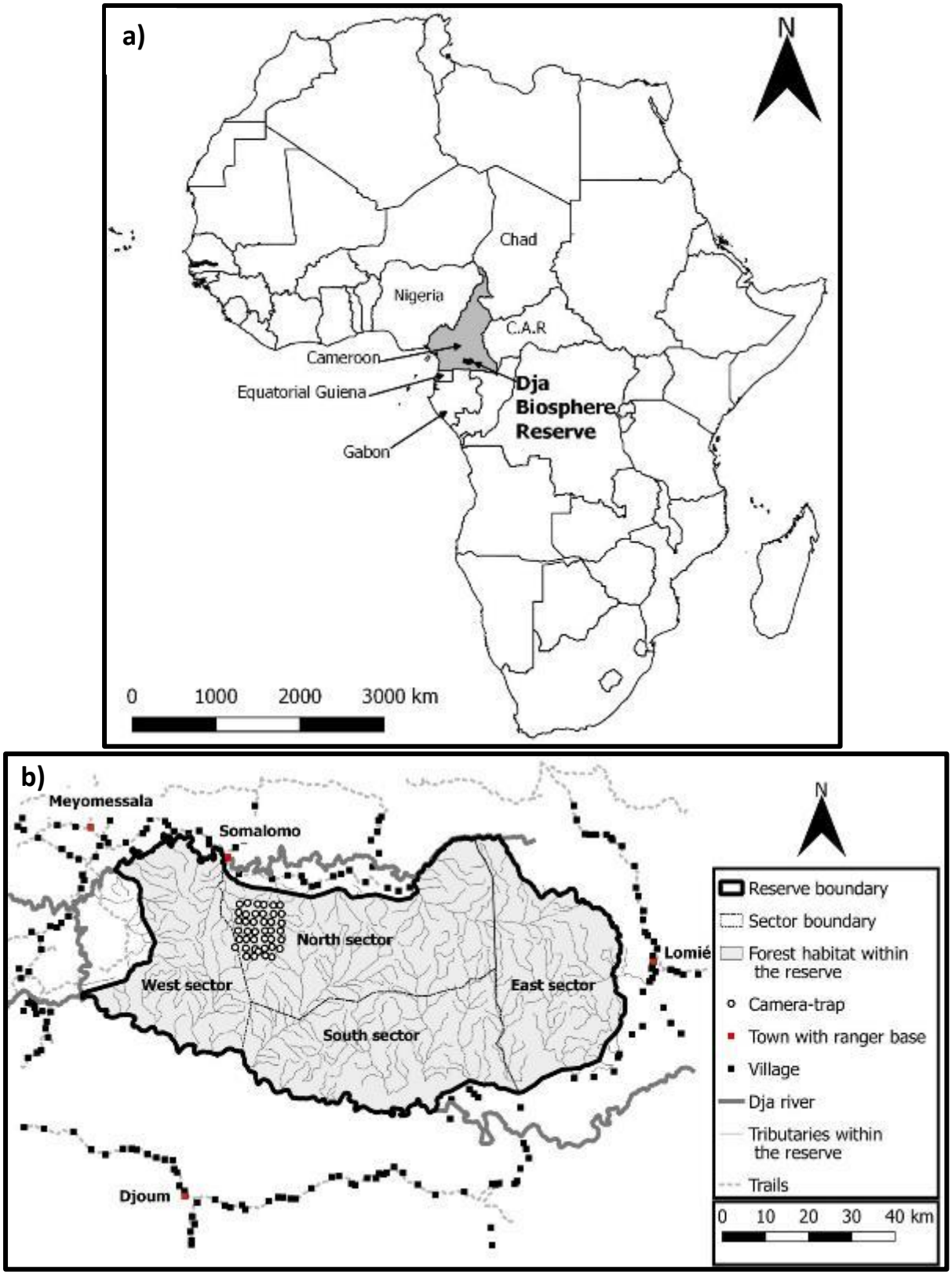


Figure 1. Map of (a) the study area in southeast Cameroon and (b) map of the camera-trap grids relative to protected area boundaries, rivers and sector divisions. Major towns with a ranger base around the reserve are labelled (b).

Survey design and camera deployment

The camera-trap survey design within the North Sector of the Dja Biosphere Reserve (DBR) consisted of 41 cameras systematically placed at two kilometre intervals in a 6 x 7 grid with 4 at the southern edge. One to two km spacing is normally recommended for mammal community surveys (Amin et al. 2014). A single camera-trap was placed at a height of 30–45 cm positioned perpendicular to game trails and pathways likely to be used by mammals at a distance of c. 4-8 m to maximize detection probability and with the aim of obtaining full body lateral images.

Thirty-nine Bushnell aggressor (Bushnell Outdoor Products, Cody, Kansas, USA) and two Reconyx HC500 (RECONYX Inc., Holman, Wisconsin, USA) digital cameras were used. The cameras took three pictures per trigger with a two second delay (Bushnell) and one second delay (Reconyx). All other default settings were used. The cameras have a trigger time of 0.2 seconds and a detection range of 25+ m for larger mammals (Bushnell & Reconyx). The cameras used an infrared flash, which minimised the risk of startling animals as would be the case with white flash. Due to an issue with the firmware of the Bushnell Aggressors, images taken at dawn and dusk would frequently be over- or underexposed, this was a known fault recognised by the manufacturer and has subsequently been resolved. The intent was to leave each camera in the field for 100 trap nights, to ensure a minimum of 1000 trap nights was achieved as recommended by O'Brien et al. (2003) to give a satisfactory level of detectability for a good proportion of the fauna.

The survey was carried out during the dry season and the small rainy season (November 2015 – May 2016). The camera installation protocol required each camera to be triggered by a field technician holding a white board with location ID, date and time upon activation and deactivation to verify camera function.

In summary, ZSL recommends the following camera-trap survey protocol for Congo Basin forests as a method suitable for accurately assessing occupancy of species and relative intactness of the larger terrestrial vertebrate fauna:

- 40 cameras in a 6 x 7 grid with inter-camera spacing of 2 km
- Cameras placed at a height of 30-45 cm on a tree to ensure smaller fauna are detected (lower portions of larger species are relatively easy to identify to species
- Ensure the horizon is in the upper half of the image
- The minimum distance for clearing of vegetation in front of camera is 4 m, the aim being to make sure that a small animal, such as a cat, would be visible 2 m in front of the camera
- Check that movement of existing plants in front of the camera will not cause false triggers
- Do not face towards rising or setting sun, where possible
- Face cameras perpendicular to game trails, where possible
- Ensure the camera is not pointing too far upwards to have debris or water block camera lens or IR trigger
- Cameras are set to take three pictures per trigger with a one to two second delay, a 0.2 trigger delay, and a minimum detection range of 25 m
- Infrared flash is used for night images (note, black flash cameras that do not have an initial red light showing produce inferior images)
- Cameras are chained to trees with chain and locks painted black
- A minimum of 16 GB memory card are used
- Non-rechargeable batteries are best, lithium are particularly good, note that locally-sourced off- market batteries often fail
- Each camera is left out for 100 trap days at a minimum
- Camera trap surveys are done in the dry and wet season, if possible

- Camera trap surveys conducted over years as part of monitoring program should always use the same protocol and should strive to be done at the same time of year.

Data analysis

Data analysis was carried out using software developed at ZSL specifically to process data from camera-trap arrays (Amin et al. 2016). This requires creation of five standard format data source files in Microsoft Excel comprising: (1) individual camera locations and information on associated fixed habitat variables; (2) individual camera settings and field configurations; (3) individual camera setup, service and recovery history; (4) image details for every photograph from each camera; and (5) optional sheet recording numeric and or text covariates for each camera location. In order to create file (4) above, image metadata (image filename, date, time) were extracted automatically from folders of the original jpg image files using Exiv2 software (Huggel 2012; http://www.exiv2.org/index.html) and compiled into the standard Excel format. Image date and time information were cross-checked against setup, service and recovery field records. Details of each image content indicating image type (wildlife, livestock or preselected categories of 'other') and species identified (with information on number, age, sex and animal behaviour where appropriate) were then added (Amin et al. 2016).

The number of animals recorded within a group was established by counting the number of individuals seen during one photographic event (see below). It is worth nothing that camera-traps are not reliable for ensuring that entire groups of animals are captured.

Species trapping rates were calculated as the mean number of independent photographic 'events' per trap day x 100, only using cameras that operated for more than 75% of the survey time period. An 'event' was defined as any sequence of images for a given species occurring after an interval of $\geq$60 min from the end of the previous three-image sequence of that species (Tobler et al. 2008). Standard errors were also calculated from the standard deviation of the daily trapping rate. Trapping rate provides a simple index of relative abundance (RAI) with the assumption that a target species will trigger cameras in relation to their density, all other factors being equal. If a standardized protocol is used for the surveys, including consistent positioning and management of cameras to ensure detection probabilities are similar, then trapping rates provide a comparative index within species, but are not generally suitable for comparisons between species.

Single-season occupancy analysis (MacKenzie et al. 2006) was used to estimate the proportion of area occupied by a species, within each of the survey grids. Occupancy is defined as the probability that a patch (that is, the camera-trap location) is occupied by a target species corrected by the probability of detecting the species. Occupancy information can help protected area managers better understand what kind of habitat or threat conditions are more or less suitable to for a given species. Occupancy estimates were corrected by detection probability (that is, the likelihood that a species was detected when present) and are, therefore, a more rigorous index of abundance for both within and between species comparisons. This, however, is limited to surveys generating adequate data sets and where camera spacing is greater than the species home range, so occupancy is not confounded by changes in the home range (Efford 2012). Therefore, for wide-ranging species who violate this assumption (African elephant, western lowland gorilla, central chimpanzee, and African buffalo), modelled occupancy cannot be used as an index of abundance and is not reported. Naïve occupancy can be regarded as the proportion of the area within the camera-trap grid that these species are using.

Detection\non-detection histories were constructed using an eight-day period as the sampling occasion, for each species and camera per survey grid. An occasion was excluded from analysis if the camera was not functional for at least 80% of each occasion. Cameras were excluded from

occupancy analysis if they were non-functional for 80% or more of the occasions. Based on this criterion 11 cameras were removed from analysis, which meant occupancy analysis was carried out on 30 cameras.

Occupancy analysis incorporating covariates was conducted to establish whether distance to the boundary or nearest mapped water source, had a significant effect on the probability of a site being occupied by a species. Models were selected using Akaike information criterion (AIC). The null model is a single season analysis without any covariates shown for each species in the table headed 'Trapping rates, occupancy and detectability'. When the AIC value of either or both covariates was lower than the null model, the adequacy of the covariate models fit were tested using a Chi squared test following 5000 simulations of a parametric bootstrap. The model was considered an adequate fit if the null hypothesis is accepted (p=>0.1). Over-dispersed models have significantly different observed residual variance from the expected residual variance. Therefore, the null hypothesis needs to be accepted for the model be considered a good fit. Finally, a model had to have non-overlapping standard errors to be considered significant.

Mammal species richness Jackknife estimates were calculated for species $\geq$0.5 kg in average adult body weight in order to minimize variation in capture probability associated with body size (smaller animals are less likely to consistently trigger cameras [Tobler et al. 2008]). Circadian (24 hour) species activity patterns were constructed by tallying the number of events per hour across each survey time period. We used the species trapping rate at each camera site to generate simple distribution maps across the camera-trap grid.

RESULTS

Camera-trap survey effort

- Total number of camera sampling sites: 41 (eight cameras failed totally and six cameras failed partially during the survey, which were operational for one, 17, 21, 56, 89 and 105 days, respectively)
- Total number of days deployed: 5,185 (3,725 operational)
- Total number of wildlife events: 7,109

Mammal Diversity

A total of 32 mammal species were detected in the North Sector in the Dja Biosphere Reserve (Table 1). This includes Western lowland gorilla ('Critically Endangered' species under IUCN Red List criteria). The 'Endangered' central chimpanzee. African elephant, mandrill (*Mandrillus sphinx* – the first record of this large species in the reserve) white-bellied pangolin (*Phataginus tricuspis*) and giant pangolin (*Smutsia gigantea*) all classified as 'Vulnerable' were also recorded.

Long-nosed mongoose (*Herpestes naso*) and marsh mongoose (*Atilax plaudinosis*) are closely related, sympatric, and very difficult to tell apart (Bahaa-el-din et al. 2013 & Ray 1997). The best distinguishing feature to identify the marsh mongoose from camera-trap images is the flat blunt head, compared to the long muzzle and prominent nose of the long-nosed mongoose (Bahaa-el-din et al. 2013). In this study, there were a total of 620 events containing either long-nosed mongoose or marsh mongoose. Of these 365/620 were most probably long-nosed mongoose and 96/620 were most probably marsh mongoose including examples of unmistakeable images of each species, leaving 159 completely unidentified. Because of uncertainty in a relatively high proportion of images these two mongoose species were analysed together at the family level (Herpestidae sp.) (Note: in the poorest images there may be confusion with cusimanse, as well).

Servaline genet (*Genetta servalina*) and crested genet (*Genetta cristata*) are thought to be sympatric

and hybridize in Cameroon (Van Rompaey & Colay 2013, Gaubert et al. 2006). The distribution of crested genet in Cameroon is unknown and contentious, but as both species are morphologically similar and cannot be easily separated on camera-trap images (Bahaa-el-din et al. 2013) all images of genet were treated as servaline genet. Therefore, some of the images classified and presented in the report as servaline genet could be crested genet.

The difference between duiker species can often rely on subtle differences in markings particularly for the 'red duiker' species. Therefore, when duiker are only partially visible in images or markings are obscured by the infra-red flash, positive identification of the species can be impossible. During this study 47,089 images of duiker species were captured only 4.4% of these images were classified as Duiker sp. (that is, not identified to species level).

It was often difficult to identify Bate's pygmy antelope (*Neotragus batesi). C*ameras producing under exposed images (a known fault with the first issue of this model, since corrected with a software patch), combined with the morphological similarities with blue duiker (*Philontomba monticola)* requiring clear imagery to enable positive identification. The presence of long thin legs with a high stepping gait (Feer 2013), a hunched forward-sloping large body and the indication of a white throat were used to identify Bate's pygmy antelope. Confusion with blue duiker could mean that trapping rates and occupancy of Bate's pygmy antelope is underrepresented in this report.

Only one murid rodent species was distinctive and large enough to be reliably identified in the camera-trap images—Emin's pouched rat (*Cricetomys emini).* All other murid and shrew species <0.5 kg were classified at a family level only. All squirrel species were classified at a family level (Sciuridae sp.) as this camera-trap survey was not designed to detect small mammals (<0.5 kg) that are predominantly arboreal. Squirrel identification was further complicated by key features, such as tail bars and stripes on the body being obstructed in infrared imagery.

Medium-to-large mammal species (≥0.5 kg) expected in the study area according to available distribution maps and literature which were not detected by the camera-trapping survey are listed in Table 2.

Table 1. Mammal species recorded by ZSL/MINFOF camera-trapping in the North Sector of the Dja Biosphere Reserve, Cameroon (2015-2016).

Family or Subfamily	Scientific Name	Local Name	IUCN Status	Habitat	Trophic Level	Avg. Adult Weight (kg)
Bovidae	*Syncerus caffer*	African buffalo	LC	Forest	Herbivore	590
Bovidae-Antilopinae	*Neotragus batesi*	Bates' Pygmy Antelope	LC	Forest	Herbivore	2.5
Bovidae-Cephalophinae	*Cephalophus callipygus*	Peters' Duiker	LC	Forest	Herbivore	20.5
Bovidae-Cephalophinae	*Cephalophus dorsalis*	Bay Duiker	NT	Forest	Herbivore	21
Bovidae-Cephalophinae	*Cephalophus nigrifrons*	Black-fronted Duiker	LC	Forest	Herbivore	14
Bovidae-Cephalophinae	*Cephalophus silvicultor*	Yellow-backed Duiker	NT	Forest	Herbivore	69
Bovidae-Cephalophinae	*Philantomba monticola*	Blue Duiker	LC	Forest	Herbivore	4
Bovidae-Tragelaphinae	*Tragelaphus eurycerus*	Bongo	NT	Forest	Herbivore	300
Bovidae-Tragelaphinae	*Tragelaphus spekii*	Sitatunga	LC	Wetland	Herbivore	80
Cercopithecidae	*Cercocebus agilis*	Agile Mangabey	LC	Forest	Frugivore	7
Cercopithecidae	*Cercopithecus cephus*	Moustached Guenon	LC	Forest	Omnivore	3.5
Cercopithecidae	*Cercopithecus nictitans*	Greater Spot-nosed Guenon	LC	Forest	Omnivore	5.5
Cercopithecidae	*Mandrillus sphinx*	Mandrill	VU	Forest	Omnivore	15
Elephantidae	*Loxodonta africana*	African Elephant	VU	Mixed	Herbivore	1000
Galagidae	*Galago sp.*	Galago sp.	N/A	Forest	Omnivore	N/A
Herpestidae	*Bdeogale nigripes*	Black-legged Mongoose	LC	Forest	Carnivore	3.5
Herpestidae	*Crossarchus platycephalus*	Cameroon Cusimanse	LC	Forest	Carnivore	1.1
Herpestidae	*Herpestes naso*	Long-nosed Mongoose	LC	Forest	Omnivore	2.9
Herpestidae	*Atilax plaudinosus*	Marsh Mongoose	LC	Wetland	Carnivore	3.0
Hominidae	*Gorilla gorilla gorilla*	Western Lowland Gorilla	CR	Forest	Herbivore	100
Hominidae	*Pan troglodytes troglodytes*	Central Chimpanzee	EN	Forest	Omnivore	50
Hystricidae	*Atherurus africanus*	African Brush-tailed Porcupine	LC	Forest	Herbivore	3
Manidae	*Phataginus tricuspis*	White-bellied Pangolin	VU	Forest	Insectivore	2.5
Manidae	*Smutsia gigantea*	Giant Pangolin	VU	Forest	Insectivore	32
Nandiniidae	*Nandinia binotata*	African Palm Civet	LC	Forest	Omnivore	3
Nesomyidae	*Cricetomys emini*	Emin's pouched rat	LC	Forest	Omnivore	1.2
Sciuridae	*Sciurid sp.**	Squirrel sp.*	N/A	Woodland	Omnivore	N/A
Suidae	*Potamochoerus porcus*	Red River Hog	LC	Woodland	Omnivore	50
Tragulidae	*Hyemoschus aquaticus*	Water Chevrotain	LC	Forest	Omnivore	11
Viverridae	*Genetta servalina*	Servaline Genet	LC	Forest	Omnivore	2.5

***** This is likely to be five squirrel species four of which are generalist and one is terrestrial, (Thomas's rope squirrel (*Funisciurus anerythrus*), Red-cheeked rope squirrel (*Funisicirus leucogenys*), Ribboned rope squirrel (*Funisciurus lemniscatus*), Fire-footed rope squirrel (*Funisciurus pyrropus*) and Lady Burton's rope squirrel (*Funisciurus Isabella*)), but due to issues with image quality positive identification was not possible.

Table 2. Mammal species expected in the sample zone according to available distribution maps and literature, but not detected by the camera-trapping sample. Eight of sixteen species are arboreal and therefore unlikely to be sampled using terrestrial camera-traps. Spotted hyena (*Crocuta crocuta*) were documented through camera-trap surveys in Nki National Park 90 km to the southeast of the DBR in 2016.

Family or Subfamily	Scientific Name	Local Name	IUCN Status	Habit
Bovidae-Cephalophinae	*Cephalophus leucogaster*	White-bellied Duiker	LC	Terrestrial
Cercopithecidae	*Colobus guereza*	Eastern Black-and-white Colobus	LC	Arboreal
Cercopithecidae	*Colobus satanas*	Black Colobus	VU	Arboreal
Cercopithecidae	*Lophocebus albigena*	Grey-cheeked Mangabey	LC	Arboreal
Cercopithecidae	*Cercopithecus neglectus*	De Brazza's Guenon	LC	Arboreal
Cercopithecidae	*Miopithecus ogouensis*	Northern Talapoin Monkey	LC	Arboreal
Felidae	*Caracal aurata*	African Golden Cat	VU	Terrestrial
Felidae	*Panthera pardus*	Leopard	NT	Terrestrial
Lorisidae	*Perodicticus potto*	Potto	LC	Arboreal
Manidae	*Phataginus tetradactyla*	Black-bellied Pangolin	VU	Arboreal
Procaviidae	*Dendrohyrax dorsalis*	Western Tree Hyrax	LC	Generalist
Suidae	*Hylochoerus meinertzhageni*	Giant Forest Hog	LC	Terrestrial
Tenrecidae	*Potamogale velox*	Giant Otter Shrew	LC	Semi-aquatic
Viverridae	*Genetta maculate*	Large-spotted Genet	LC	Terrestrial
Viverridae	*Poiana richardsonii*	Central African Oyan	LC	Arboreal
Orycteropodidae	*Orycteropus afer*	Aardvark	LC	Terrestrial

Species Accumulation Per Camera Trap Effort

The species accumulation curves for medium-to-large (≥0.5 kg) terrestrial mammal species, the main target group for camera-traps placed at ground level, are shown in Fig. 2. The estimated species richness converged at 148 days. This suggests that most, if not all, medium-to-large (≥0.5 kg) terrestrial mammals species present in the North Sector were detected during the survey.

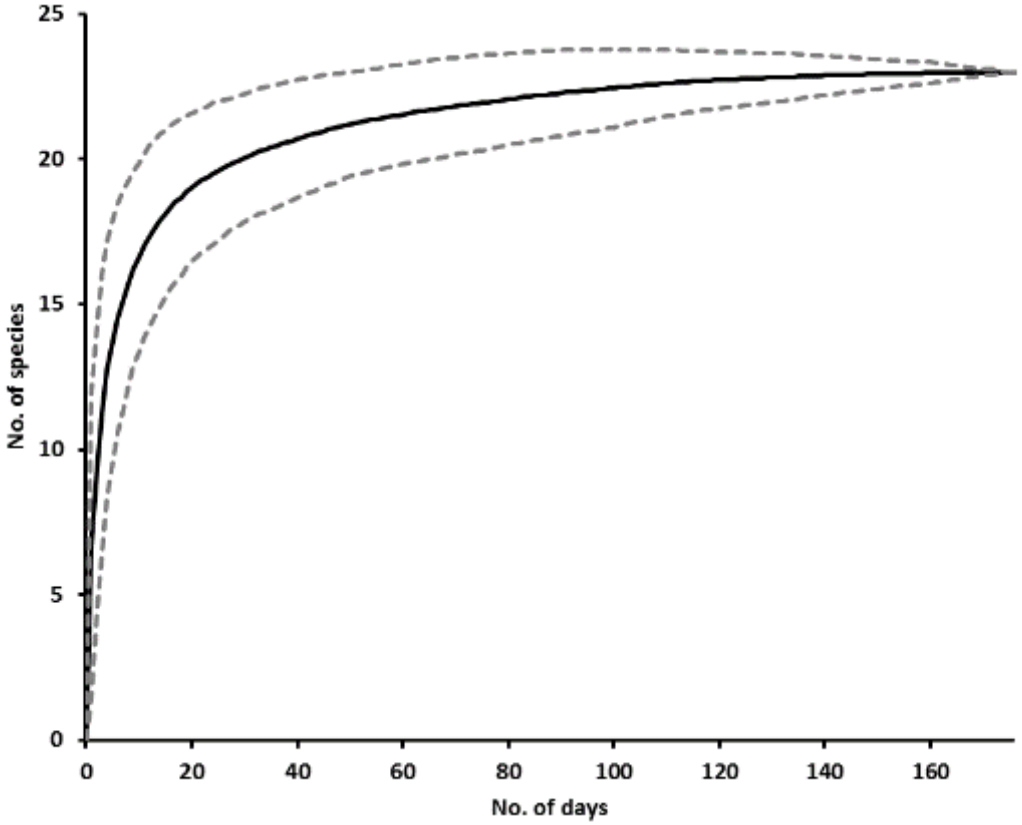


Figure 2. Rarified species accumulation curve for medium-to-large terrestrial mammals in the Northern sector of the Dja Biosphere Reserve (2015-2016). The grey dashed lines represent confidence intervals.

SPECIES ACCOUNTS

1) BLUE DUIKER (*Philantomba monticola)*

- Blue duiker was the most frequently recorded mammal species.
- Camera-trap data indicate blue duiker are active throughout the day, with pronounced peaks at dawn and dusk.
- Blue duiker were photographed twice foraging with Peter's duiker.
- Groups of 3 (all 1.1.1) were seen 26 times at 10 cameras.
- Occupancy did not change with increasing distance from the boundary or from water courses.
- A dark band across the rump was present in most colour image, consistent with the form *P. (m.) congica* (Castello 2016a).

Global conservation status:
Least Concern (IUCN ASG 2016g)

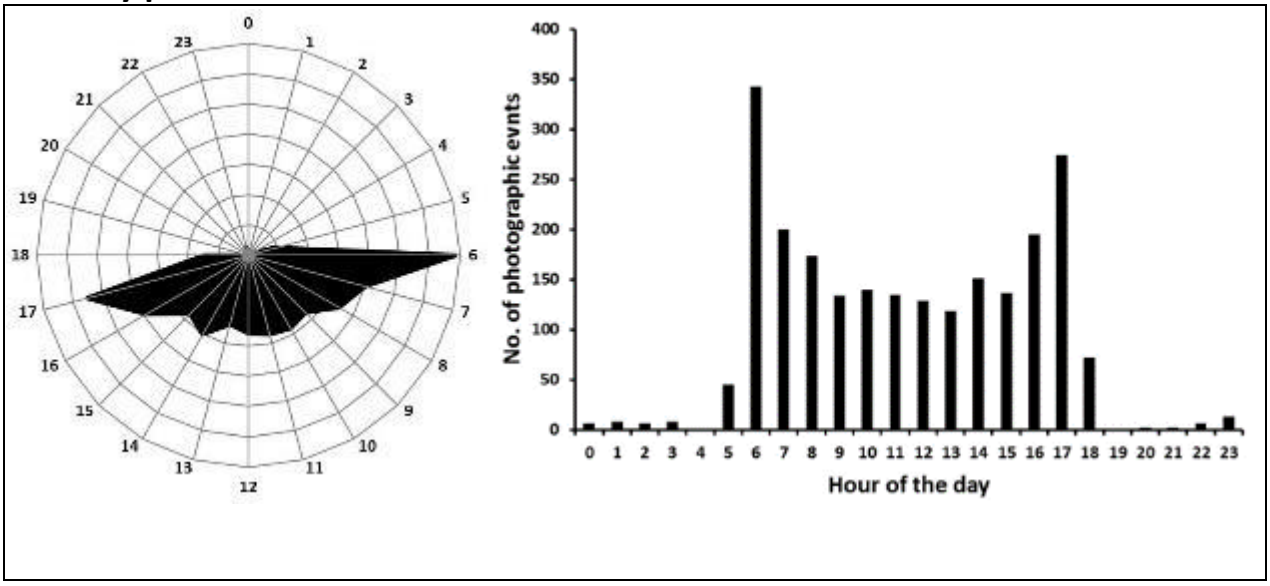
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	30	2,296	30,623

Trapping rates, occupancy and detectability

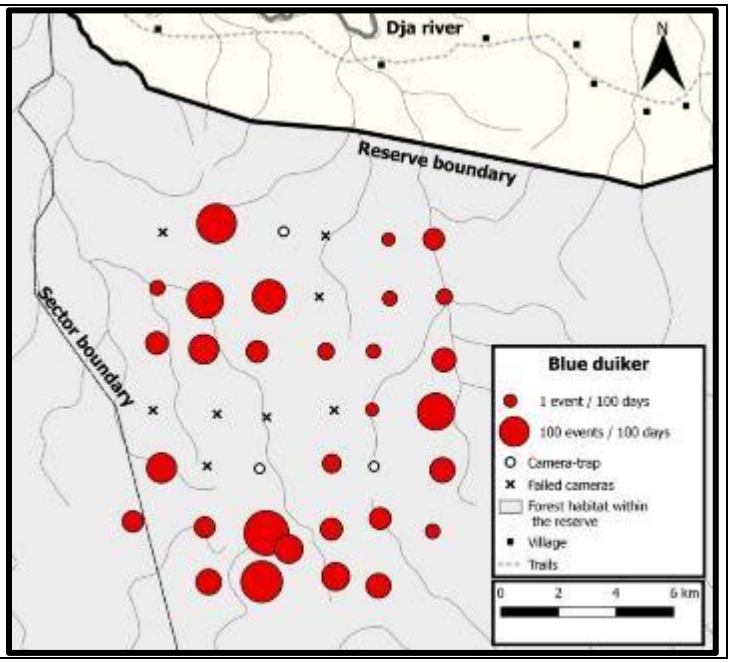
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	62.07 (1.59)	0.97	0.97 (0.03)	0.8 (0.02)

Activity pattern

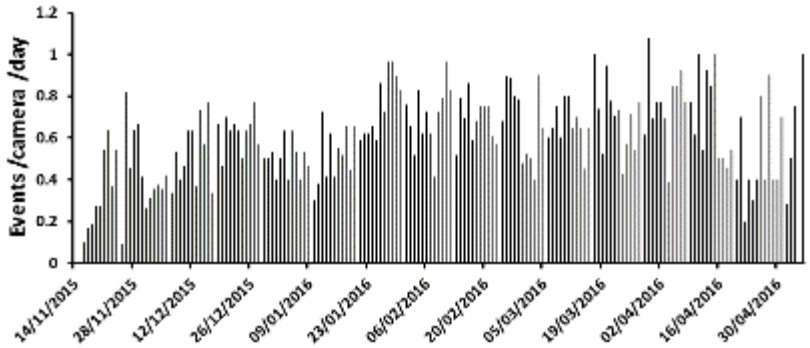


Blue duiker continued

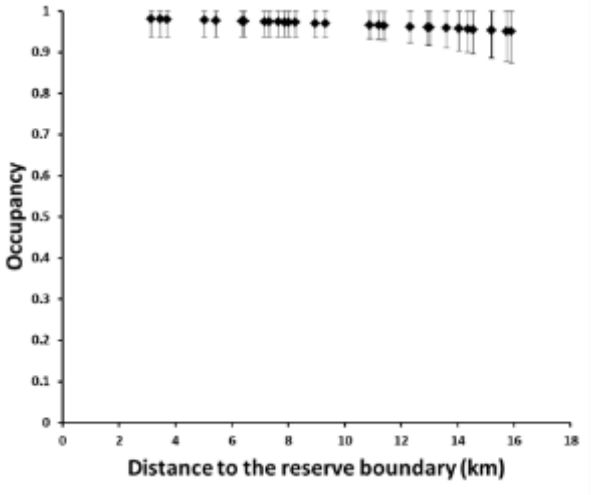
Variation in trapping rate through the camera grid:

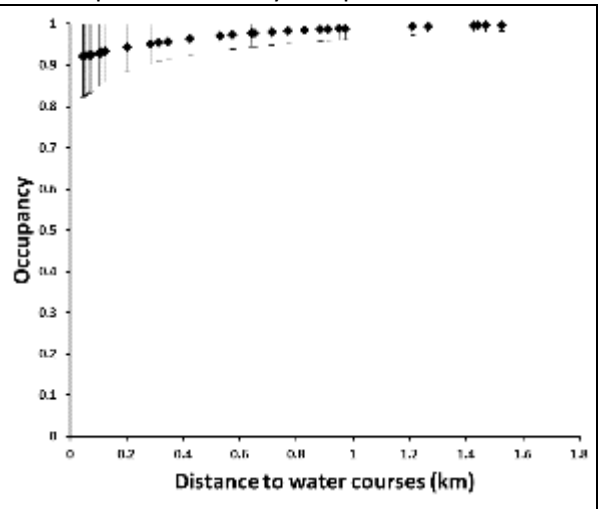


Temporal variation in detections: Blue duiker were detected consistanly during the survey.



Spatial variation in occupancy: Modelling showed no evidence of changing occupancy with distance from boundary or water source; covariates did not improve efficiency compared to null.





2) PETER'S DUIKER *(Cephalophus callipygus)*

- An endemic species to western central Africa.
- Camera-trap events a mainly diurnal, with sporadic nocturnal activity.
- Peter's duiker had significantly higher trapping rates than the other two sympatric larger duikers.
- Fire-crested alethe (*Alethe castanea)* were photographed foraging with Peter's duiker. Other bird species were seen 'riding' Peter's duiker for the first time, though not identified due to image quality.

Global conservation status:
Least Concern (IUCN ASG 2016a)

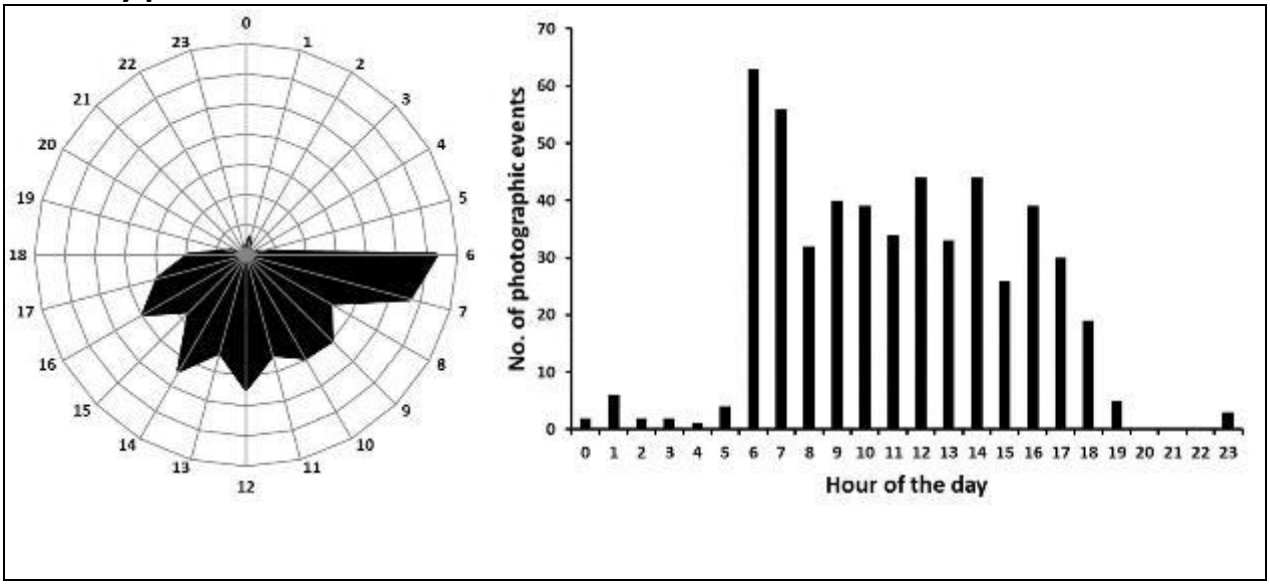
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	30	524	8,469

Trapping rates, occupancy and detectability

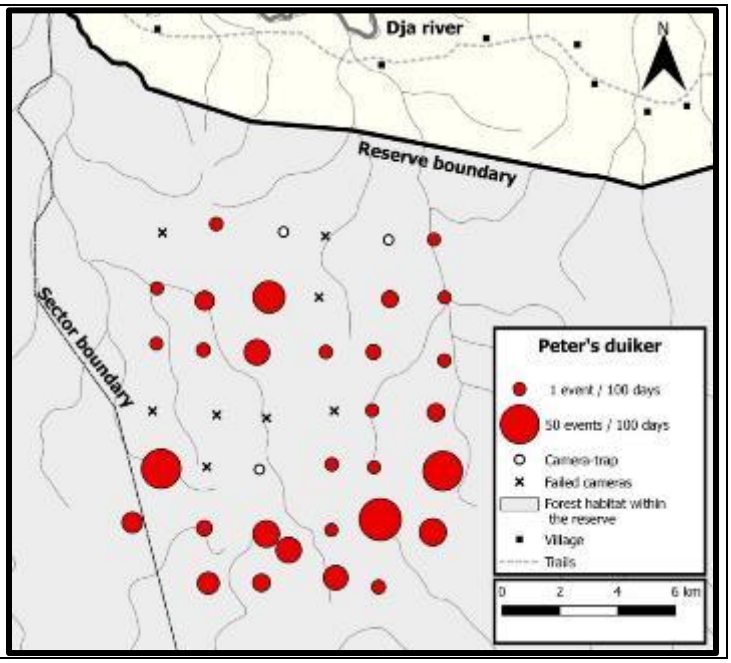
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	13.8 (0.68)	0.93	0.93 (0.05)	0.46 (0.03)

Activity pattern

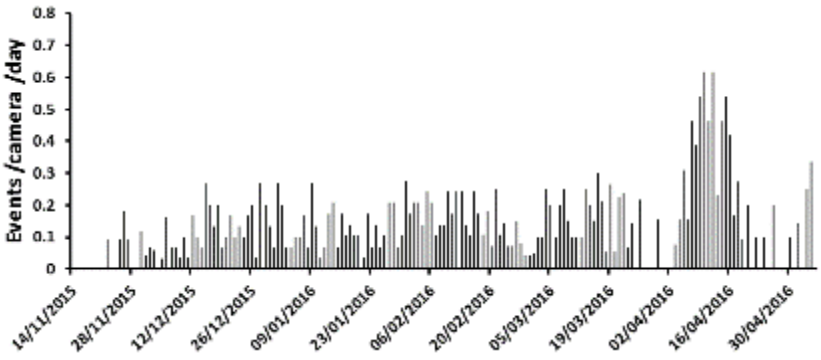


Peter's duiker continued

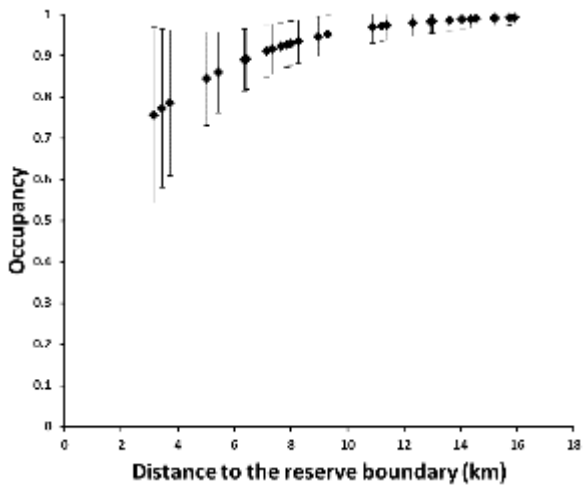
Variation in trapping rate through the camera grid:

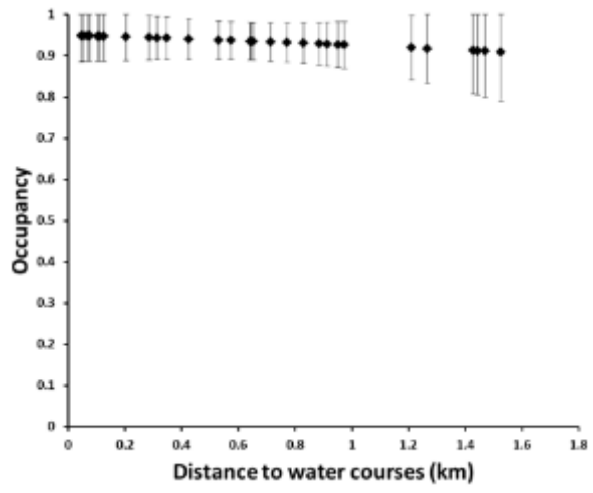


Temporal variation in detections: The cause of the increase of events in April is unkown.



Spatial variation in occupancy: Modelling showed no evidence of occupancy change with distance from boundary or water source; covariates do not improve efficiency relative to null.





3) BAY DUIKER *(Cephalophus dorsalis)*

- Distributed throughout the camera-trap grid with a modelled occupancy of 100%.
- A strictly nocturnal activity pattern was observed, this provides ecological separation from similar sized duikers (Castello 2016b).
- Courtship behaviour observed on 06/12/2015 at 04:43, this included pursuit, persistent following, circling and genital sniffing.
- Significantly lower abundance than Peter's duiker has been recorded in other reserves (Van Vilet 2007).

Global conservation status:
Near Threatened (IUCN ASG 2016b)

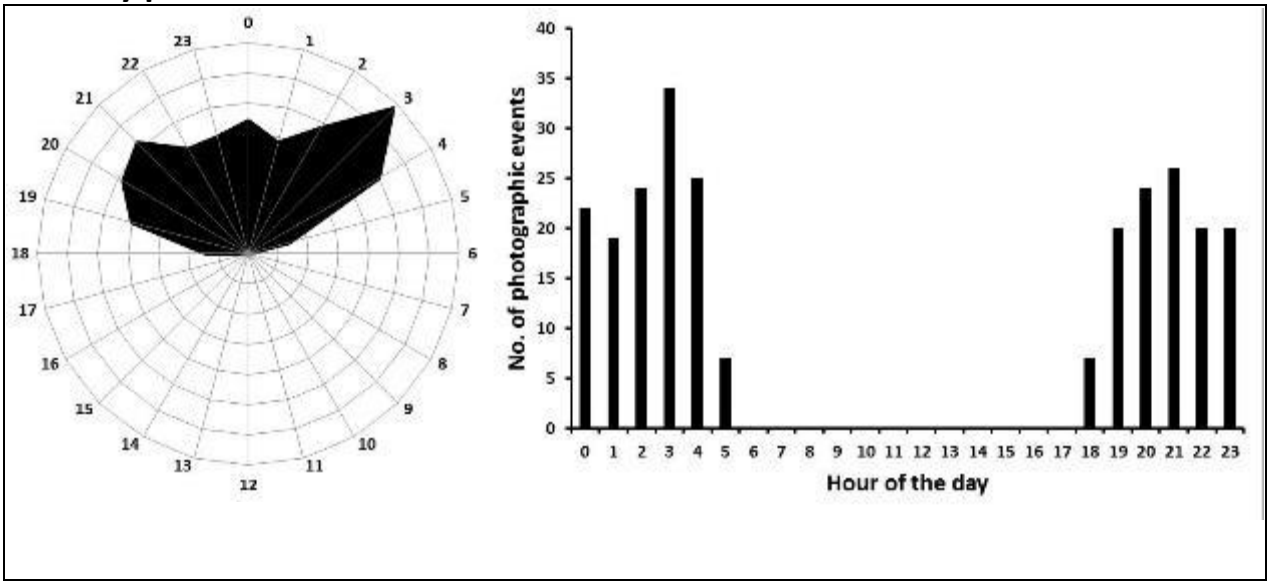
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	31	248	2,909

Trapping rates, occupancy and detectability

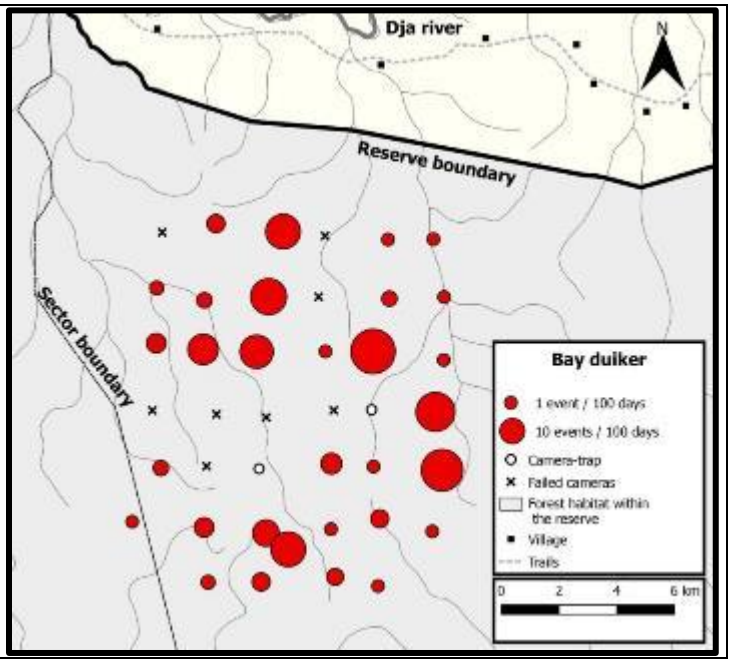
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	6.81 (0.46)	0.97	1 (0.0)	0.32 (0.02)

Activity pattern

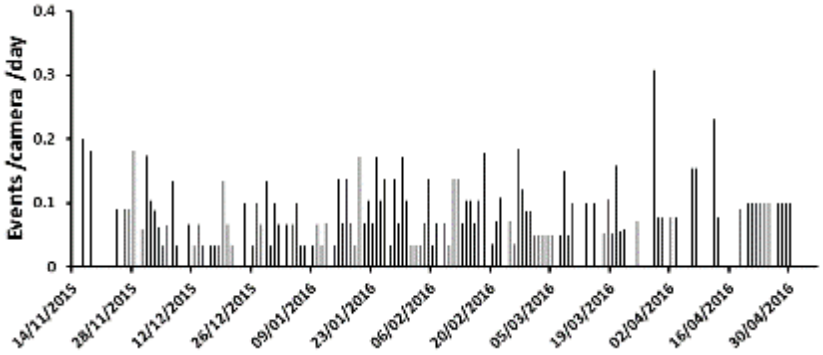


Bay duiker continued

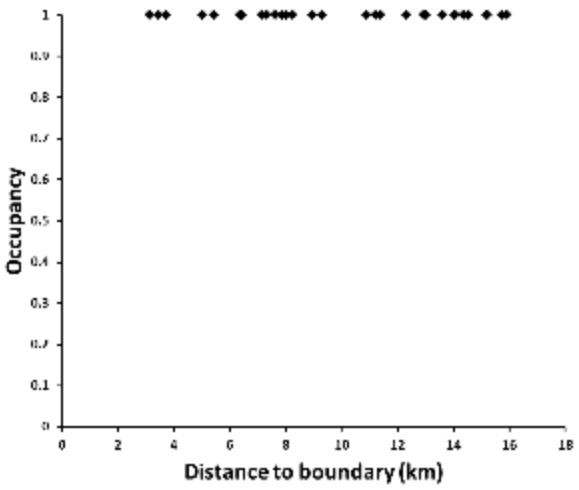
Variation in trapping rate through the camera grid:

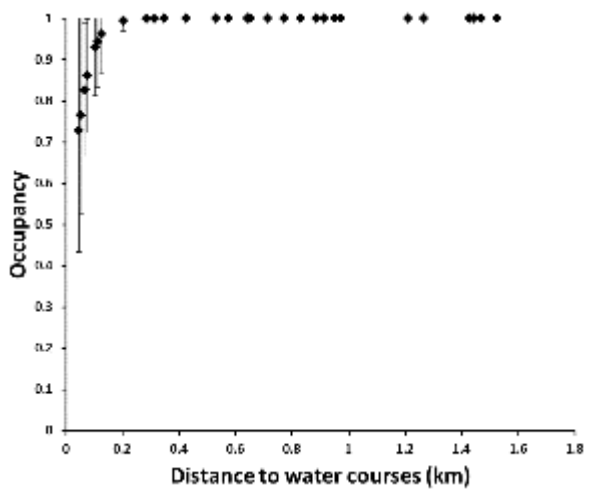


Temporal variation in detections: Bay duiker were detected throughout the survey period.



Spatial variation in occupancy: Modelling showed no evidence of changing occupancy with distance from boundary; distance from water source had overlapping standard error values.





4) YELLOW-BACKED DUIKER *(Cephalophus silvicultor)*

- The least frequently recorded of the three larger sympatric duiker species.
- Solitary apart from two events with two adults foraging together.
- The activity pattern indicates yellow-backed duiker is predominantly crepuscular with peaks of activity at dawn and dusk, but is also sporadically active throughout the 24 hour cycle.
- Increased nocturnal activity has been reported nearer human settlements (Hart 2000), as a possible behavioural response to hunting pressures (Kingdon & Lahm 2013).

Global conservation status:
Near Threatened (IUCN ASG 2016d)

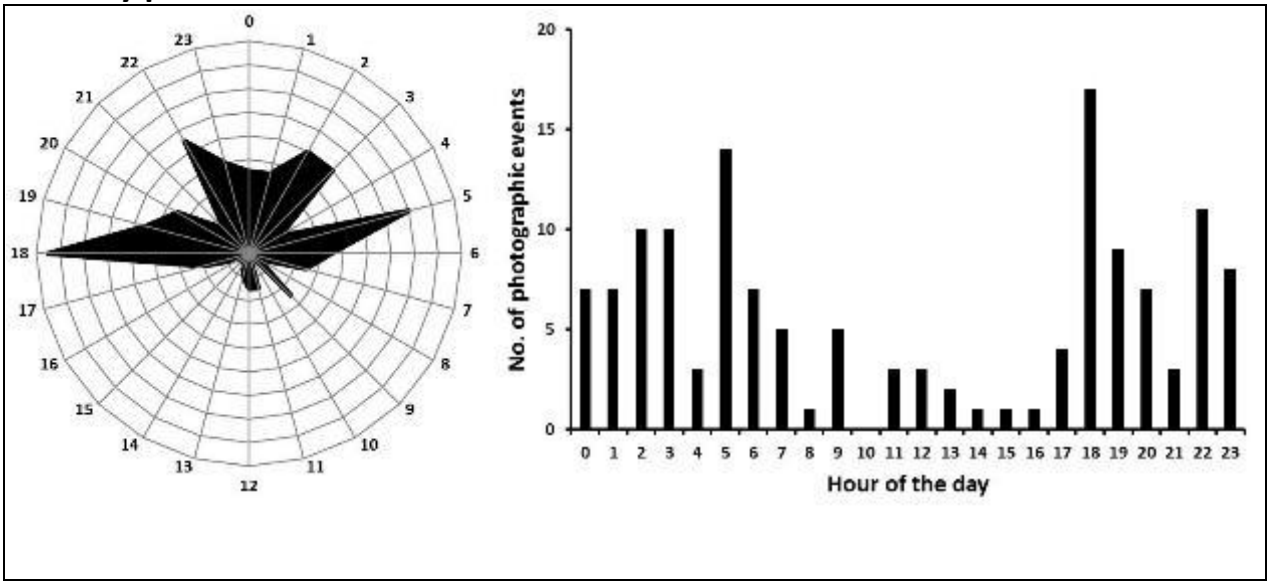
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	28	139	2,097

Trapping rates, occupancy and detectability

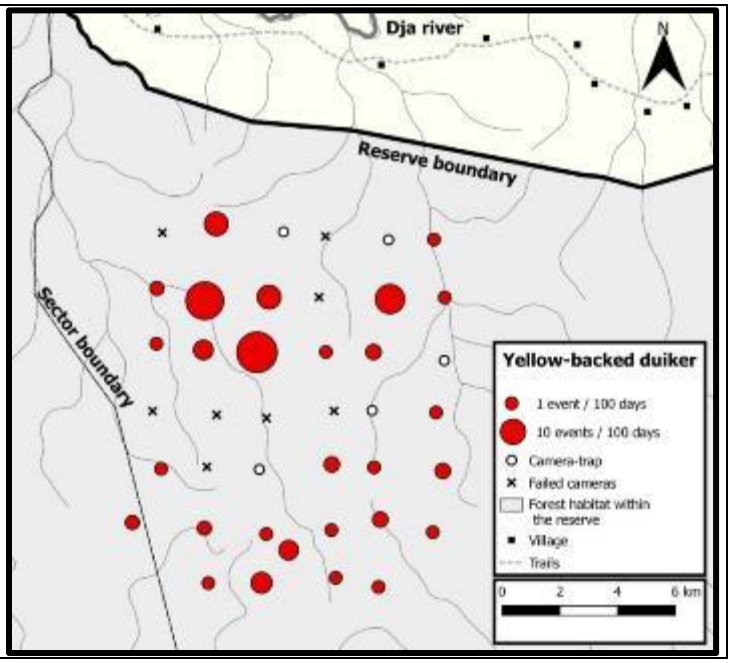
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	3.51 (0.35)	0.9	1 (0)	0.2 (0.02)

Activity pattern

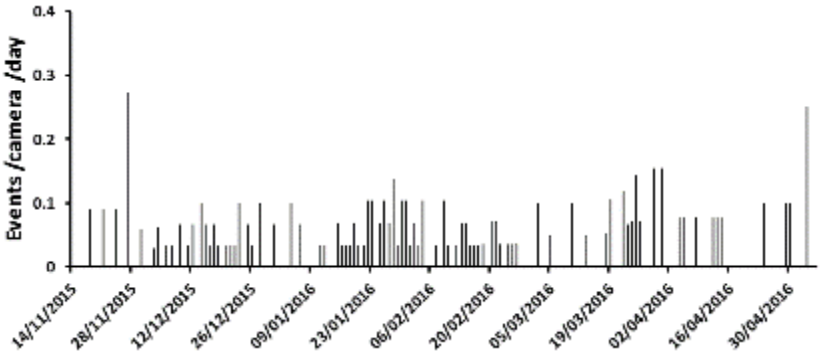


Yellow-backed duiker continued

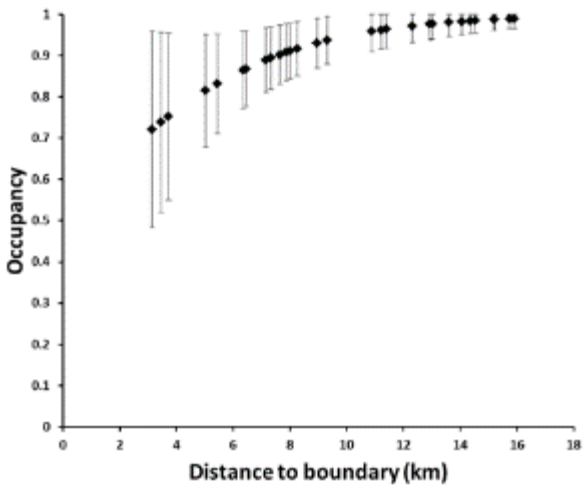
Variation in trapping rate through the camera grid:

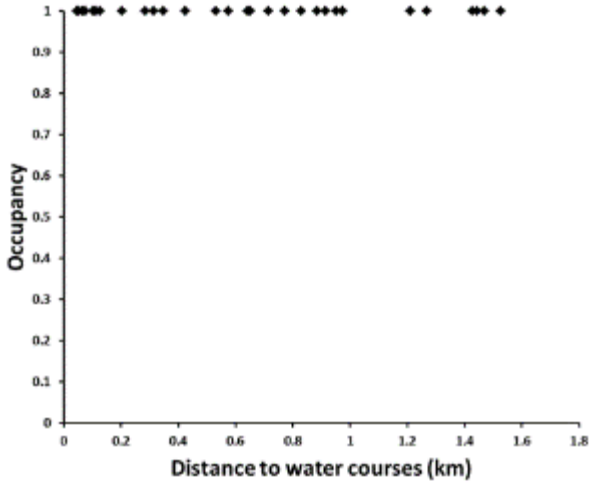


Temporal variation in detections:



Spatial variation in occupancy: Modelling showed no evidence of changing occupancy with distance from water source; distance from boundary had overlapping standard error values.





5) BLACK-FRONTED DUIKER *(Cephalophus nigrifrons)*

- Two of the four cameras detecting black-fronted duiker were located in swamps, the species' preferred habitat.
- The least frequently encountered duiker species, suggesting relatively low abundance in the northern sector.
- Timing of camera-trap events indicate a predominantly diurnal activity pattern peaking at 9am with intermittent nocturnal activity.
- Chestnut pelage and black fore legs to elbow and hind legs up to the hock; present in most colour image, consistent with the form *C. (n.) nigrifrons* (Plumptre 2013).

Global conservation status:
Least Concern (IUCN ASG 2016c)

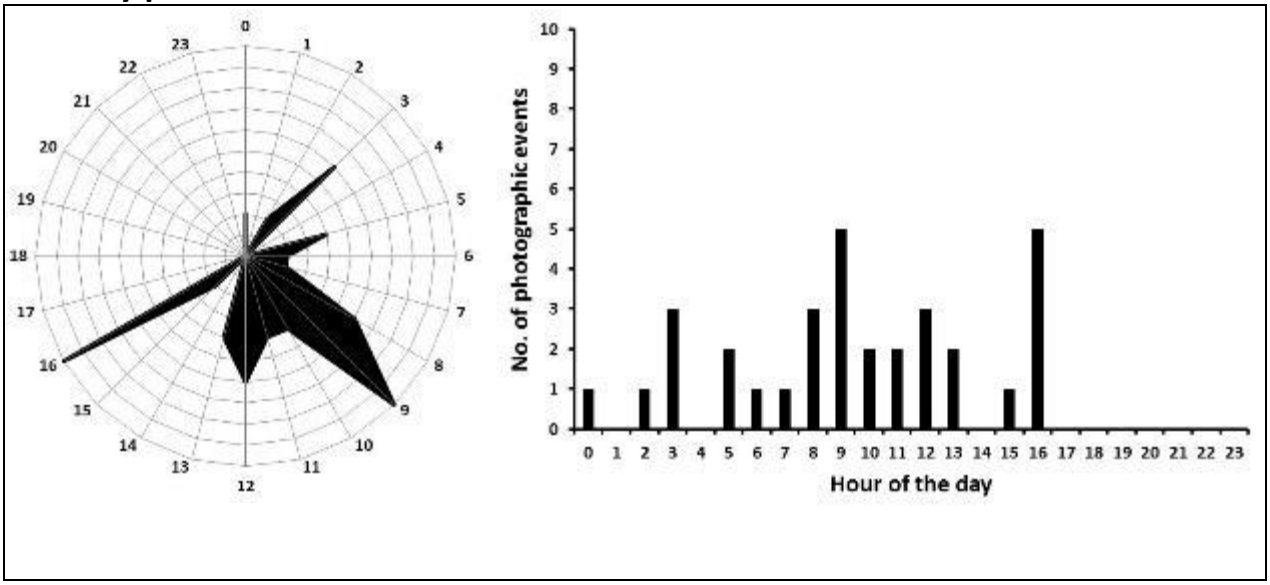
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	4	32	897

Trapping rates, occupancy and detectability

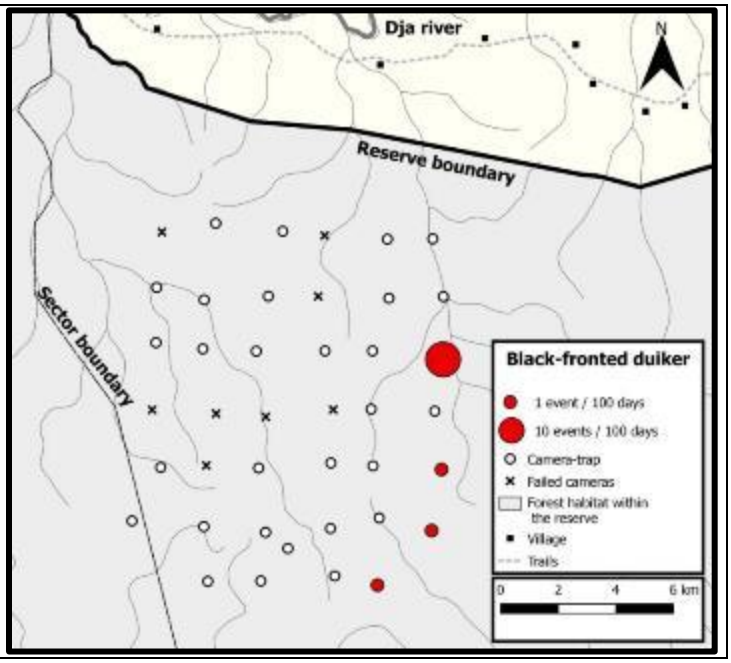
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.96 (0.21)	0.13	0.14 (0.06)	0.26 (0.05)

Activity pattern

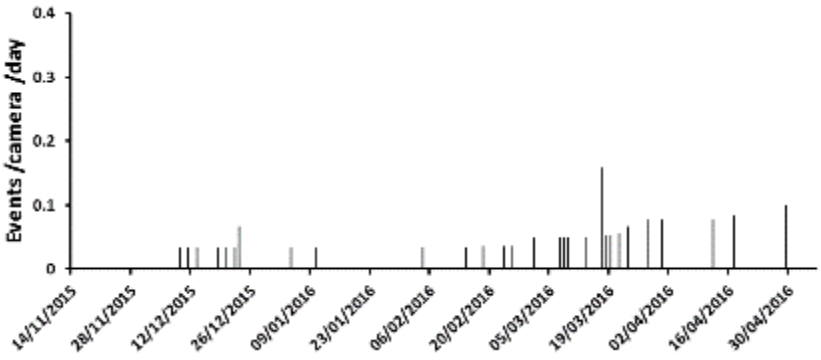


Black-fronted duiker continued

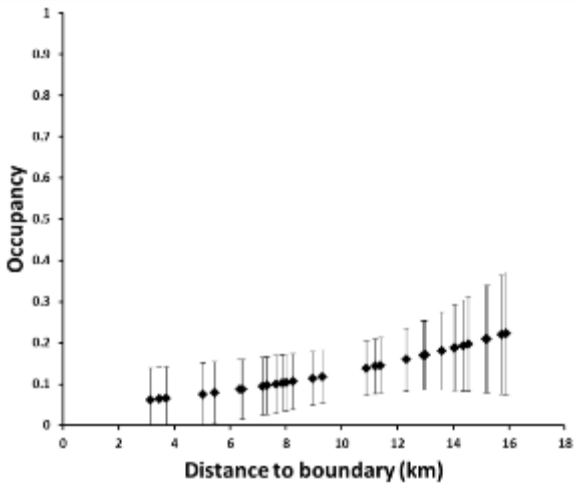
Variation in trapping rate through the camera grid:

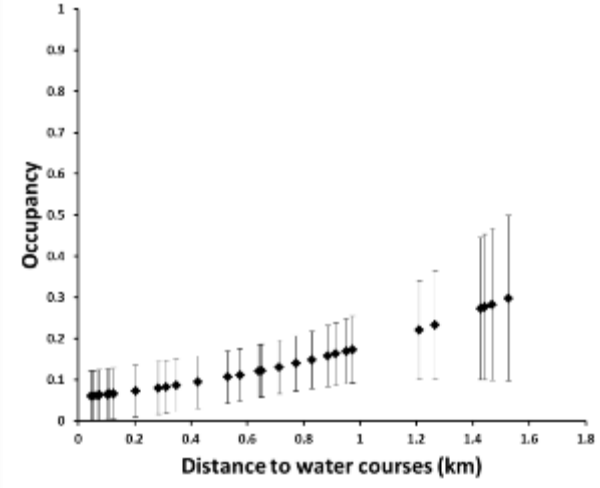


Temporal variation in detections:



Spatial variation in occupancy: Modelling showed no evidence of changing occupancy with distance from boundary or water source; covariates did not improve efficiency compared to null.





6) BATES' PYGMY ANTELOPE (*Neotragus batesi)*

- Identifying Bates's pygmy antelope was complicated because reliable features such as head profile, white throat and markings behind ears can be distorted or invisible under infra-red imagery.
- Timing of camera-trap events indicates a preference for nocturnal activity.
- The variation in trapping rates suggests that pygmy antelope are more frequently encountered further into the reserve.
- Previous studies concluded encounter rates were higher within 14 km of villages close to the boundary (Muchaal & Ngandjui 1999, Feer 2013). This was based on a sample of six records.

Global conservation status:
Least Concern (IUCN ASG 2016f)

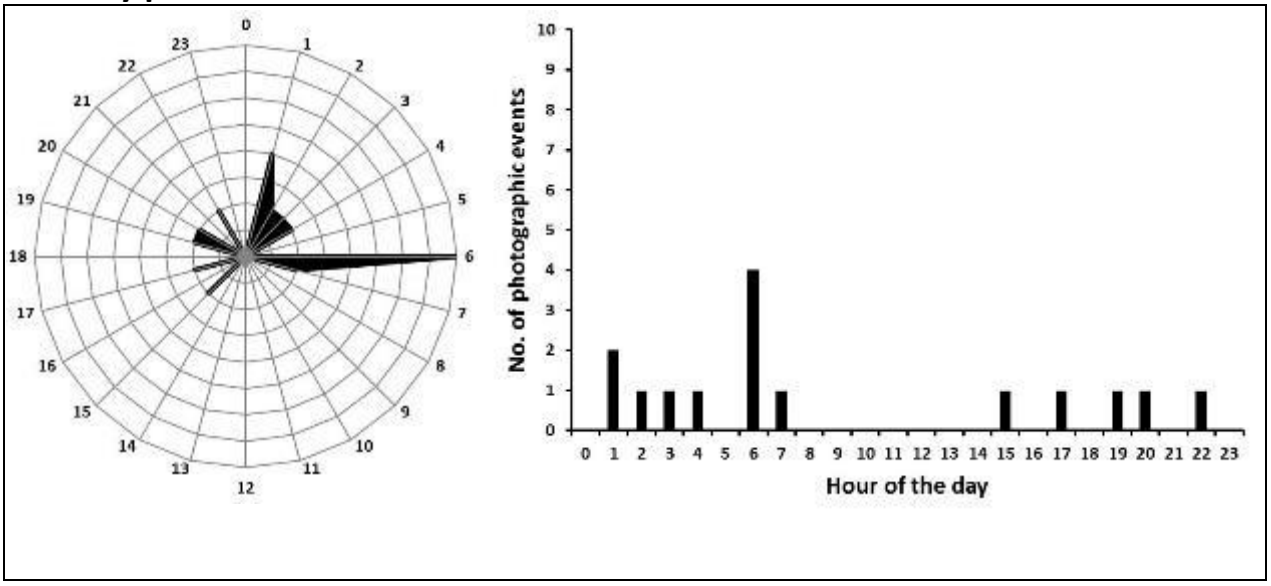
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	6	15	140

Trapping rates, occupancy and detectability

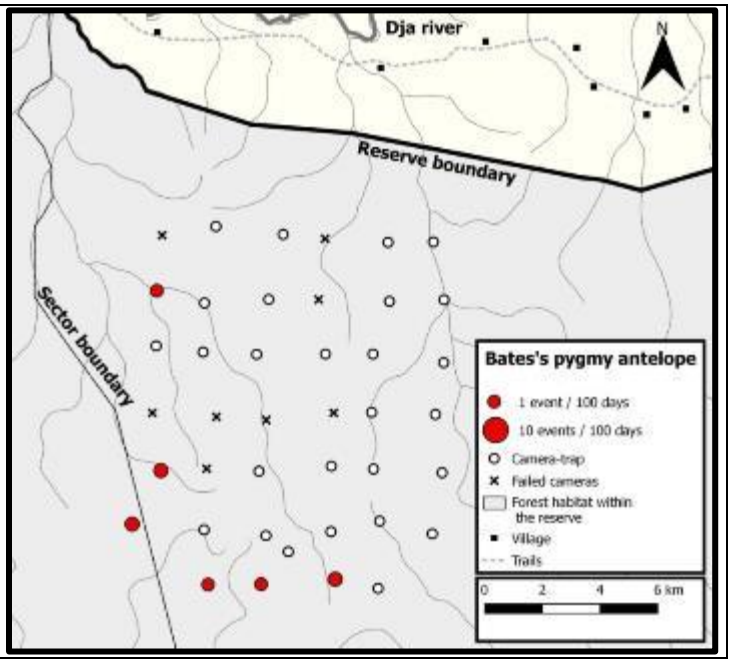
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.46 (0.12)	0.13	0.25 (0.10)	0.11 (0.04)

Activity pattern

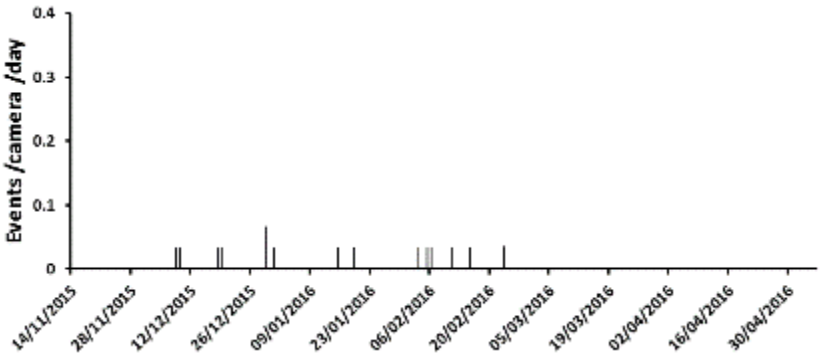


Bates' pygmy antelope continued

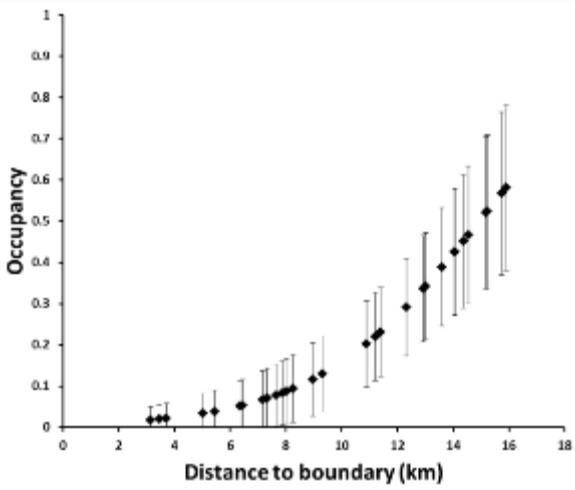
Variation in trapping rate through the camera grid:

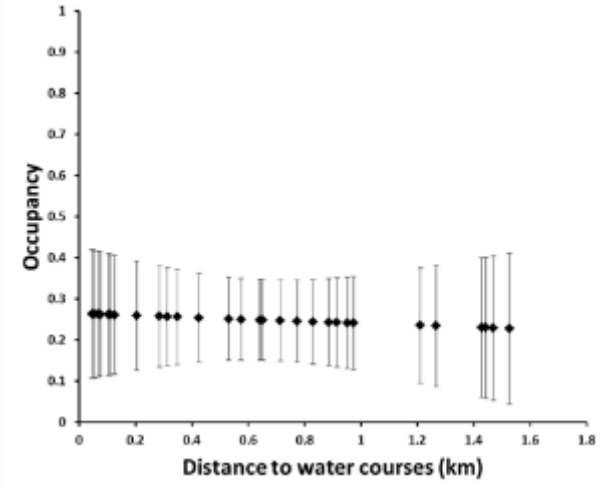


Temporal variation in detections:



Spatial variation in occupancy: Occupancy increases towards interior; distance to the boundary was the only covariate which improved efficiency relative to null.





7) BONGO (*Tragelaphus eurycerus)*

- Bongo were only recorded at the two cameras placed in the more open rocky outcrop and grassland habitat.
- Low trapping rates are likely because bongo are known to prefer transition vegetation found at forest edges and in new growth areas (Elkan & Smith 2013).
- The least frequently recorded forest antelope with only two solitary adults recorded at night at two different and widely-separated camera-traps.

Global conservation status:
Near Threatened (IUCN ASG 2016h)

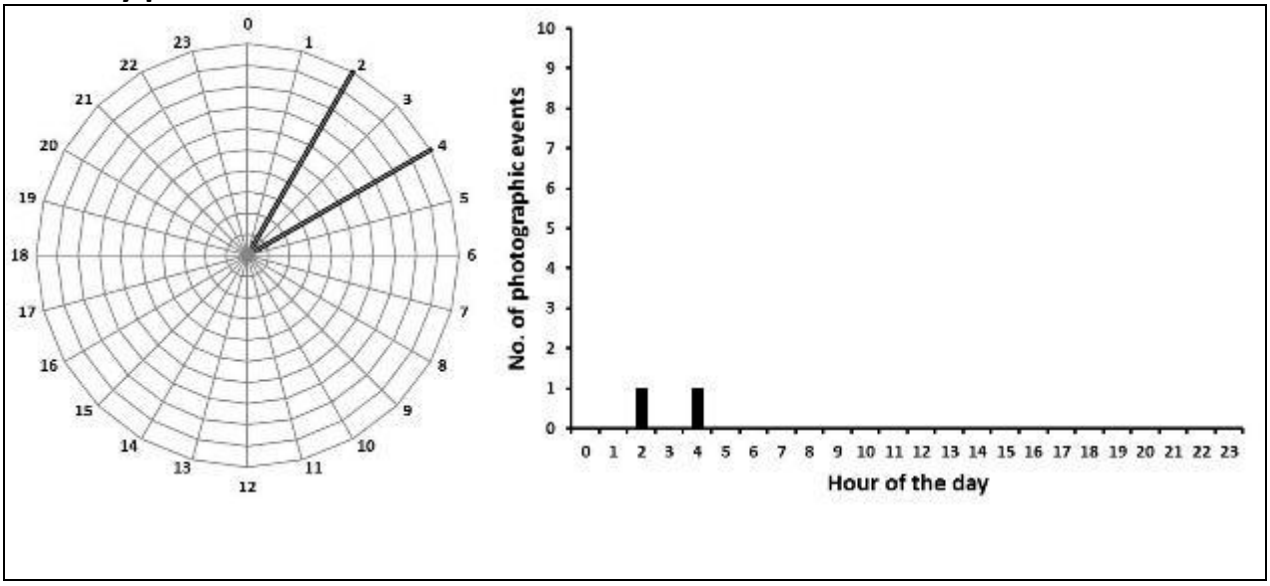
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	2	2	21

Trapping rates, occupancy and detectability

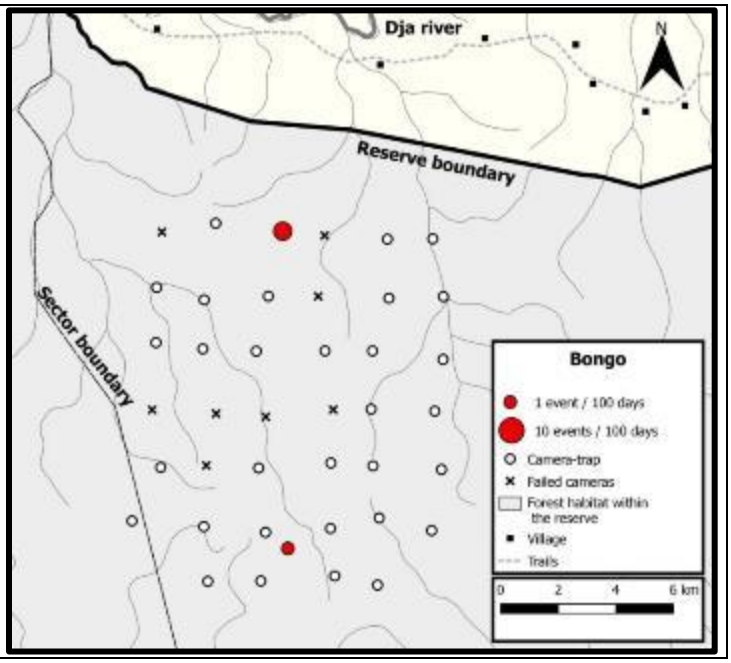
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.07 (0.05)	0.06	N/A	N/A

Activity pattern

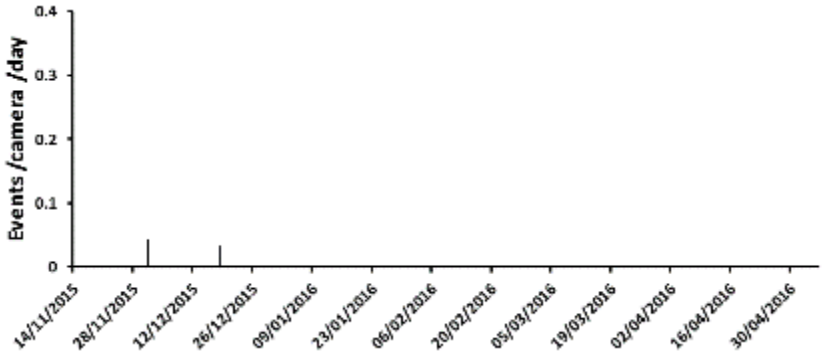


Bongo continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

8) SITATUNGA (*Tragelaphus spekii)*

- There was a total of 3 males and 2 females recorded during the survey.
- Timing of camera trap events indicates a strictly nocturnal activity pattern.
- All detections occurred at <651m from the nearest river, highlighting the sitatunga's preference for marsh and swamp habitat.
- The sitatunga is particularly vulnerable to snares (Kingdon 1984) due to their regular use of the pathways in swamps to move between resting and feeding areas (May & Lindholm 2013).

Global conservation status:
Least Concern (IUCN ASG 2016i)

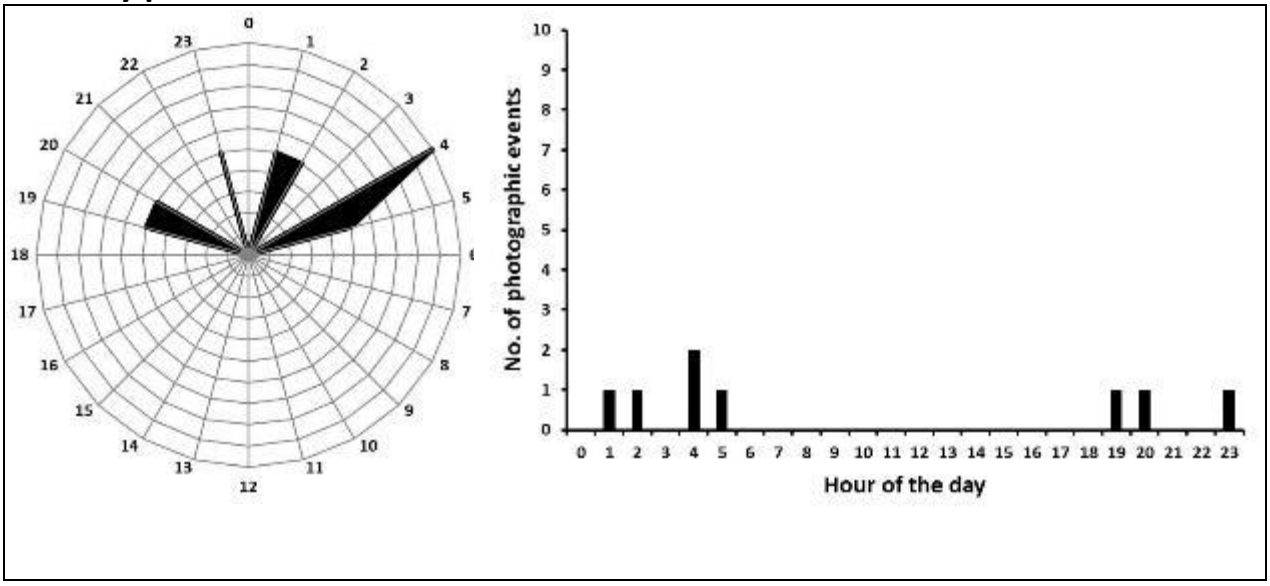
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	4	8	67

Trapping rates, occupancy and detectability

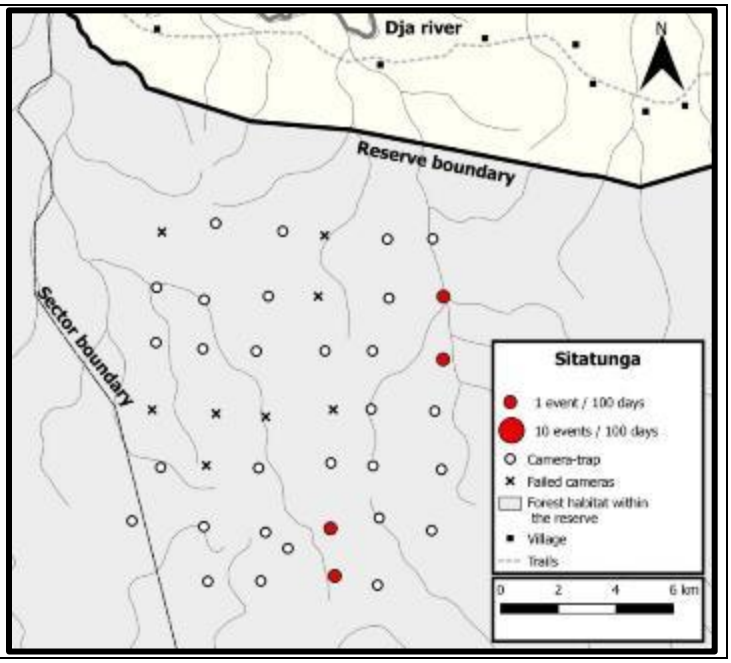
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.27 (0.09)	0.13	N/A	N/A

Activity pattern

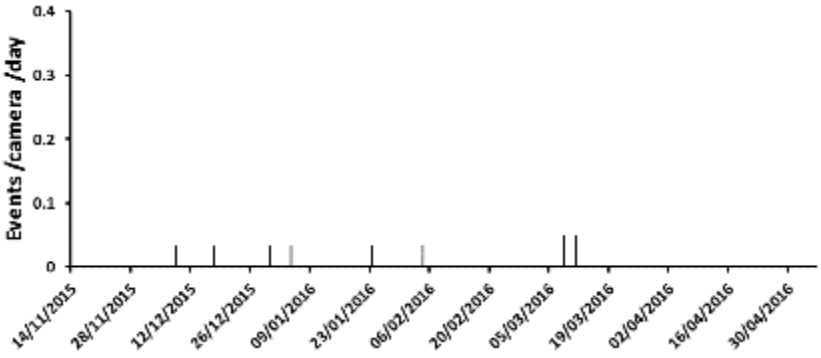


Sitatunga continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

9) WATER CHEVROTAIN (*Hyemoschus aquaticus)*

- The only tragulid species present in Africa.
- A predominantly solitary mammal, all detections in this survey were of single adults.
- A strictly nocturnal species with sporadic periods of activity during the night.
- Detected at 75 and 348 meters from the nearest water course, which are their primary means of escape from predators.
- Water chevrotain are often targets in bushmeat hunting as they are particularly vulnerable to snares (Hart 2013a).

Global conservation status:
Least Concern (IUCN ASG 2016e)

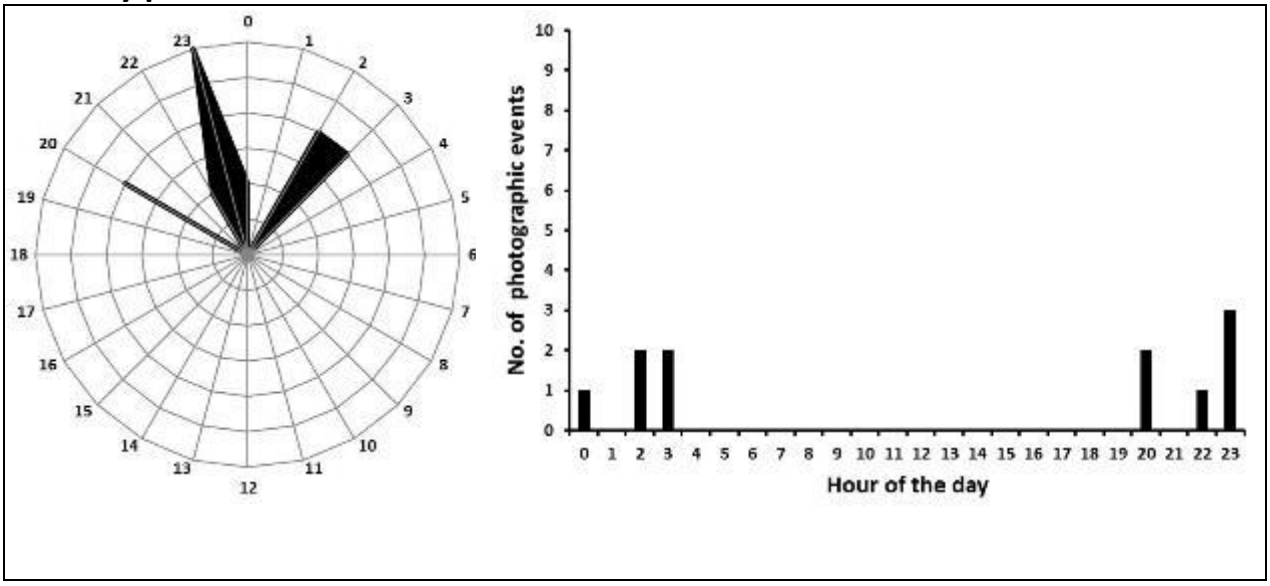
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	2	11	126

Trapping rates, occupancy and detectability

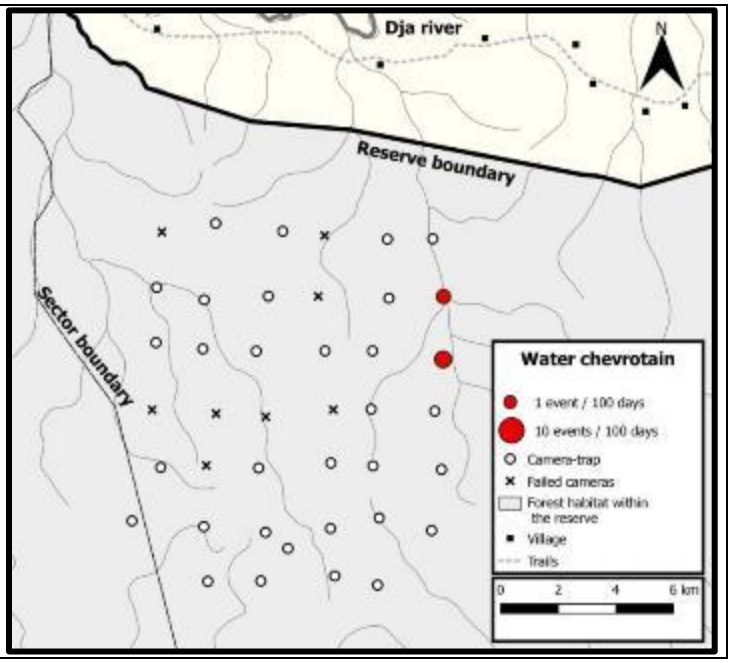
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.27 (0.1)	0.06	N/A	N/A

Activity pattern

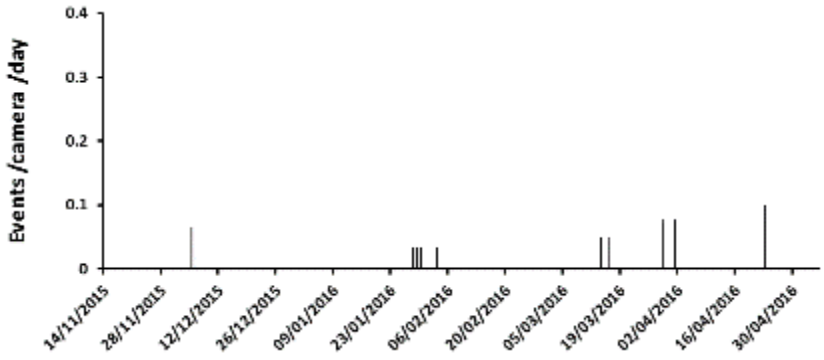


Water chevrotain continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

10) AFRICAN BUFFALO (*Syncerus caffer)*

- Two white tufts of hair on ears, small straight horns and overall red base colour to the pelage, consistent with the form *S. (c.) naffer* (Prins & Sinclair 2013).
- The largest group recorded was comprised of two adults and juvenile.
- As only two cameras were placed on bais the low numbers in the survey are perhaps restricted by forest buffalo's preference for open grassland habitat (Bekhuis et al. 2008).
- The few detections suggest that foraging occurs during the day and around dusk.

Global conservation status:
Least Concern (IUCN ASG 2008)

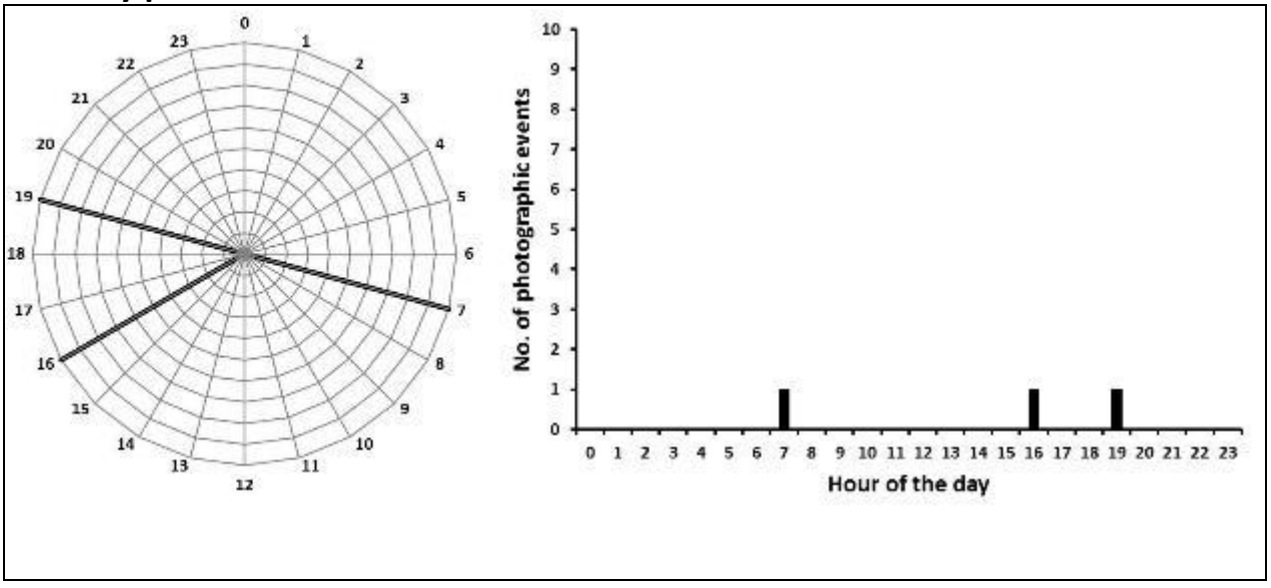
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	2	3	117

Trapping rates, occupancy and detectability

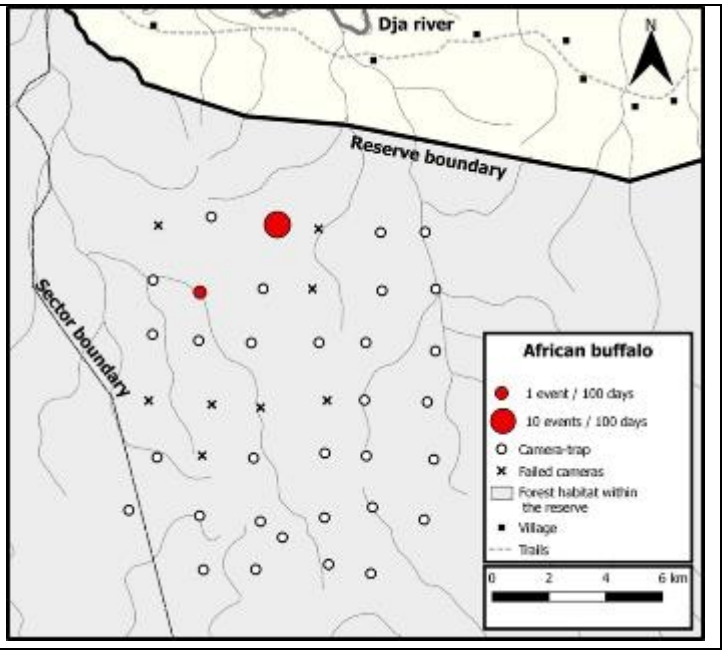
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Proportion of area in use	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.03 (0.03)	0.05	N/A	N/A

Activity pattern

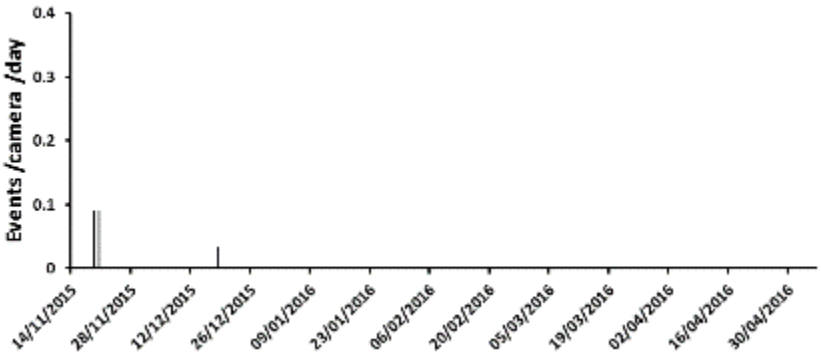


African buffalo continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

11) RED RIVER HOG (*Potamochoerus porcus)*

- Mainly encountered in groups with 75% of events containing >1 individual.
- Primarily detected at night, but with a peak of activity around dusk and sporadic activity throughout the day.
- Contrary to other studies of red river hog occupancy (McCollum et al. 2016), the probability of site being occupied increased with increasing distance to water sources. The reason for this is unknown.
- 1562 of 1640 diurnal images were taken at cameras >8.9 km from the reserve boundary. Red river hogs tend to be active diurnally in areas of low hunting pressure.

Global conservation status:
Least concern (Reyna et al. 2016)

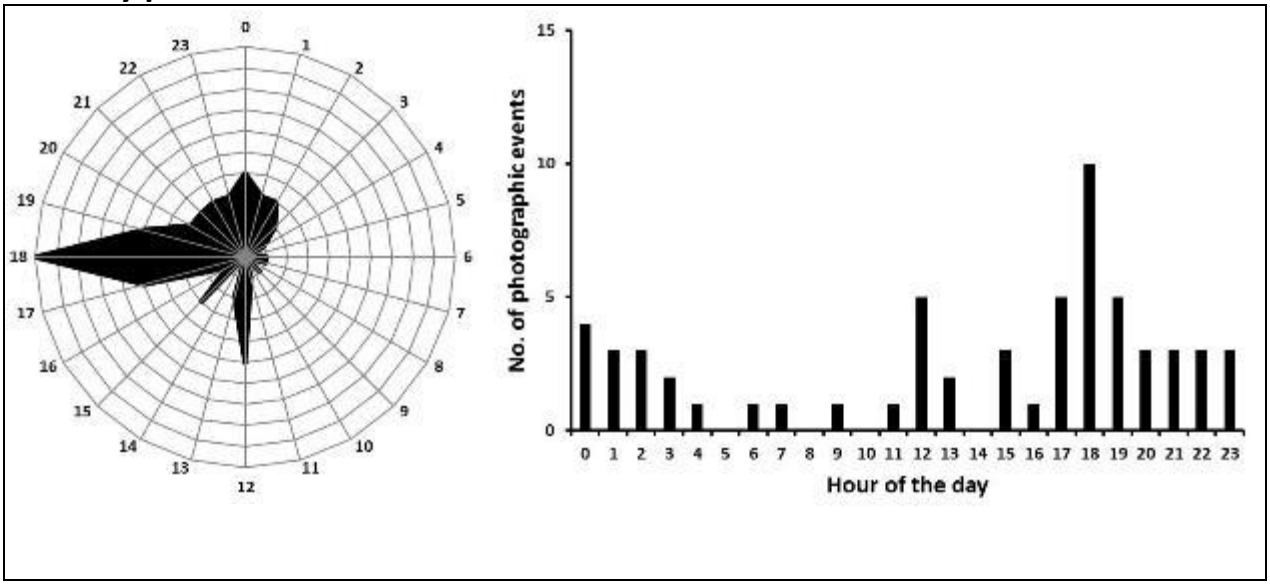
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	20	60	4,507

Trapping rates, occupancy and detectability

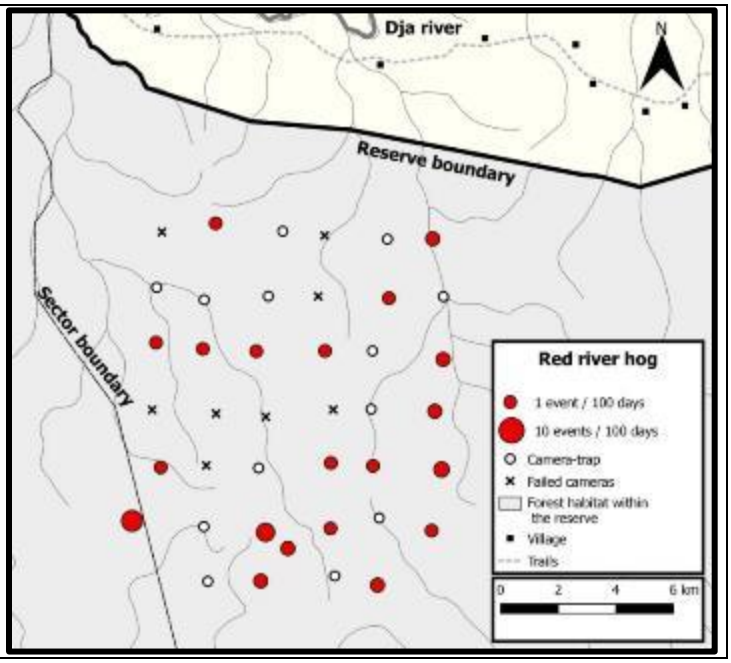
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	1.62 (0.23)	0.67	0.77 (0.10)	0.14 (0.02)

Activity pattern

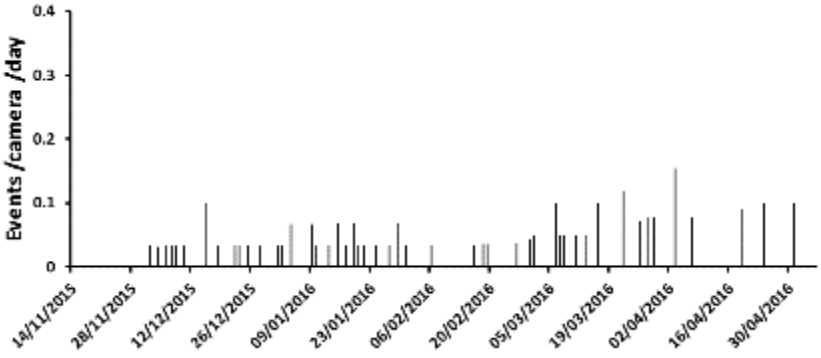


Red river hog continued

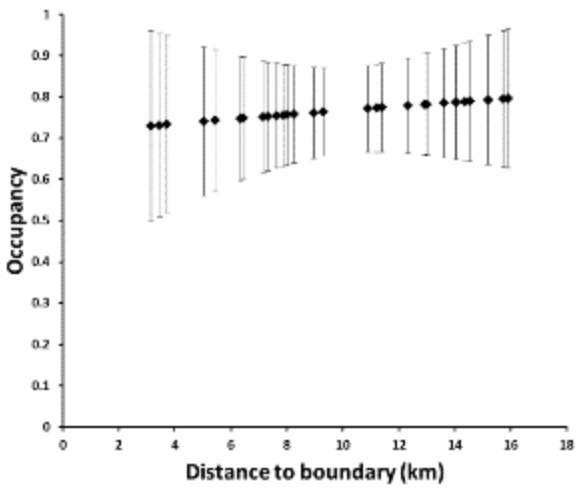
Variation in trapping rate through the camera grid:

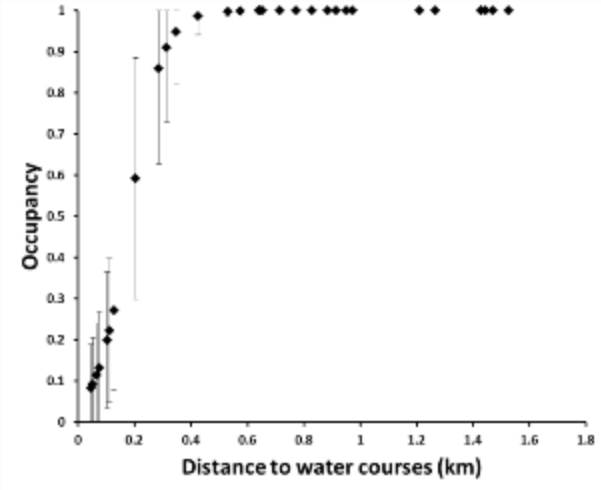


Temporal variation in detections:



Spatial variation in occupancy: Occupancy increased significantly with increasing distance to the nearest water course; distance to water source improved model efficiency compared to the null.





12) BLACK-LEGGED MONGOOSE (*Bdeogale nigripes)*

- Endemic to equatorial rainforests of central Africa.
- Despite being considered to be rare throughout most of its range (Van Rompaey & Colyn 2013) black-legged mongoose was detected at a similar rate to other small carnivores.
- Largely solitary with only four events at four different cameras containing a pair of adults together.
- Strictly nocturnal activity pattern.
- Occupancy increased significantly with both distance to the boundary and water courses. Sensitive to disturbance (Bahaa-el-din et al. 2003)

Global conservation status:
Least concern (Angelici & Do Linh San 2015)

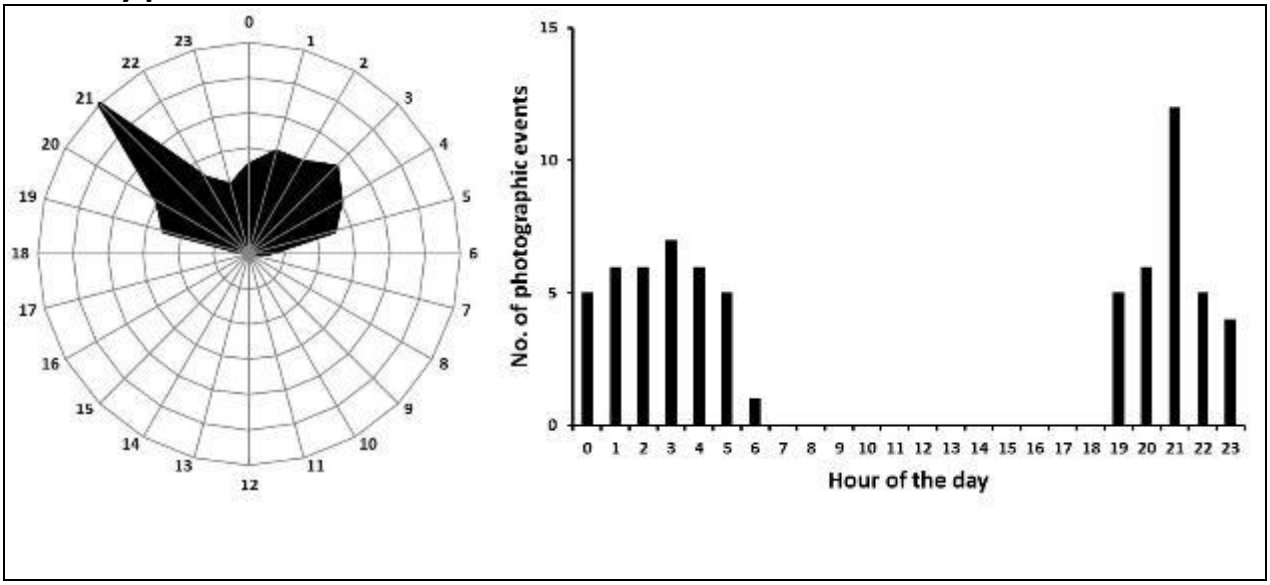
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	16	68	519

Trapping rates, occupancy and detectability

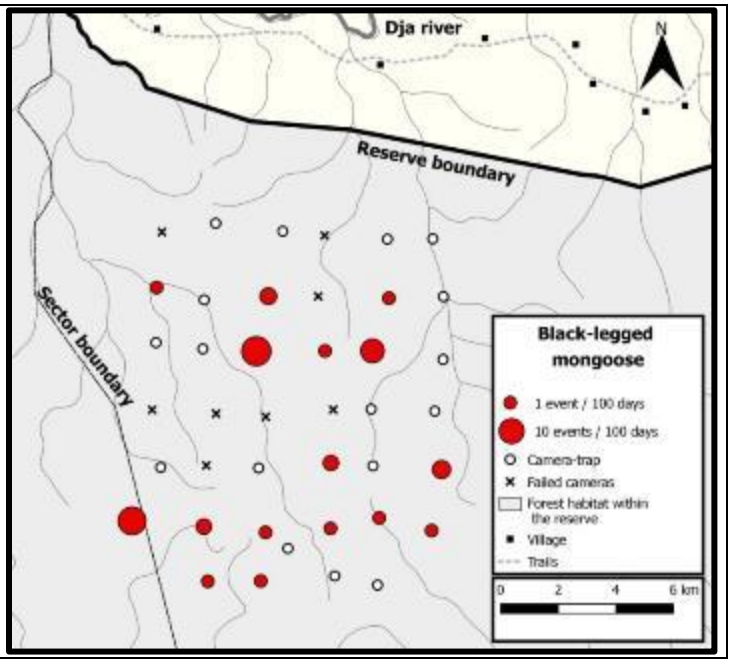
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	1.86 (0.24)	0.5	0.53 (0.10)	0.19 (0.03)

Activity pattern

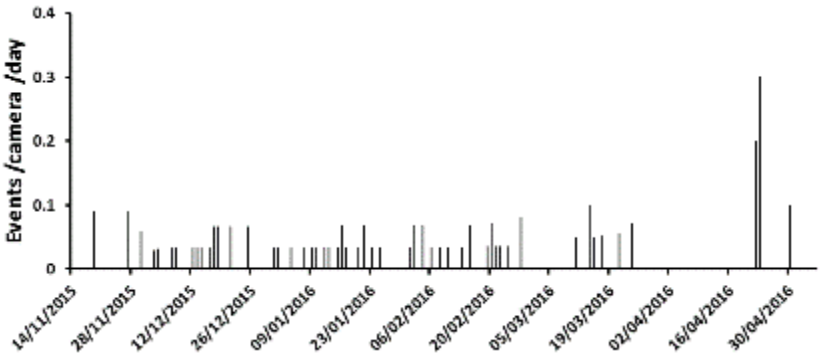


Black-legged mongoose continued

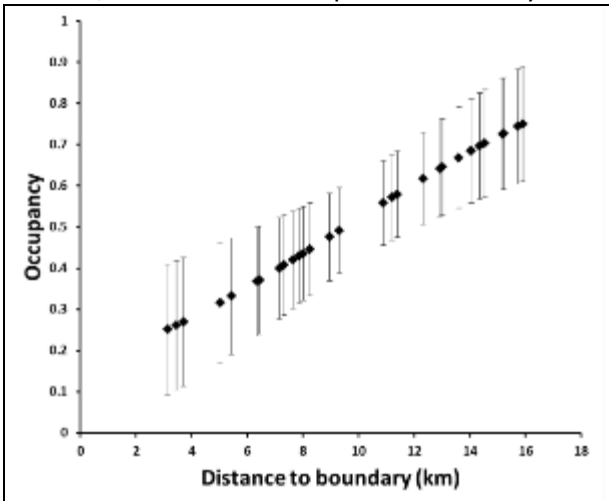
Variation in trapping rate through the camera grid:

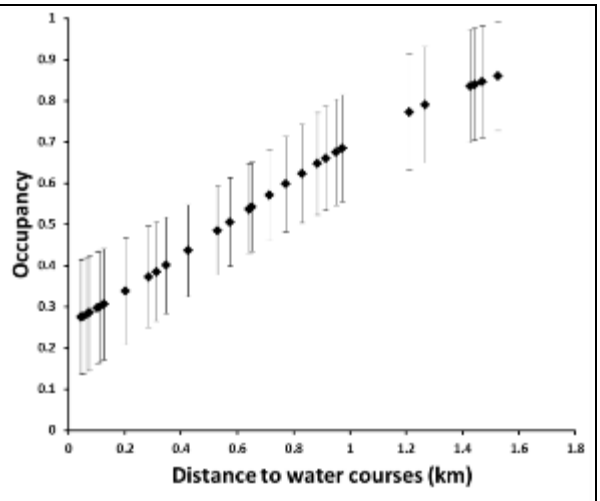


Temporal variation in detections:



Spatial variation in occupancy: Occupancy increases towards interior and away from water course, both covariates improved efficiency relative to null.





13) LONG-NOSED MONGOOSE et al. *Herpestes naso et al*.

- Due to difficulty in differentiating between long-nosed mongoose (left) and marsh mongoose (opposite) this account represents combined records of both species.
- Herpestidae sp. was widely distributed throughout the survey area with a modelled occupancy value of 100%.
- All encounters were of solitary individuals.
- Note: Genetic affinity with *Atilax* suggests re-assignment to genus *Xenogale* may be appropriate (Van Rompaey & Colyn 2013)

Global conservation status:
N/A

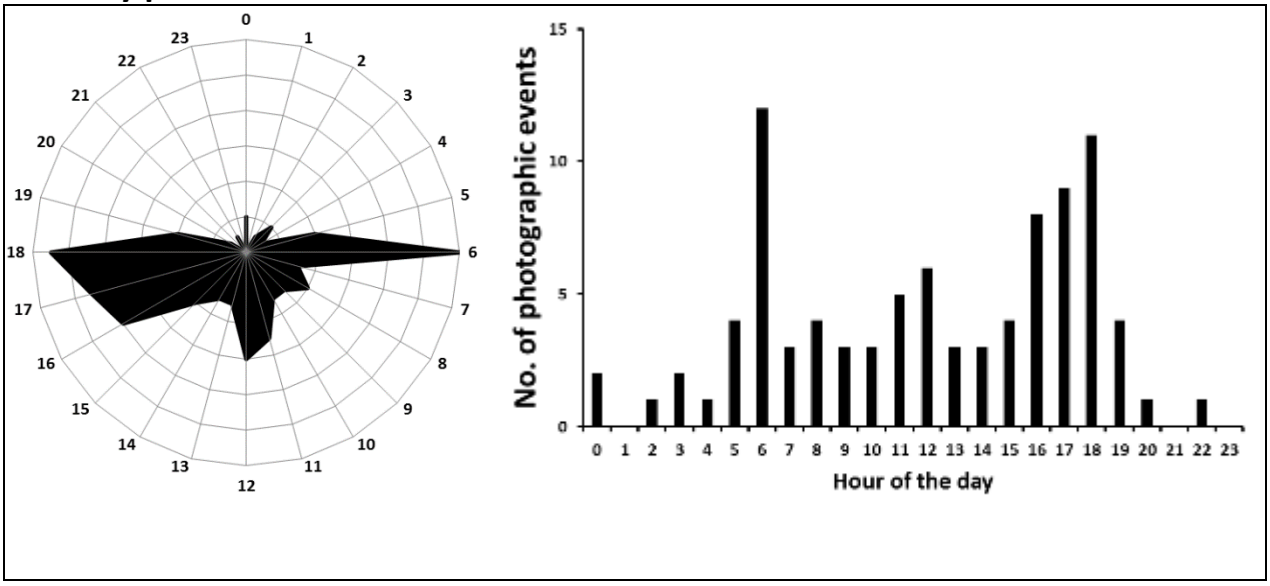
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	23	90	653

Trapping rates, occupancy and detectability

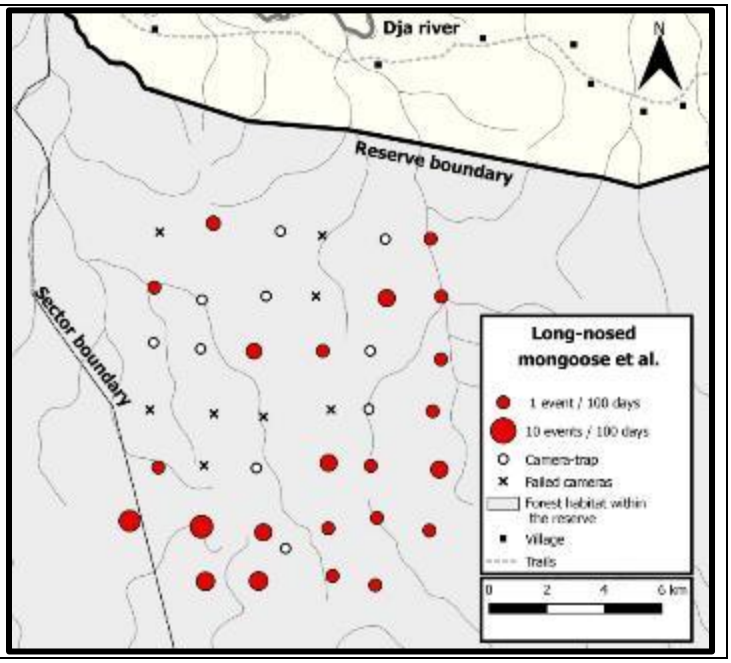
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	2.49 (0.29)	0.77	1 (0)	0.15 (0.02)

Activity pattern

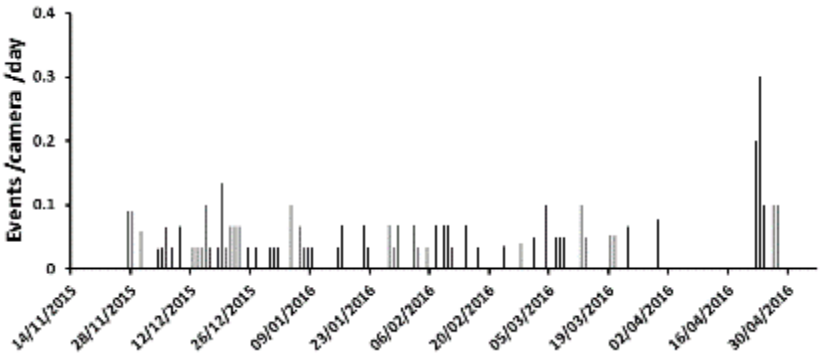


Herpestes naso et al. continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: As this species account is probably comprised of two species occupancy analysis is not appropriate.

14) CAMEROON CUSIMANSE (*Crossarchus platycephalus)*

- An endemic species to western central Africa.
- The most frequently observed of the four mongoose species in the northern sector.
- A social and highly gregarious species with the largest number recorded in one photographic event during the survey containing six individuals.
- Demonstrates a strictly diurnal activity pattern, foraging during daylight hours with peaks of activity in the afternoon.
- The even distribution throughout the camera-trap grid in forested areas highlights it's preference for undergrowth in rainforest habitats (Goldman 2013).

Global conservation status:
Least Concern (Angelici & Do Linh San 2016)

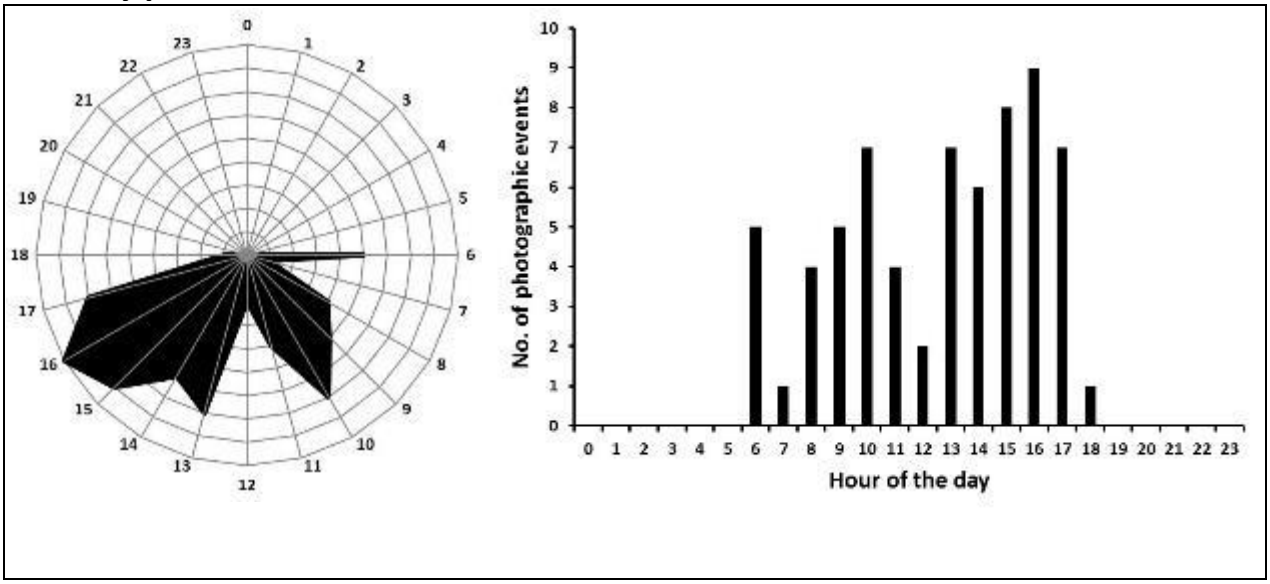
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	22	66	929

Trapping rates, occupancy and detectability

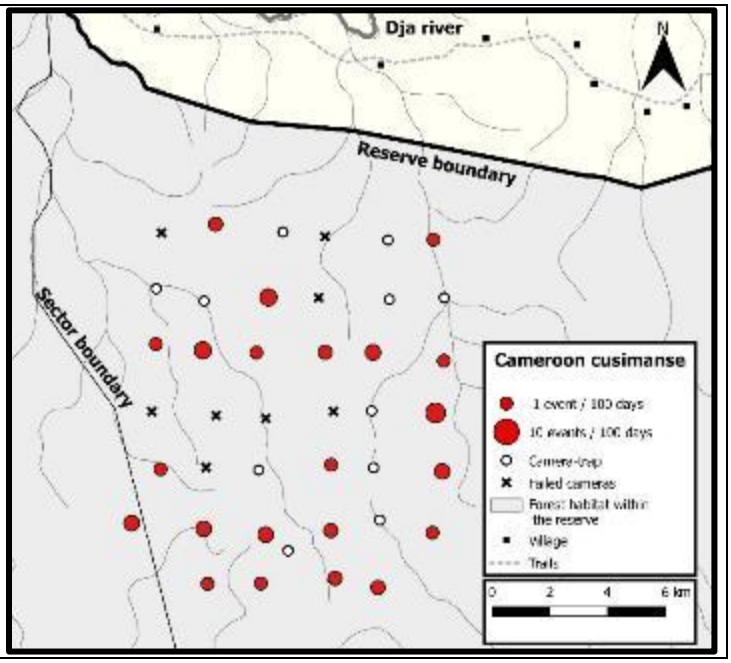
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	1.72 (0.27)	0.67	0.72 (0.09)	0.17 (0.02)

Activity pattern

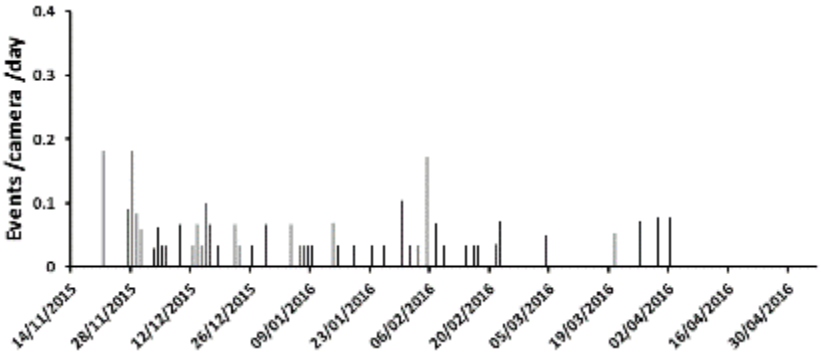


Cameroon cusimanse continued

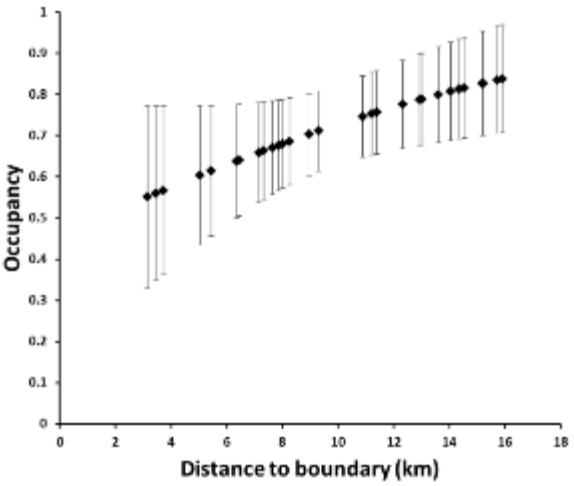
Variation in trapping rate through the camera grid:

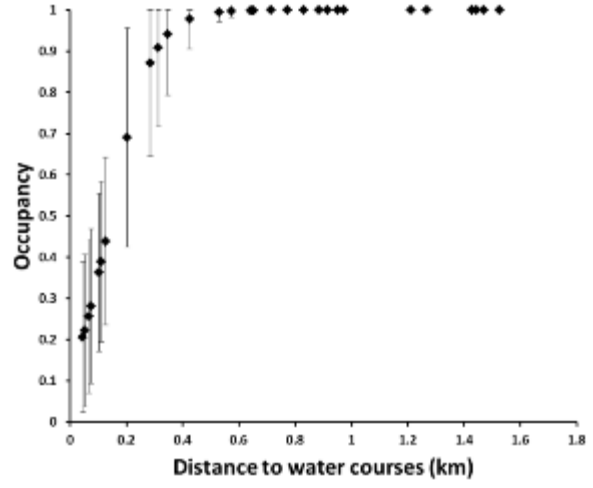


Temporal variation in detections:



Spatial variation in occupancy: Occupancy increases with distance from water course; distance to water source improved model efficiency relative to the null.





15) AFRICAN PALM CIVET (*Nandinia binotata)*

- Despite being a primarily arboreal species, the African palm civet was detected relatively frequently.
- Only solitary adults were detected during this survey.
- As expected for this nocturnal species all detections occurred at night (18:00-05:00).
- Distributed evenly throughout the camera-trap grid.

Global conservation status:
Least Concern (Gaubert et al. 2015)

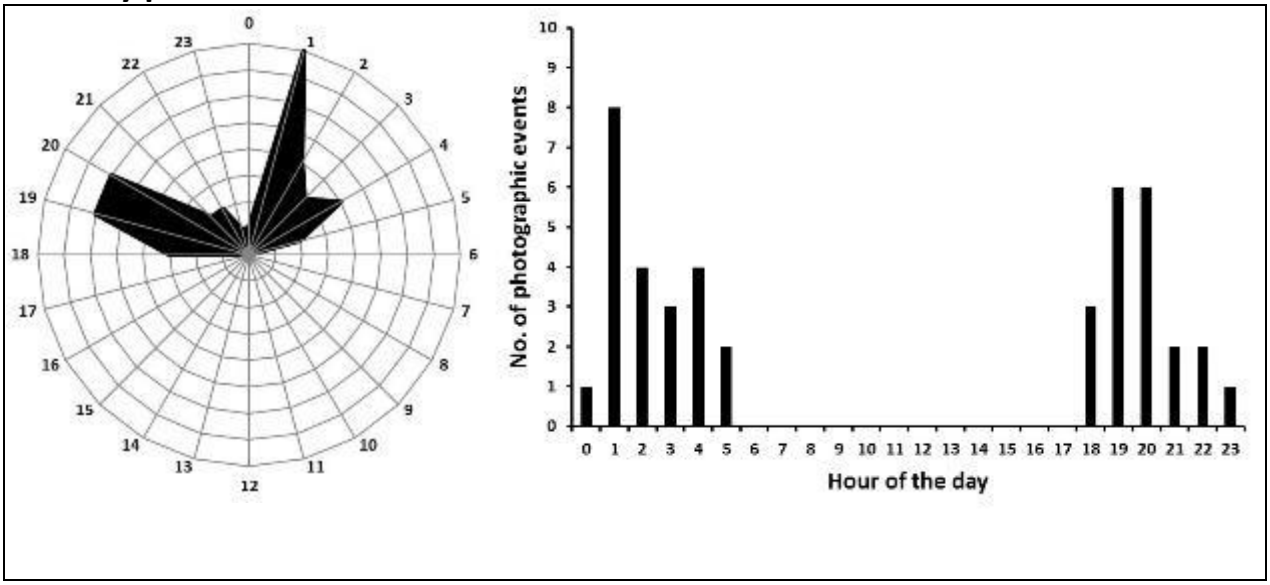
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	20	42	231

Trapping rates, occupancy and detectability

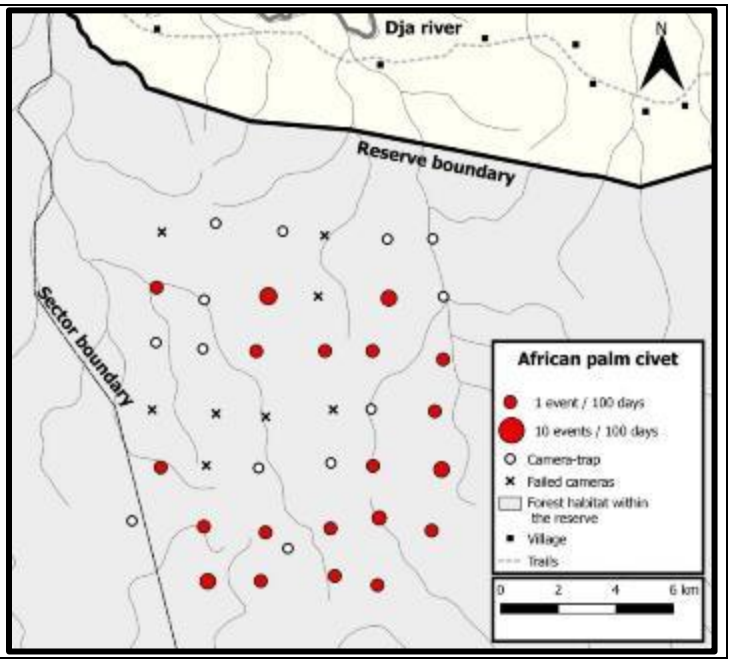
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	1.11	0.6	N/A	N/A

Activity pattern

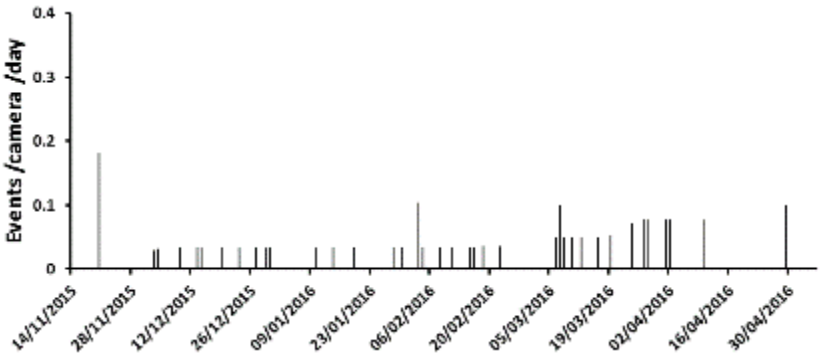


African palm civet continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The detection probability was too low (<0.1) to reliably model occupancy.

16) SERVALINE GENET (*Genetta servalina)*

- The servaline genet is a generalist species moving both on the ground and in trees (Van Rompeay & Colyn 2013) and was the most frequently detected carnivore species.
- The most widespread carnivore species recording 100% occupancy in the northern sector.
- Predominantly a solitary species all detections during the survey were of solitary individuals.
- The possibility that images may represent crested genet (*Genetta cristata)* was considered, but the south-eastern limits of its distribution are currently uncertain and require further research.

Global conservation status:
Least Concern (Gaubert et al. 2016)

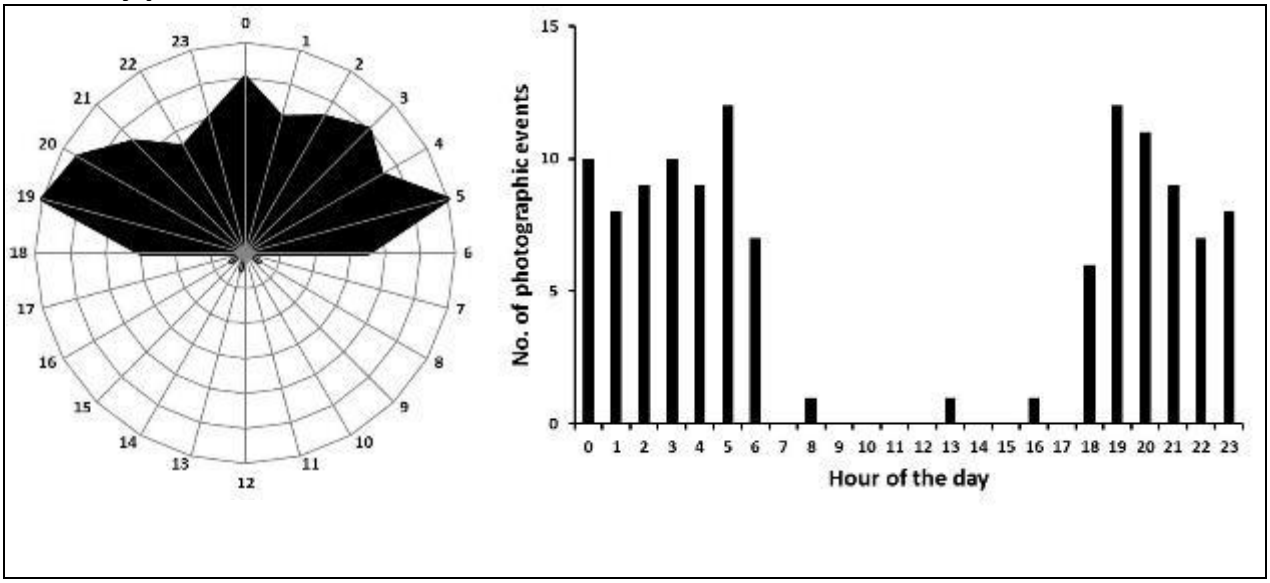
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	29	121	752

Trapping rates, occupancy and detectability

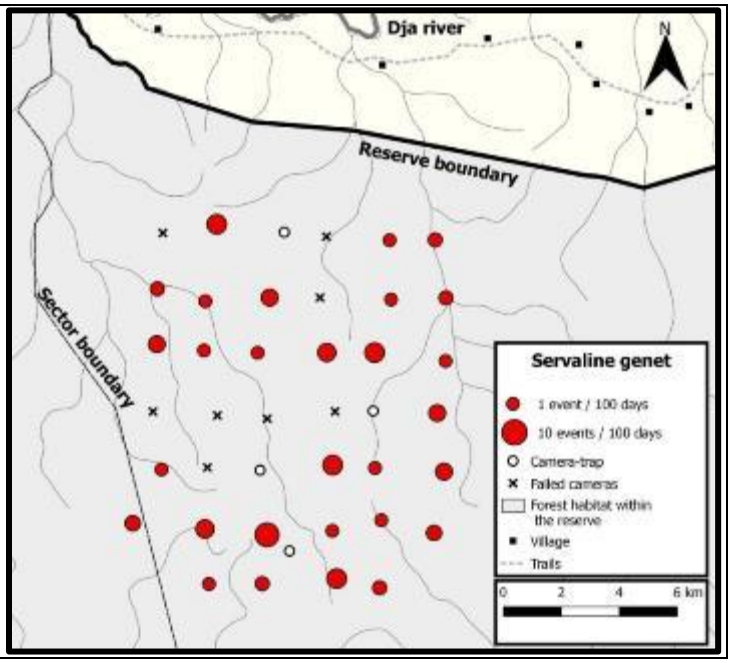
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	3.57 (0.38)	0.93	1 (0)	0.22 (0.02)

Activity pattern

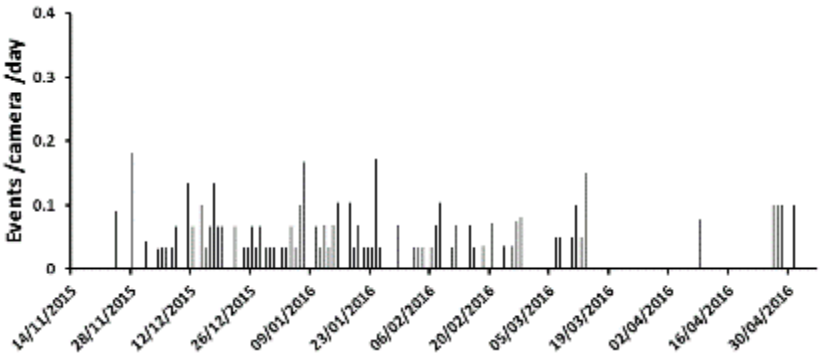


Servaline genet continued

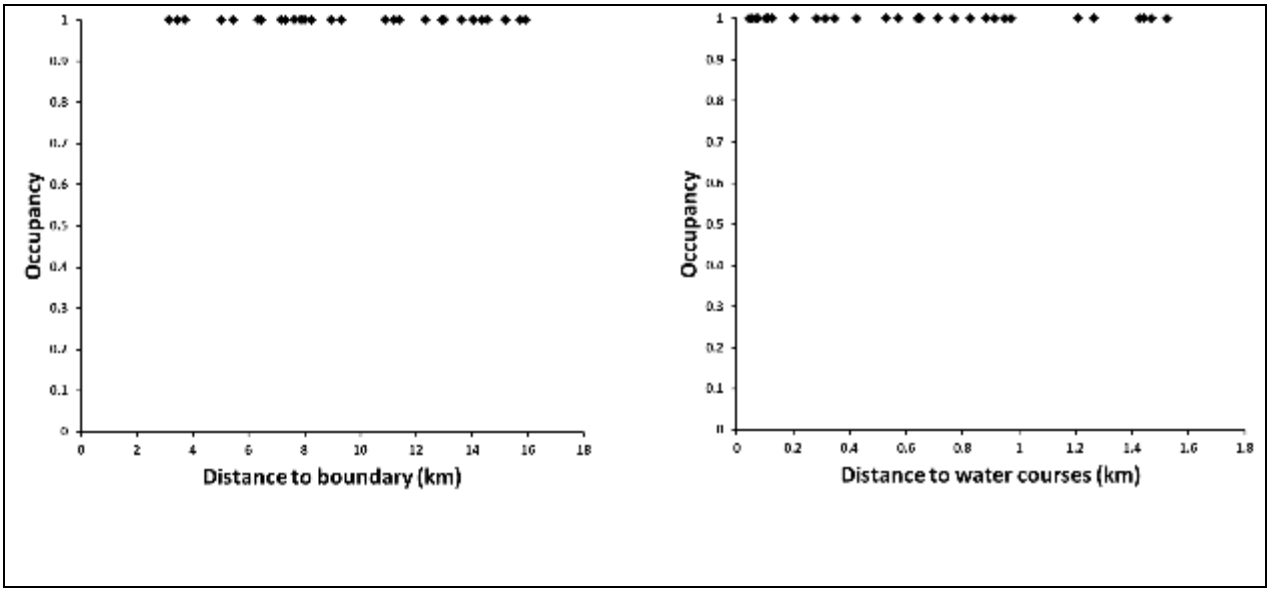
Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: Widespread throughout the camera-trap grid and covariates do not improve model efficiency relative to null.



17) AFRICAN ELEPHANT (*Loxodonta africana)*

- The largest number detected was comprised of six individuals (1.4.1).
- An adult male in musth was part of this large group, with evidence of temporal secretions and urine dribbling [see image].
- 14 detections were of apparently solitary elephants.
- Timing of camera-trap events indicates a sporadic activity pattern throughout the 24 hour cycle. Nocturnal activity can be associated with human disturbance such as poaching (Wrege 2012 & Turkalo 2013).
- 50% of the range was actively in use by elephants during this survey.

Global conservation status:
Vulnerable (Blanc 2008)

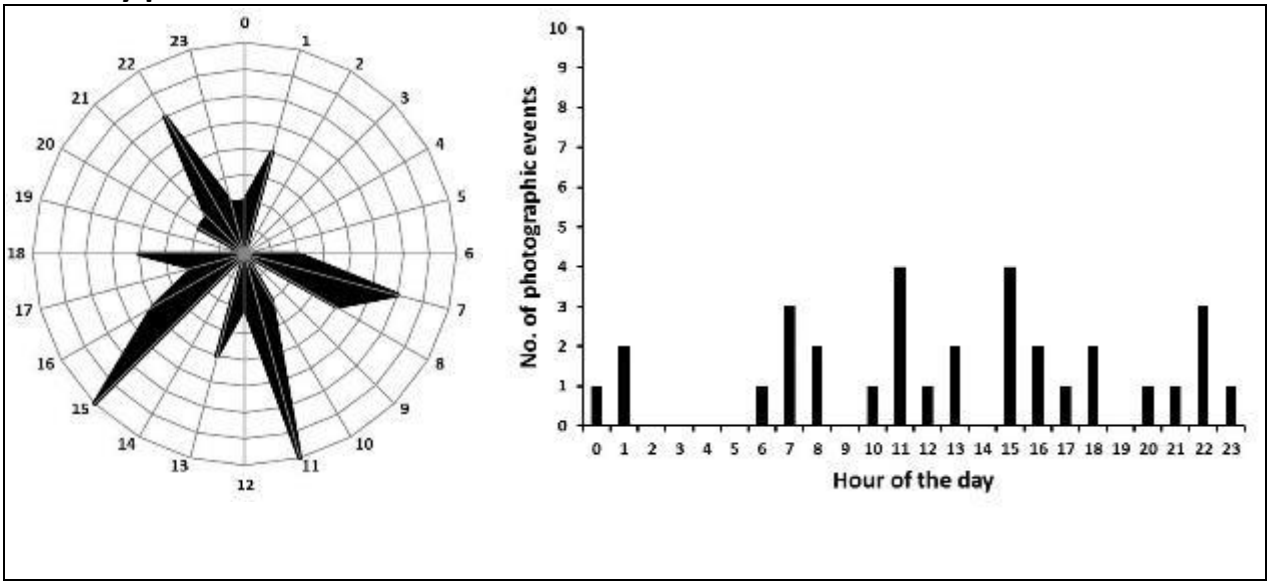
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	15	32	2,632

Trapping rates, occupancy and detectability

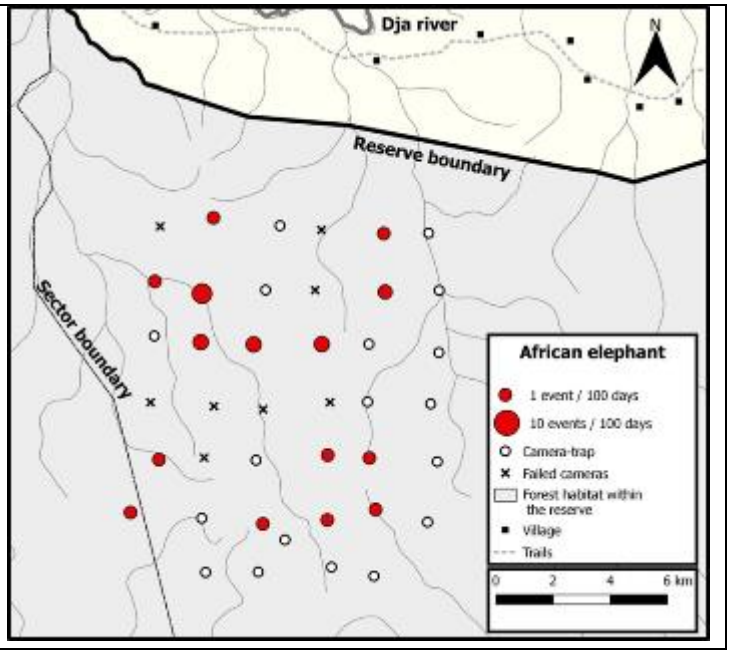
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Percentage of range in use	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.93 (0.21)	0.5	N/A	N/A

Activity pattern

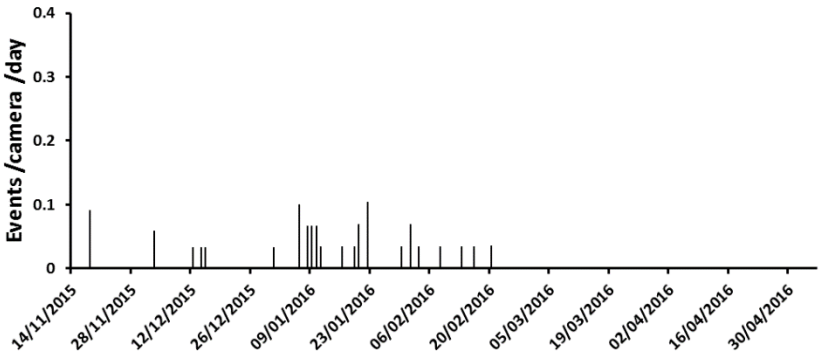


African elephant continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: Due to their large home ranges which exceed inter-trap distances, occupancy analysis could not be conducted for elephants.

18) CENTRAL CHIMPANZEE (*Pan troglodytes troglodytes)*

- The most frequently encountered primate species within the northern sector of the reserve.
- There were several recordings of females carrying juveniles, but the maximum group size detected was seven, a group size indicative of disturbed habitat elsewhere (Thompson & Wrangham 2013).
- As expected for this diurnal species all detections were during the day (05:00-18:00).
- Due to their large home ranges occupancy could not be modelled for chimpanzee. They used 67% of the available area covered within the survey.

Global conservation status:
Endangered (Maisels et al. 2016)

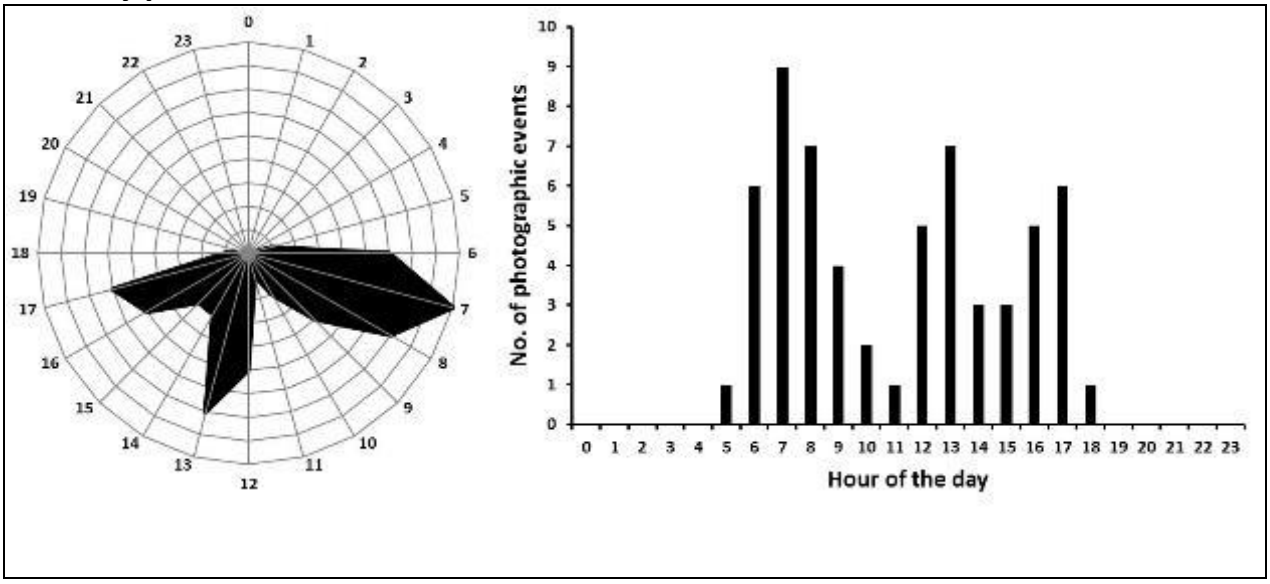
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	20	60	843

Trapping rates, occupancy and detectability

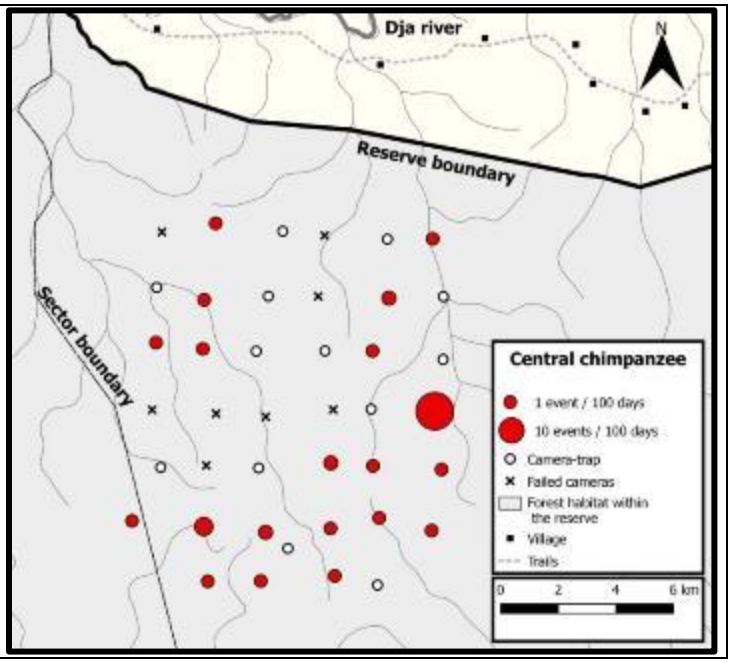
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Percentage of range in use	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	1.71 (0.24)	0.67	N/A	N/A

Activity pattern

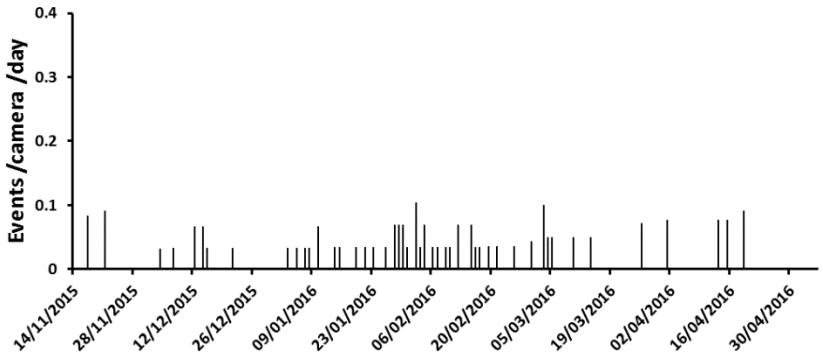


Central Chimpanzee continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: Due to their large home ranges which exceed inter-trap distances, occupancy analysis could not be conducted for chimpanzee.

19) WESTERN LOWLAND GORILLA (*Gorilla gorilla gorilla)*

- Endemic to western central Africa.
- Four of the six events were of solitary adults; the largest number of individuals observed in one event was three (1.1.1).
- Detected at 665-695 masl, which is higher than usual as most western lowland gorilla populations are found at <500 masl (Maisels et al. 2016).
- Diurnal according to the timing of camera-trap events.
- Low trapping rates and a limited distribution suggest they are rare within the northern sector of the Dja Reserve.

Global conservation status:
Critically Endangered (Maisels et al. 2016)

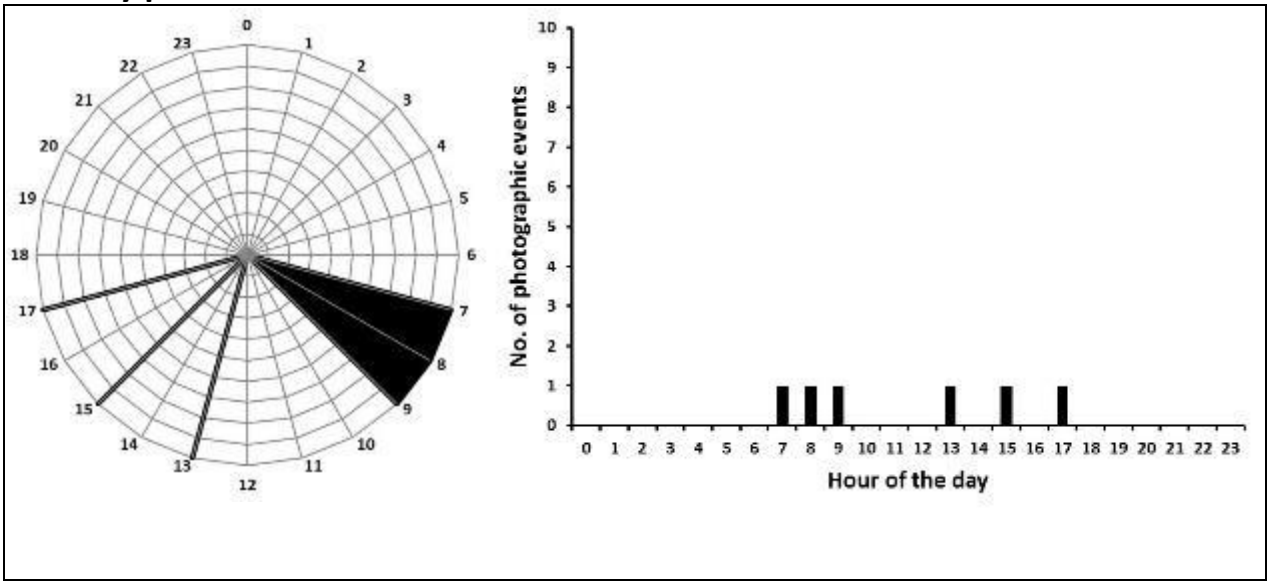
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	5	6	63

Trapping rates, occupancy and detectability

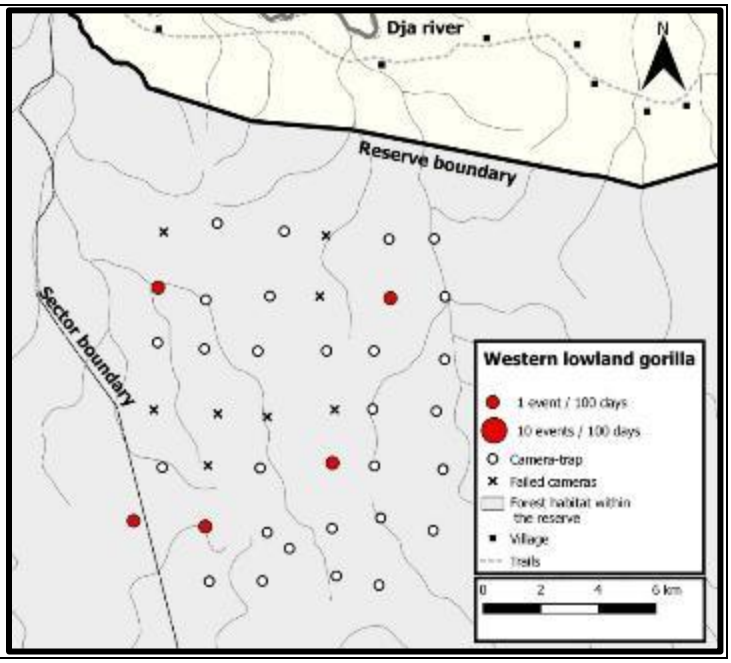
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Percentage of range in use	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.14 (0.07)	0.17	N/A	N/A

Activity pattern

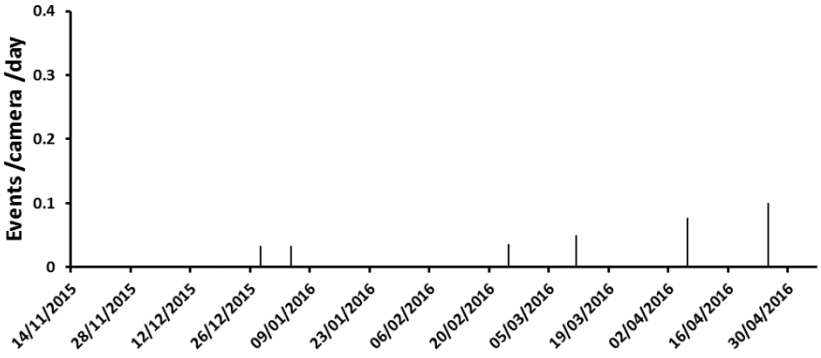


Western lowland gorilla continued

Variation in trapping rate through the camera grid:



Temporal variation in detections: Spoaridcally detected throughout the survey period.



Spatial variation in occupancy: Due to their large home ranges which exceed inter-trap distances, occupancy analysis could not be conducted for gorilla.

20) MANDRILL (*Mandrillus sphinx)*

- The detection of mandrill in this survey is the first confirmation of its presence east of the significant barrier of the Dja River, extending its range by 20 km (Ngo Bata et al. *in press*).
- The least recorded terrestrial primate; both detections were of a solitary adult male during the day.
- Further camera-trap surveys will aid in establishing whether there are groups of mandrills residing within the reserve, as well as lone males.

Global conservation status:
Vulnerable (Oates & Butynski 2008)

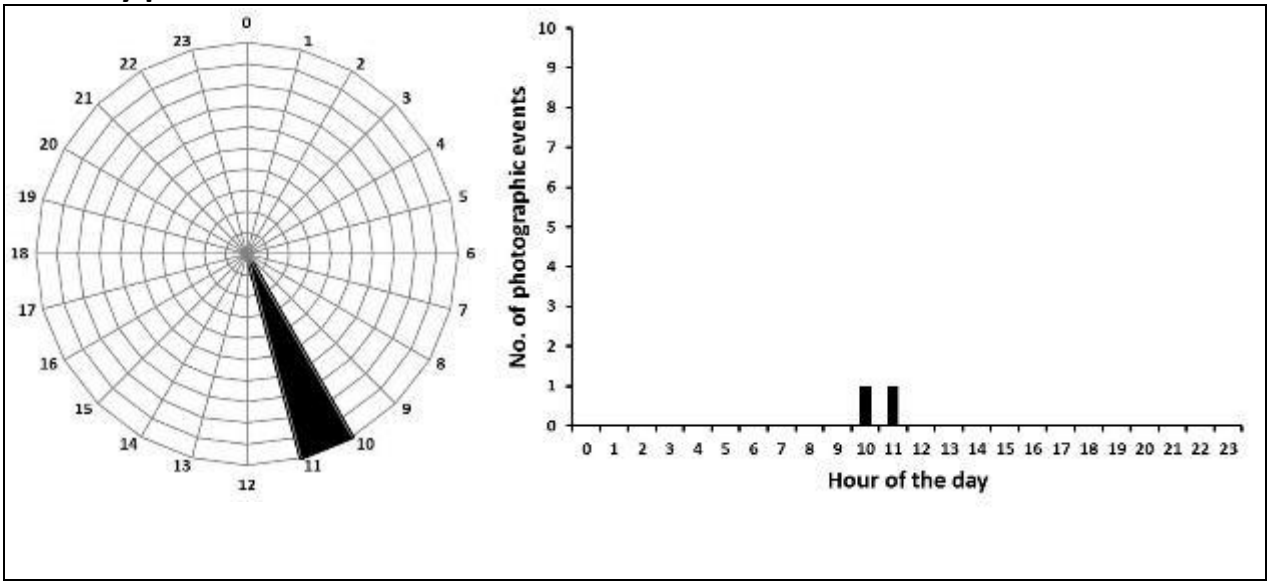
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	2	2	12

Trapping rates, occupancy and detectability

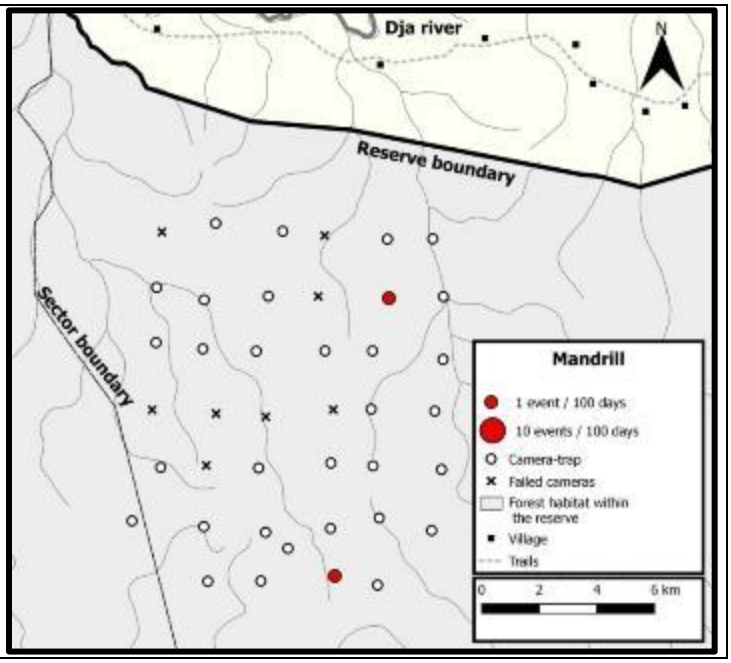
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.04 (0.04)	0.07	N/A	N/A

Activity pattern

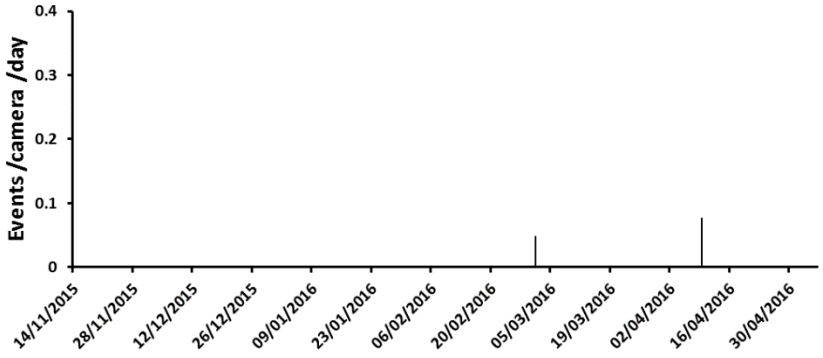


Mandrill continued

Variation in trapping rate through the camera grid:



Temporal variation in detections: Only two detections throughout the survey period.



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

21) MOUSTACHED GUENON (*Cercopithecus cephus cephus)*

- Very few encounters of this common arboreal species which spends 60% of its time 10-15 m high in the mid canopy (Gautier-Hion et al. 1981).
- The camera-trap survey was not designed to reliably detect arboreal species.
- A strictly diurnal activity pattern with a pronounced peak during the middle of the day, when they are known to descend to forage for insects.

Global conservation status:
Least Concern (Oates et al. 2008)

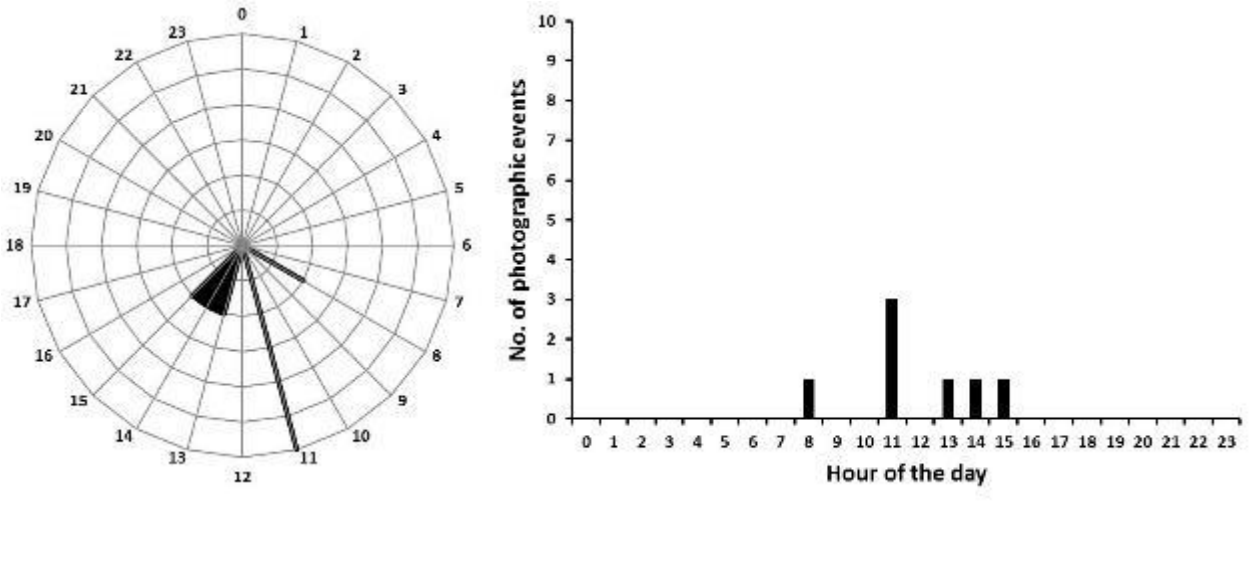
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	7	7	27

Trapping rates, occupancy and detectability

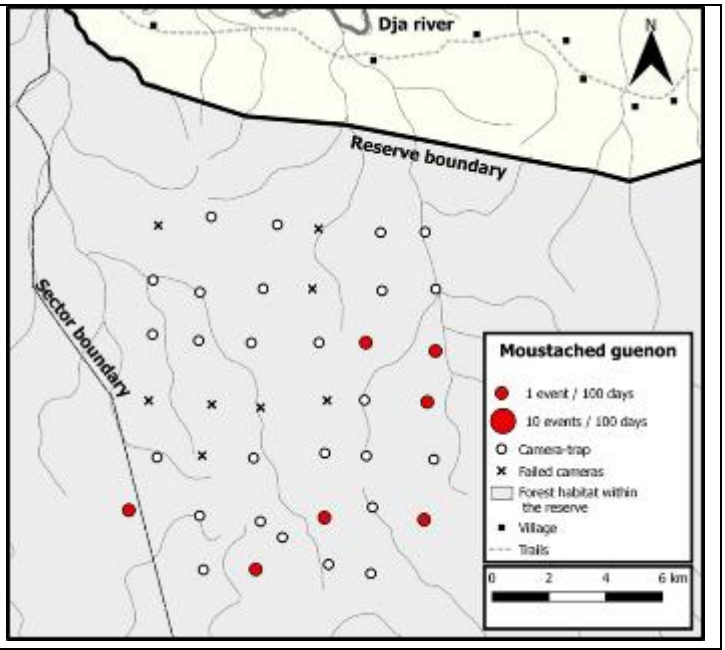
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.21 (0.09)	0.2	N/A	N/A

Activity pattern

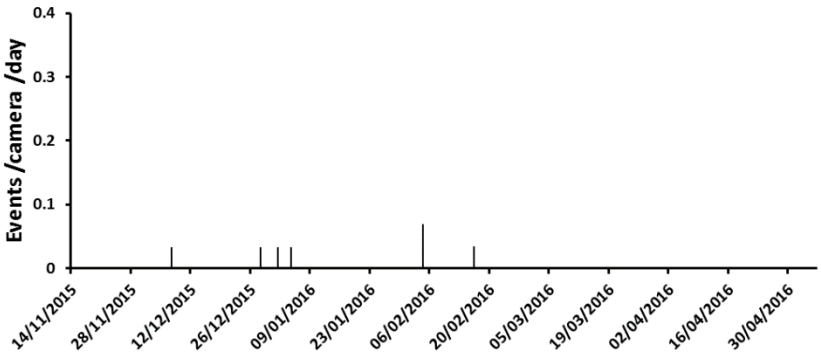


Moustached guenon continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

22) GREATER SPOT-NOSED GUENON (*Cercopithecus nictitans)*

- Diurnal and arboreal, very few detections are likely due to the species only coming to the ground to cross open areas (Gautier-Hion 2013).
- All events were of solitary individuals.

Global conservation status:
Least Concern (Oates & Groves 2008)

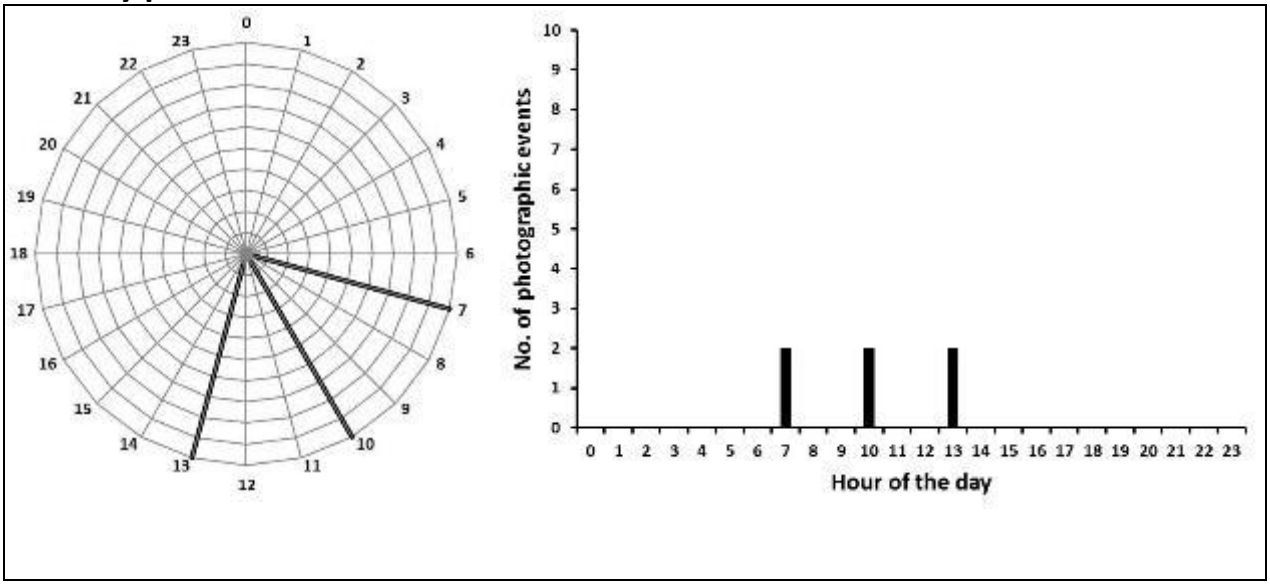
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	4	6	45

Trapping rates, occupancy and detectability

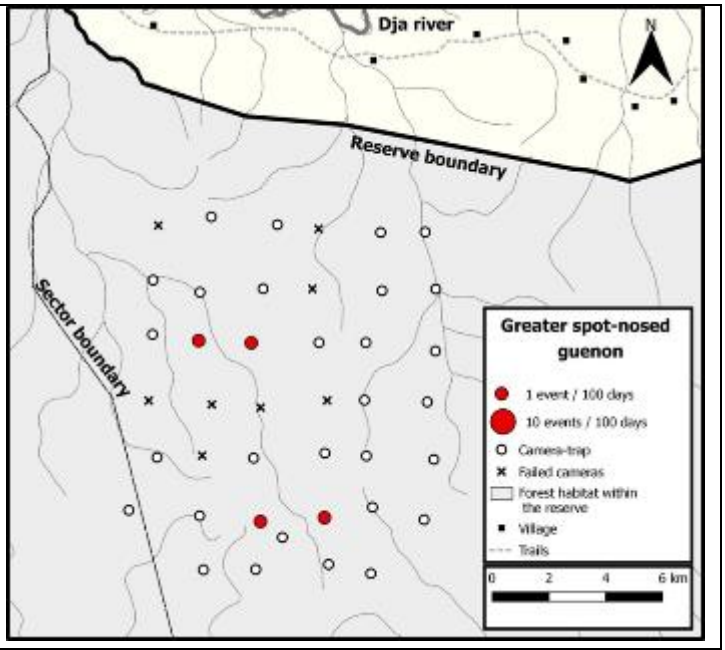
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.18 (0.08)	0.13	N/A	N/A

Activity pattern

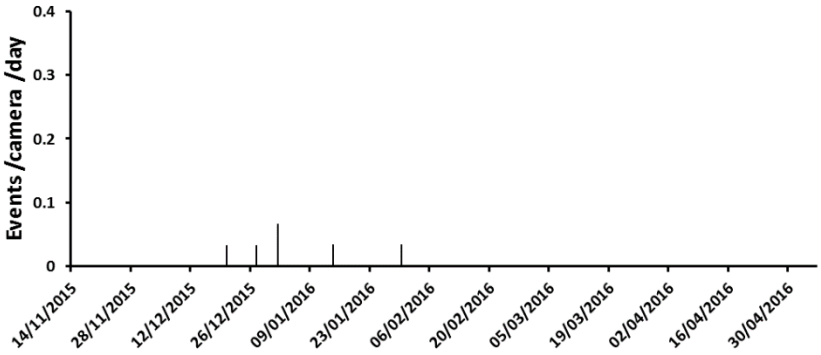


Greater spot-nosed guenon continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

23) AGILE MANGABEY (*Cercocebus agilis)*

- A strictly diurnal semi-terrestrial primate.
- The distribution map shows that in this sector they were only recorded in the interior of the forest at least 12-14 km from the boundary. This pattern is observed in other protected areas where abundance is related to human hunting pressure (Shah 2013).
- Numbers detected ranged from 2-24 individuals, including groups of adults, sub-adults and juveniles.

Global conservation status:
Least Concern (Hart et al. 2008)

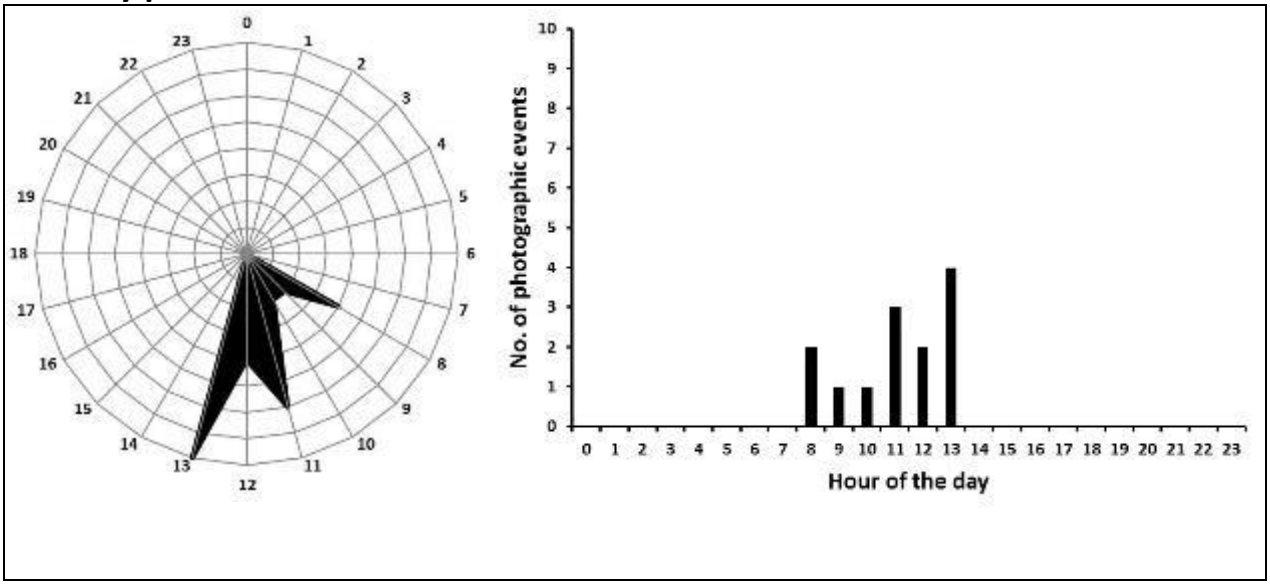
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	8	13	580

Trapping rates, occupancy and detectability

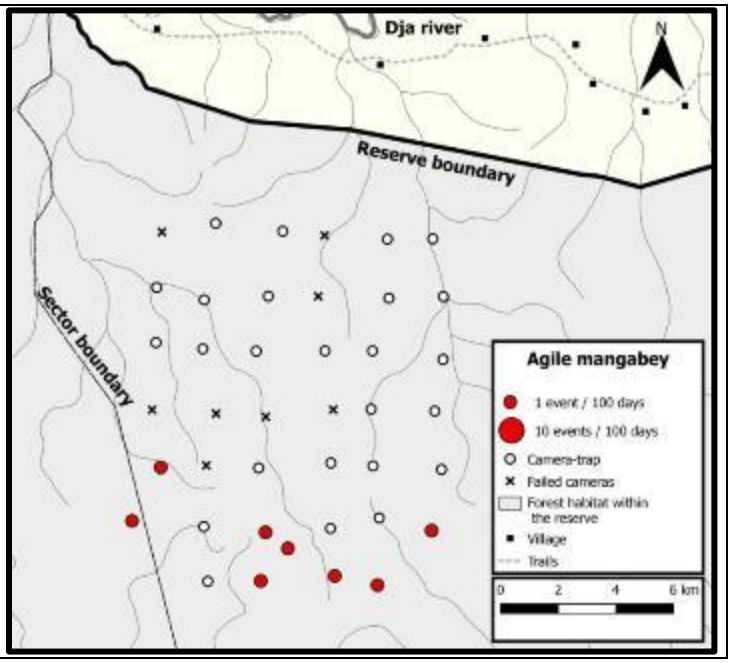
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.4 (0.1)	0.27	N/A	N/A

Activity pattern

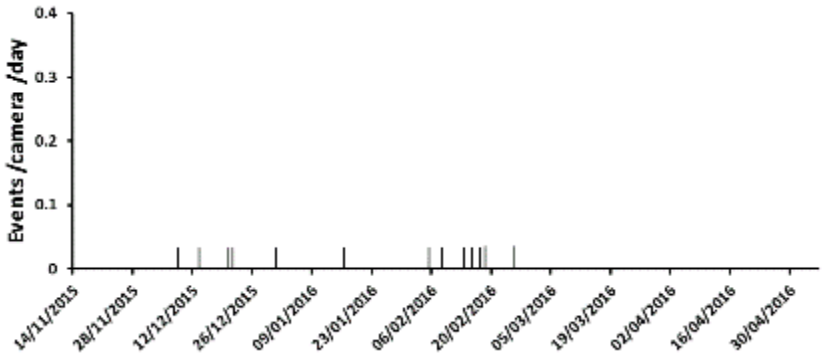


Agile mangabey continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

24) GALAGO SP.

- Only one nocturnal event occurred at the furthest south east camera of the grid.
- As the individual has a thick tail, appearance of a mask-patch and was photographed on the forest floor it is likely either Allen's Galago (*Sciurocheirus alleni*) or Gabon Squirrel Galago (*Sciurocheirus gabonensis*) based on IUCN distribution maps.
- Camera-trapping is not suitable for reliable bush baby identification due to swift movements and low nocturnal image resolution.

Global conservation status:
N/A

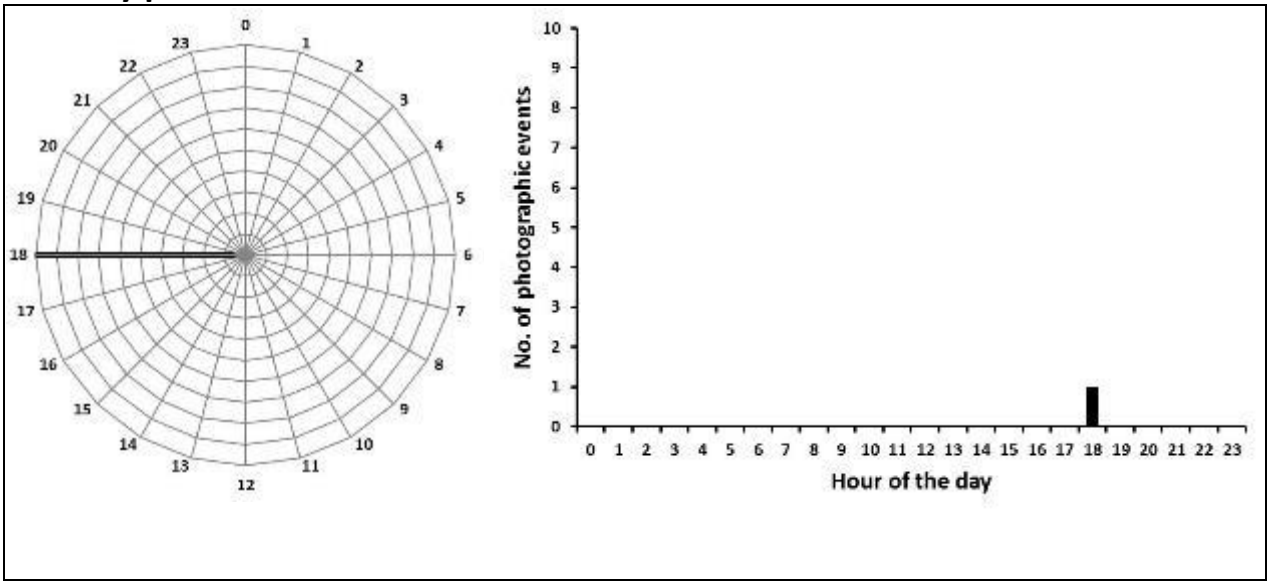
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	1	1	3

Trapping rates, occupancy and detectability

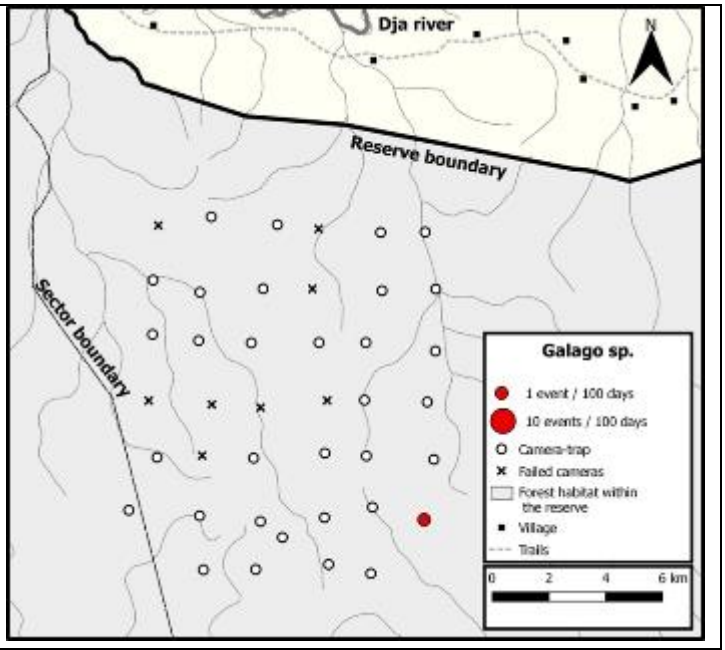
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.03 (0.03)	0.03	N/A	N/A

Activity pattern

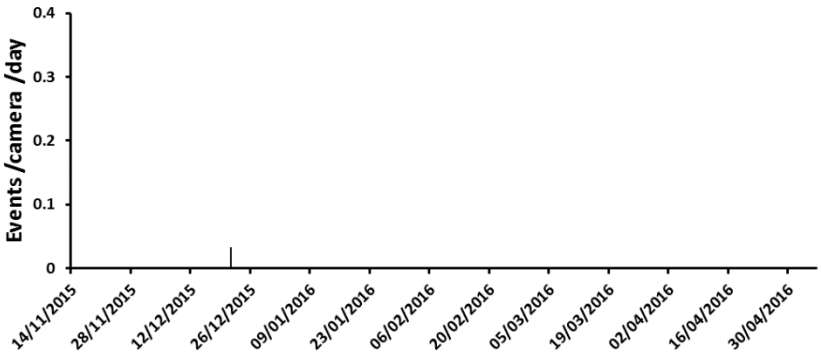


Galago sp. continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

25) GIANT PANGOLIN *(Smutsia gigantea)*

- All detections were of a solitary adult pangolin. Identification of individuals is not feasible using infra-red imagery.
- 90% of records of the giant pangolin occurred >8 km from the reserve boundary.
- The distribution map suggests they are encountered more frequently towards the centre of the reserve.
- Camera-trap encounters as expected indicate a nocturnal activity pattern peaking at 4 AM.
- One event took place just after dawn at 7am, which is thought to be unusual for this species (Kingdon et al. 2013).

Global conservation status:
Vulnerable (Waterman et al. 2014b)

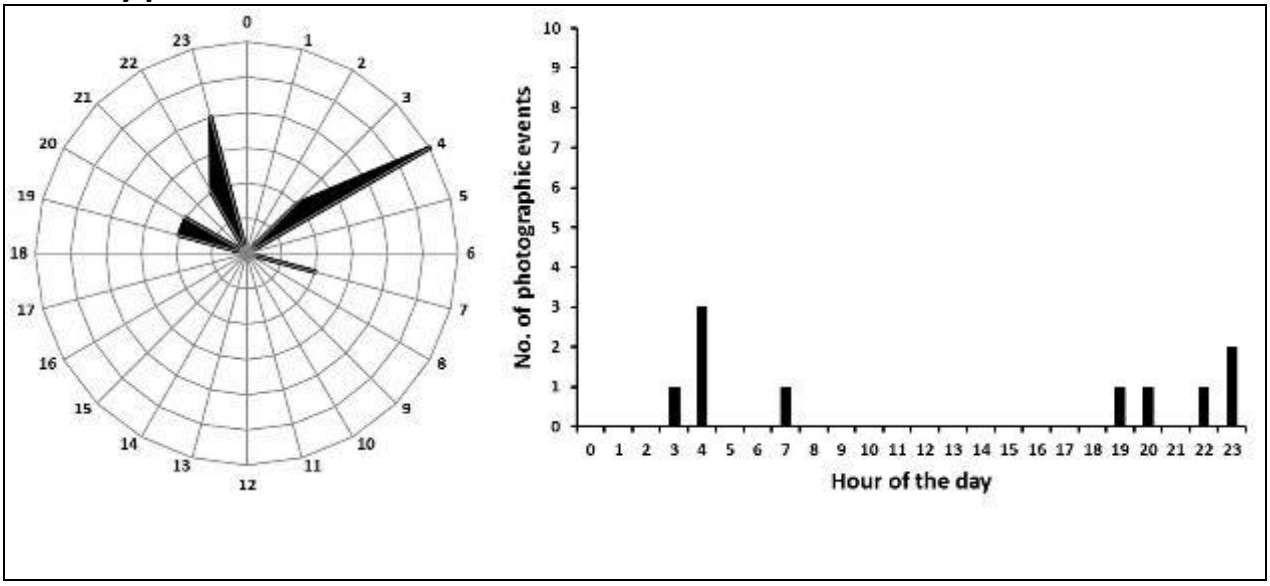
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	7	10	72

Trapping rates, occupancy and detectability

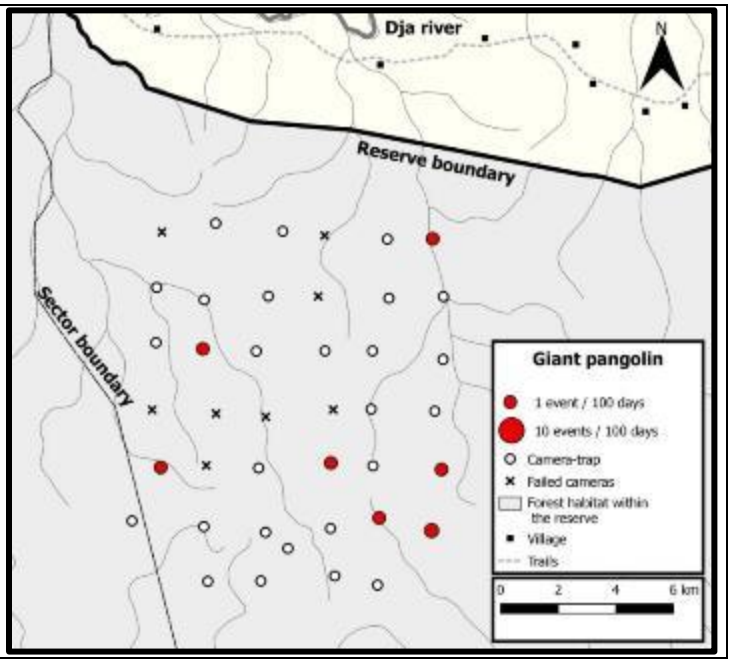
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.22 (0.08)	0.21	N/A	N/A

Activity pattern

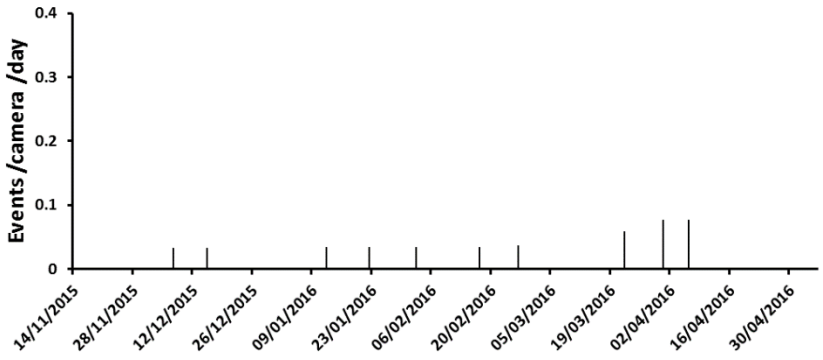


Giant pangolin continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

26) WHITE-BELLIED PANGOLIN *(Phataginus tricuspis)*

- White-bellied pangolin was the most frequently detected pangolin species, recording double the number of events compared to giant pangolin.
- Timing of camera trap data suggests a strictly nocturnal activity pattern.
- The species distribution map suggests that they are more frequently encountered towards the interior of the reserve.
- The white-bellied pangolin is equally adapted to foraging in trees and on the ground (Kingdon & Hoffman 2013).

Global conservation status:
Vulnerable (Waterman et al. 2014a)

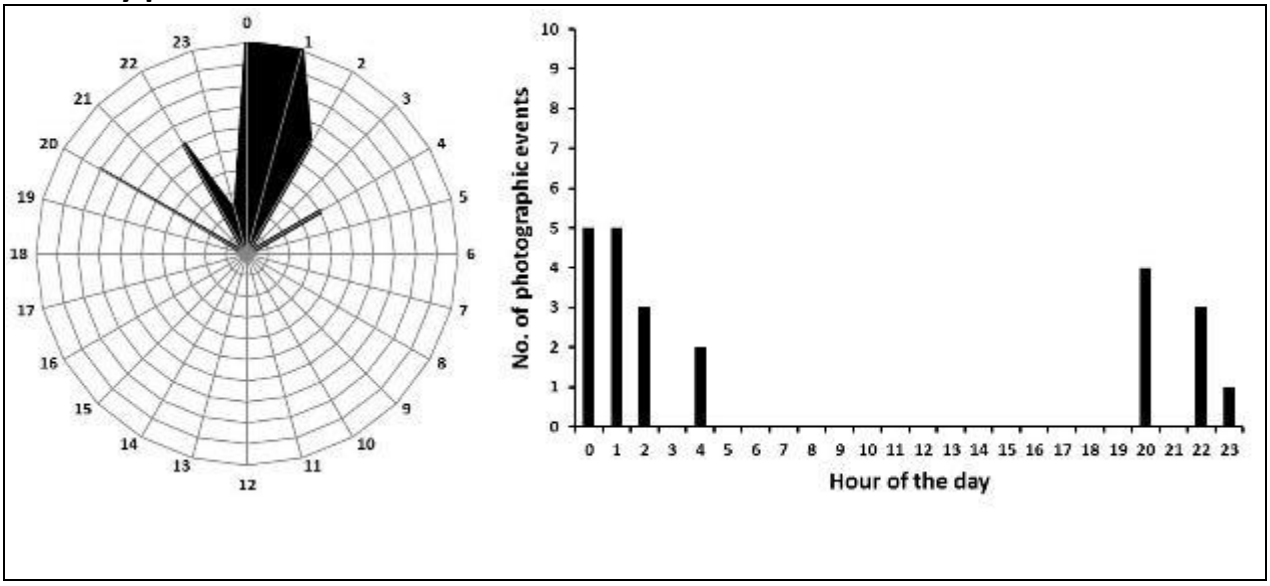
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	12	23	174

Trapping rates, occupancy and detectability

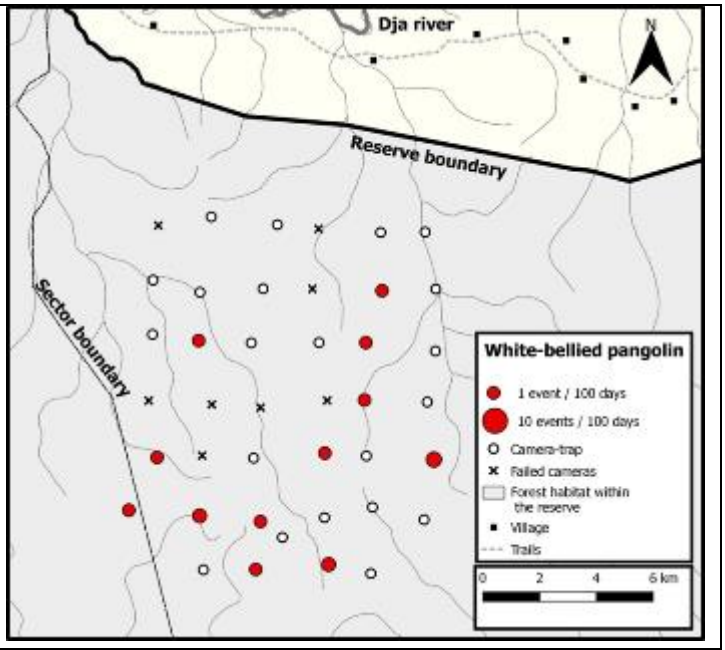
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	0.66 (0.15)	0.36	N/A	N/A

Activity pattern

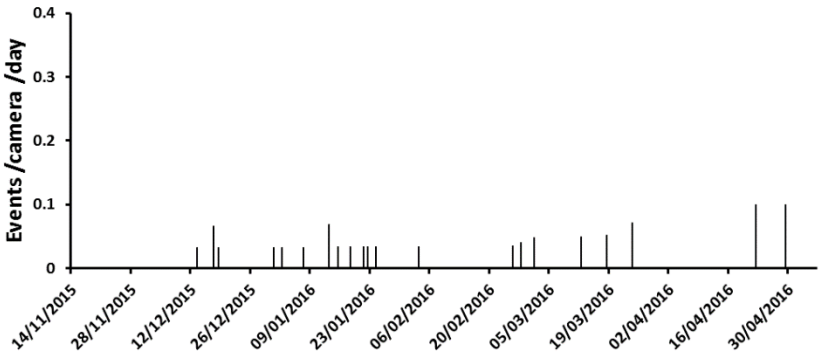


White-bellied pangolin continued

Variation in trapping rate through the camera grid:



Temporal variation in detections:



Spatial variation in occupancy: The temporal and spatial distribution of detections was insufficient to reliably model occupancy.

27) EMIN'S POUCHED RAT *(Cricetomys emini)*

- The largest African forest murid rodent.
- No preference for habitat type within the northern sector as it was evenly distributed throughout the camera-trap grid.
- Timing of camera-trap events demonstrates a strictly nocturnal activity pattern.
- An important prey species for small carnivores such as long-nosed mongoose and black-legged mongoose (Ray 2013).
- A solitary species with all detections being of individuals.

Global conservation status:
Least Concern (Cassola 2016)

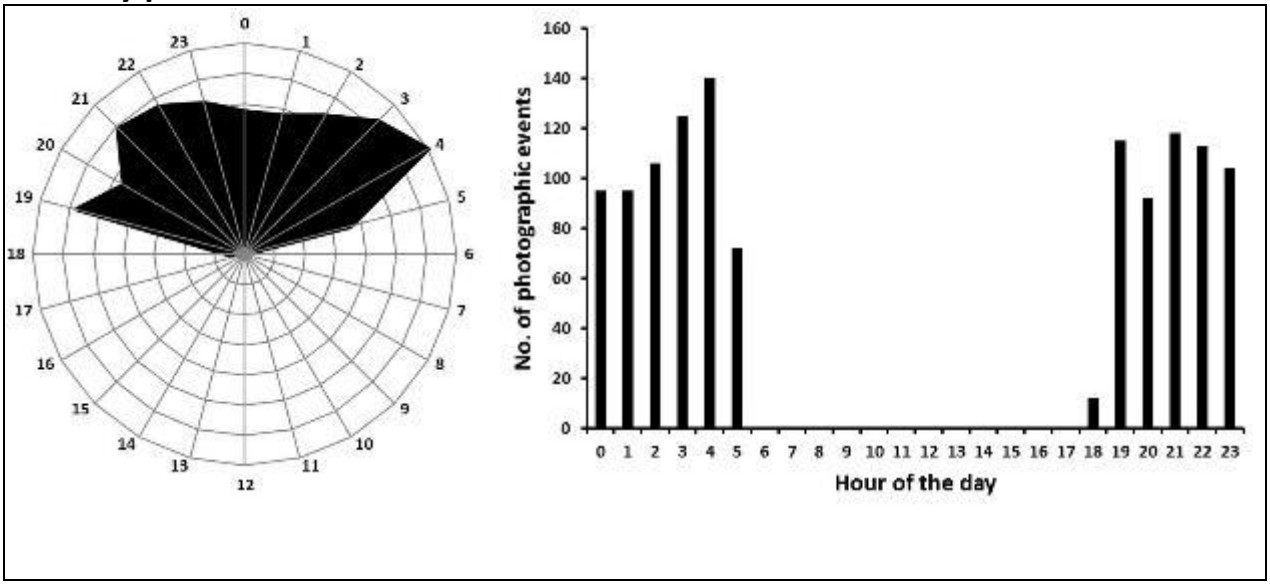
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	31	1,187	10,862

Trapping rates, occupancy and detectability

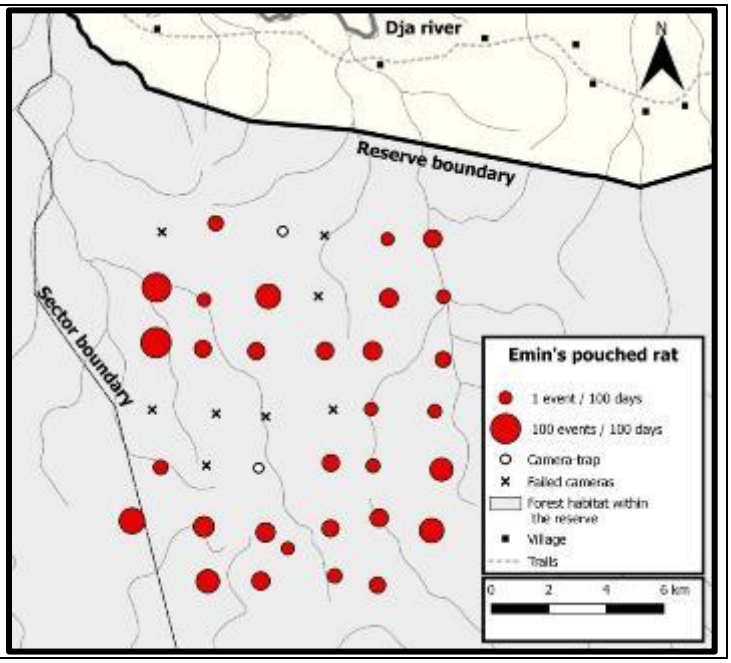
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	30.2 (1.4)	1	1 (0)	0.7 (0.02)

Activity pattern

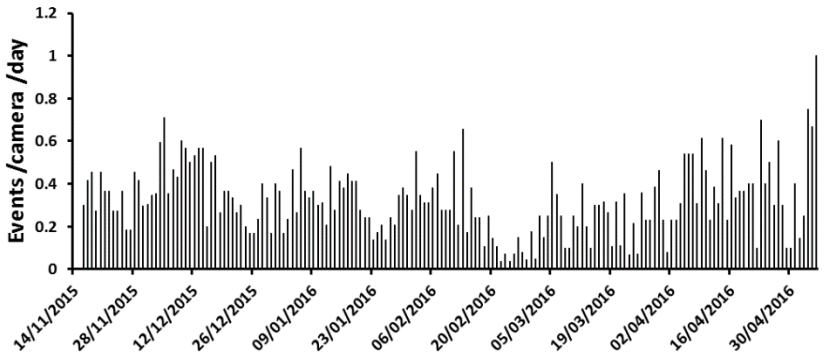


Emin's pouched rat continued

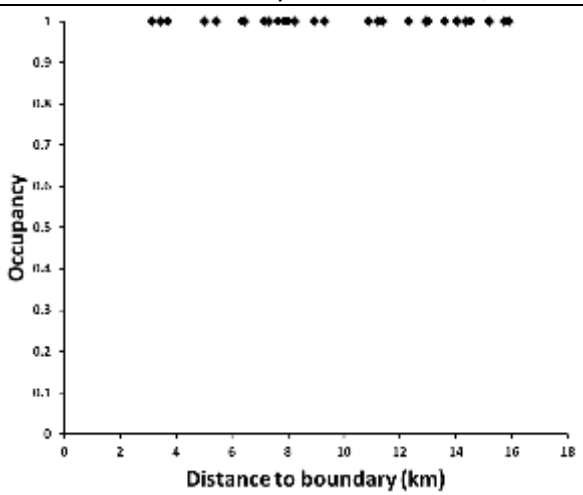
Variation in trapping rate through the camera grid:

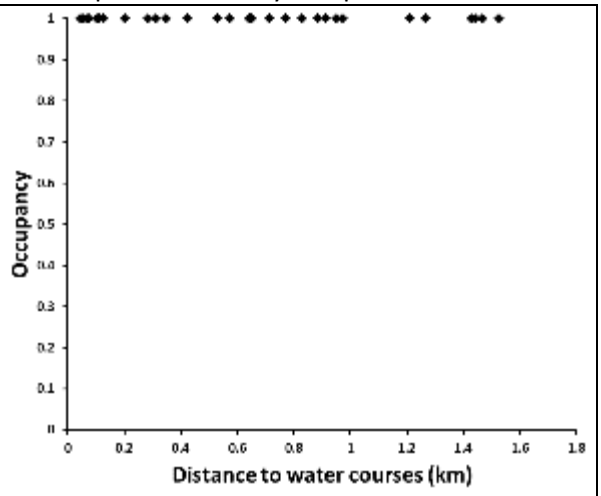


Temporal variation in detections:



Spatial variation in occupancy: Modelling showed no evidence of changing occupancy with distance from boundary or water source; covariates did not improve efficiency compared to null.





28) AFRICAN BRUSH-TAILED PORCUPINE *(Atherurus africanus)*

- Timing of events suggests a trimodal nocturnal activity pattern, peaking at 19:00-20:00, 00:00 -01:00 and 03:00-04:00 with two rest periods.
- A majority of events were of individual adults. However, six pairs of adults and an adult and a juvenile were recorded together.
- Photographed following a Servaline Genet on 11/12/2015, the reasons for this are unclear as it was only observed once.
- Occupancy values increased with distance to the boundary of the reserve, possibly due hunting pressure (Happold 2013).

Global conservation status:
Least Concern (Hoffman & Cox 2016)

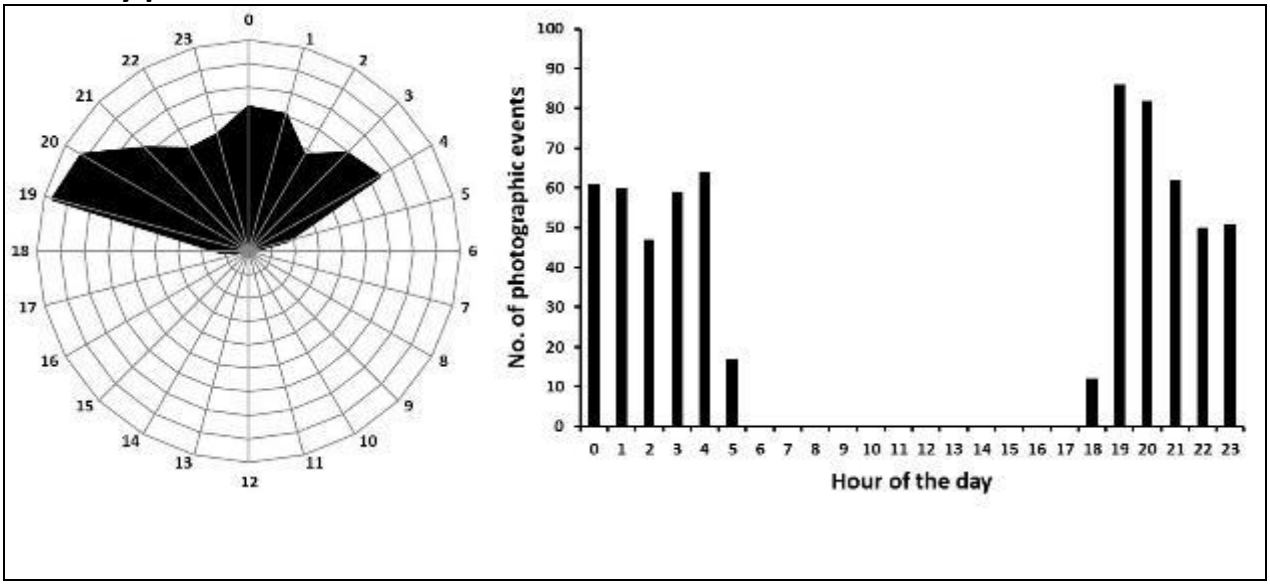
Camera-trap survey results

Survey	No. of camera sites	No. sites detected	No. of events	No. of images
North sector survey 2015 - 2016	33	30	651	5,188

Trapping rates, occupancy and detectability

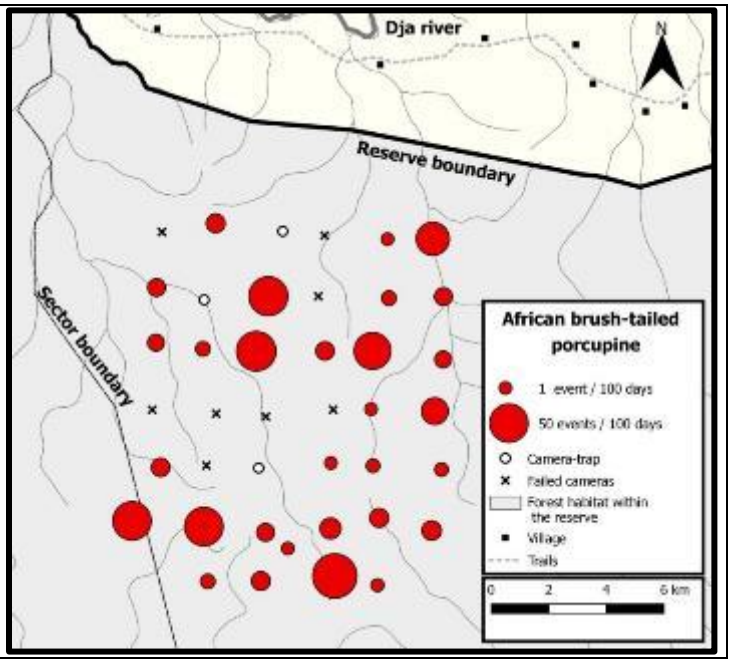
Survey	Trapping rate / 100 days (SE)	Occupancy		
		Naïve occupancy	Modelled occupancy (SE)	Detection probability (SE)
North sector survey 2015 - 2016	17.9 (0.88)	0.93	0.94 (0.05)	0.54 (0.02)

Activity pattern

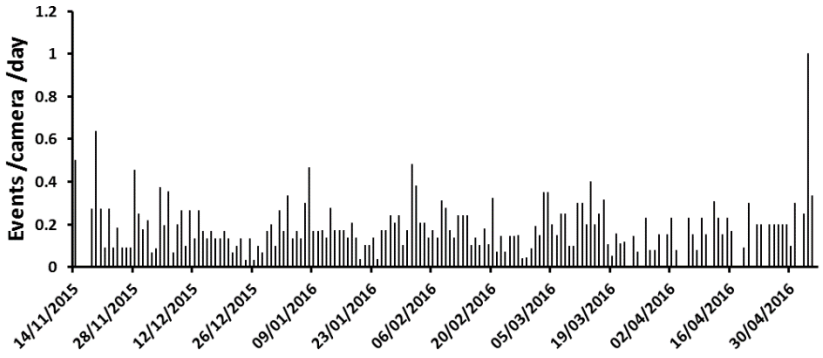


African brush-tailed porcupine continued

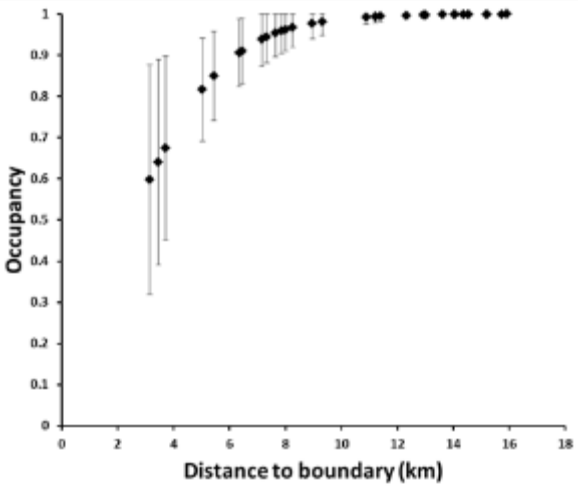
Variation in trapping rate through the camera grid:

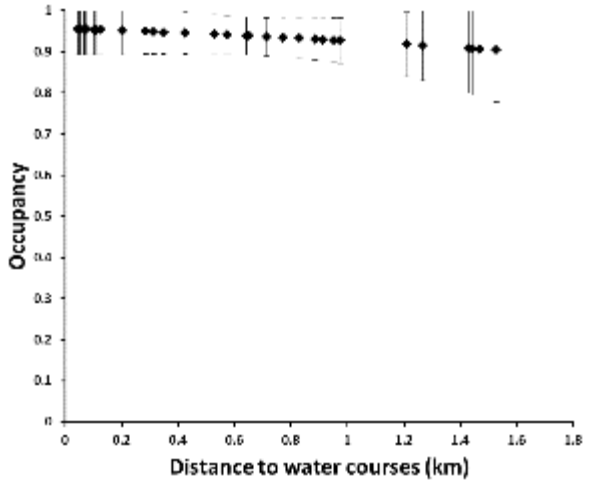


Temporal variation in detections:



Spatial variation in occupancy: Occupancy increases towards interior; distance to the boundary was the only covariate which improved efficiency relative to null.





DISCUSSION

Threats to the Biodiversity of the Dja Biosphere Reserve

The Dja landscape is currently experiencing ongoing degradation of habitats and diminishment of vertebrate faunas driven by road-building, settlement, logging operations, dams, agroindustry clearance, mining operations, and intense bushmeat and illegal wildlife trade poaching (Ngandjui 1997, Muchaal & Ngandjui 1995, 1999, Ngandjui & Blanc 2000, 2001, UNESCO 2011, Diedhiou & Diawara 2015, MINFOF & IUCN 2015). Fortunately, forest loss and degradation within the Dja Faunal Reserve, a sizeable (5,260 km^2) and contiguous expanse of tropical forests more than times the size of Greater London, is minimal (see Brashares et al. 2001). The trees remain standing and the government is committed to help them remain so (MINFOF 2004).

Logging occurs within surrounding forestry management units (FMU) that function as important extensions of natural habitat around the reserve and support wildlife that are part of the effective populations of DBR wildlife. The tree cover will largely remain in the FMUs. However, the largest size classes of targeted tree species are being widely removed within FMUs, their loss having long-term cascading ecological impacts as they provided key food resources for many larger vertebrates and they had an inordinately large contribution to seed and seedling production of the species across landscapes. The road networks within FMUs also facilitate access for poaching and act as dispersal routes for invasive *Wasmannia auropunctata* ants (Walsh et al. 2004). Equally concerning, contiguous tracts of intact forest that connect the Dja Reserve to adjacent forest blocks (that is, landscape corridors) are rapidly disappearing due to settlement and clearing along roads and the reserve may soon be somewhat of an island for larger species, such as elephant and gorilla. The Forestry Management Unit (FMU) 10-036 SIM located on the southeast corner of the reserve remains the last functional corridor for wide-ranging species, such as forest elephant, in the Dja to the greater Tri-National Dja-Odzala-Minkebe Landscape (TRIDOM) forested landscape.

The most rapid and significant biodiversity loss in the Dja Reserve is the defaunation of the ecosystem (Ngandjui 1997, Ngandjui & Blanc 2001, UNESCO 2011, Robinson 2013). Indeed, defaunation is a widespread and significant threat throughout Congo Basin forests (Craigie et al. 2010, Abernethy et al. 2013). The loss of larger animals takes key seed dispersers out of the ecosystem, alters forest succession patterns, removes forest 'architects' (for example, elephants keep forest clearings open), and disrupts food webs (Abernethy et al. 2013, Turkalo et al. 2013). Within the Dja landscape, larger vertebrate faunas are being depleted and lost as poaching for ivory, pangolin scale, great apes, and bushmeat is widespread and intensifying throughout the landscape, including within the reserve (Bobo et al. 2014, ZSL & MINFOF 2016), and legal trophy hunting continues in designated zones outside of the DBR. The increase in infrastructure associated with industries around the reserve has also been shown to reduce habitat availability and isolate populations of wildlife (for example, forest elephants in the Congo Basin), threatening their long-term conservation (Blake et al. 2008) and, simultaneously, allowing hunters easier access to previously relatively inaccessible areas (Fa & Brown 2009).

Given the intense hunting pressure throughout the DBR landscape, a key management question is whether there are core areas within the broader reserve that can function as refugia to allow vulnerable species to persist over time even under current hunting levels. Presently, certain sectors within the Dja Reserve are suggested to have higher concentrations of great apes and elephants than other sectors from line and recce transect data (for example, the northeast sector; see Latour 2010, MINFOF & IUCN 2015), but it remains uncertain if this variation stems from more favourable habitat, fewer threats, or seasonal movements. Rugged terrain, swampy habitats, distance from settlements and rivers, and frequency of patrols may all be factors that can enhance the refuge value of a particular area (see Bashares et al. 2001). This camera-trap survey enables managers to (1)

better estimate how impacted the larger terrestrial vertebrate fauna is from hunting and (2) begin to build a picture of which factors may or may not contribute to protecting vulnerable populations and, if they can, how management activities can enhance or diminish the effect. Combined with future camera-trap surveys data, it can help confirm variations in wildlife concentrations across the DBR observed through line transect and recce surveys, as well as patrol-based direct encounters.

Mammalian Terrestrial Megafauna Persists in the Dja Biosphere Reserve

This first systematic camera-trap survey for medium-to-large terrestrial mammals in the Dja Biosphere Reserve has provided evidence that it remains an important protected area for the conservation of medium-to-large terrestrial mammals in the Congo Basin. This contradicts previous reports (Steyn 2015). Despite pervasive bushmeat hunting and intensifying illegal trade in elephant ivory, pangolin scale, and great apes, the survey has documented continued presence of all these species in a small sample area (3-4% of the greater reserve) located relatively close to permanent settlement (that is, from 6 to 19 km). The detection of several species on the IUCN Red List of Endangered Species, including Western lowland gorilla (Critically Endangered), central chimpanzee (Endangered), African (forest) elephant (Vulnerable), giant pangolin (Vulnerable), bongo (Near Threatened), and white-bellied pangolin (Vulnerable), highlights the persistence of populations of these vulnerable species within the reserve.

Although twenty-three medium-to-large terrestrial mammals were recorded, no medium- or larger-sized carnivores were detected. Notably, this includes the only two felid species (leopard [*Panthera pardus*] and African golden-cat [*Caracal aurata*]) expected to occur within the study area. The species rarefaction curve reached an asymptote and the species richness estimate converged after 170 and 148 days of survey effort, respectively. This convergence suggests that most of the species that occur in the area of the camera-trap grid were detected. As this survey was conducted only in one sector of the DBR, the failure to detect the two species of felid is not conclusive evidence that they are absent from the reserve as even a large survey effort using camera-traps does not guarantee complete inventories (Rovero 2010). Both species are rare and elusive (Bahaa-el-din et al. 2015, Henschel & Ray 2003) and greater survey effort and future camera-trap surveys in different sectors are required to establish the status of the larger carnivore species within the reserve as a whole. The non-detection of wild felids in this survey may be due, in part, to their natural rarity or be a consequence of their vulnerabilty to snares (Bahaa-el-din et al. 2015). The latter may drive wild felids to be among the first species to 'disappear' as poaching intensifies in Congo Basin forests. Note spotted hyena, a large carnivore, were documented by camera-trap at Nki National Park located roughly 90 km to the southeast of the DBR in 2016. The species occurrence in the DBR is presently uncertain.

In 2016, The World Heritage committee expressed its concern as stated in document 40 COM 7B.79, paragraph 6 (http://whc.unesco.org/en/soc/3454) regarding the findings of the 2015 joint World Heritage Centre/IUCN Reactive Monitoring mission (Diedhiou & Diawara 2015) regarding the serious threats to the Outstanding Universal Value (OUV) (see Table 3) of the Dja Reserve World Heritage Site. It stated that, alongside the lack of environmental impact mitigation from the nearby Mékin Dam and Sud Hévéa rubber plantation, the increase in poaching resulted in a worrying decrease in the numbers of large mammals, in particular the elephant (Diedhiou & Diawara 2015). Large mammal populations, including those of forest elephant and great apes, are, assuredly, decreasing in the DBR landscape, but the findings of this survey show that none, except perhaps the two wild felid species, have been extirpated and abundances for many species are not exceptionally low, such as for the larger-bodied duikers.

Estimating the 2016 Intactness of the Dja Biosphere Reserve's Larger Terrestrial Vertebrate Fauna
In tropical forests around the world, one can generally categorize the 'intactness' of larger terrestrial vertebrate assemblages (that is, terrestrial megafauna) along a continuum of intactness (that is, presence of naturally occurring species and ecological guilds in populations within their natural range of variation and maintaining their functional role in an ecosystem) as follows (Fig. 3, Table 3):

(1) **intact** (that is, the full complement of naturally-occurring species and guilds present within their natural ranges of variation and maintaining their ecological roles);

(2) **relatively intact** (that is, most, but not all, of naturally-occurring species and guilds present within their natural ranges of variation and maintaining their ecological roles);

(3) **diminished** (that is, most to all species are present but in reduced abundance below their estimated natural range of variation and some ecological roles and guilds becoming compromised);

(4) **depleted** (that is, a number of more vulnerable species are missing along with their ecological roles and whole functional guilds are largely gone); and

(5) **largely extirpated** in an **'empty forest'** syndrome (Redford 1992, Harrison 2011, Wilkie et al. 2011, Abernethy et al. 2013, Donoso et al. 2017) condition (that is, all but the least vulnerable larger vertebrates have been extirpated along with their ecological roles) (Fig. 3).

Defining what constitutes a relatively intact fauna is important to establish useful benchmarks for assessing how impacted megafauna might be in any given area. Intact faunas are increasingly rare in the region and there is natural variation among assemblages for ecological reasons. However, a comprehensive evaluation of older surveys (for example, Lejoly 1995, Williamson & Usongo 1995, Gartlan 1996, Whitney & Smith 1998) and recent surveys across the broader TRIDOM landscape and region (Morgan et al. 2006, Latour 2010, Wittemyer 2013, Bobo et al. 2014, Beudels-Jamar et al. 2016, Nzooh Dongmo 2016abc) can be used to provide a benchmark for what a relatively intact megafauna 'should' be in the region (that is, for example, what it would have been 100 years ago).

In the defaunation process, wildlife populations in tropical forest ecosystems are generally diminished or extirpated due to direct hunting or indirect mortality from traps and snares. Species may also disappear over time as available habitat goes below minimum-area and condition requirements from habitat degradation, fragmentation, and isolation. Some species may also be extirpated as keystone species that play an inordinately important role in maintaining critical ecological processes disappear. For example, forest elephants help keep forest clearings open that are favoured by bongo. And some species, like white-bellied duiker, are suggested to be sensitive to even low levels of anthropogenic disturbance (Hart 2013b). However, the current overarching driver of defaunation in Congo Basin forests is hunting for bushmeat and species targeted by the international illegal wildlife trade (for example, forest elephant, pangolins, and great apes).

Various species, and perhaps key ecological processes and guilds, are predictably lost or shift in their relative importance, in general, as hunting intensifies and continues over time (Redford 1992, Oates 1996, Harrison 2011, Wilkie et al. 2011, Remis & Robinson 2012, Abernethy et al. 2013, Poulsen et al. 2017; Fig. 3). For example, felids and larger primates tend to disappear first, followed by larger mammals, such as elephant and bongo. White-bellied duiker are also believed to be particularly sensitive to disturbance and are lost quickly. Given the intense targeting of giant pangolin for their scales for the illegal wildlife trade (IWT), this poorly-known species may be among this group of highly vulnerable species, as well. Larger primates and larger birds, especially frugivorous species, also tend to decline under sustained and intense hunting conditions. In the diminished fauna status

category, we would expect that all these species will only be present at lower abundances or be absent entirely. In the depleted status category, for example, larger duikers, such as the yellow-backed, Peter's, and Bay are typically hunted out, along the more vulnerable species. In 'empty forest' situations, giant pouched rats, porcupines, blue duiker, and smaller-bodied generalist species tend to be the only species that persist in any numbers. The loss of larger predators can also result in 'mesopredator release', whereby small-to-medium sized carnivores (that is, mesopredators) become more abundant as competition and mortality associated with the presence of larger predators declines, though the extent of this effect may depend on the sensitivity of mesopredators to snaring and other trapping methods and the process is not well understood in Congo Basin ecosystems (see Abernethy et al. 2013).

How can we use camera trap surveys to accurately predict which status category a given forest megafauna falls within? Line transects and recce surveys are well-suited for estimating populations of forest elephant and great apes (Latour 2010, Walters 2010, Nzooh Dongmo et al. 2016abc). Such surveys are not particularly good, however, at gathering useful data for smaller species that leave less visible or identifiable sign. For example, MINFOF & IUCN (2015) failed to detect giant pangolin, species of smaller carnivores, porcupines, or pouched rats throughout the entire reserve, and they lumped all three red duiker species together. Camera trap surveys are quite efficient for collecting useful data for these species, especially those with smaller home ranges, and those that are nocturnal, shy, and cryptic. They also appear to be useful for reliably distinguishing unambiguous presence of some of the larger and more vulnerable species, for example, chimpanzee, and gorilla. Trapping rates of camera traps may also correlate well with abundance data from and line transect and recce surveys, but this needs to be further evaluated (see Walters 2010). Line transect and recce surveys may be able to detect changes in elephant, chimpanzee, and gorilla populations with greater sensitivity than camera-trap survey data (see Latour 2010, Walters 2010, MINFOF & IUCN 2015), though this requires further testing to better understand the strengths and limitations of each survey method for different subsets of the fauna. Another outstanding question is whether patrol-based encounter rates demonstrate similar trends for assessing where a forest fauna sits within the intactness continuum (for example, ZSL & MINFOF 2016). In summary, camera-traps surveys initially appear to be quite useful for determining if a given forest still remains in the relatively intact or diminished status category, especially as they are comparatively less intrusive than other methods. Because they are quite good at surveying smaller-bodied cursorial, cryptic, and nocturnal species (see Bahaa-el-din et al. 2015, Nakashima 2015), they are particularly important for assessing the status of forest faunas in the depleted and 'empty forest' condition, as well as providing confirmation of the relatively intact and/or diminished state ascertained through line transect and recce survey data. Camera-trap data may be used in combination with distance sampling and encounter data to provide a broader, more accurate, and more finely-resolved picture (spatially and in terms of the overall faunal assemblage) of the extant terrestrial vertebrate fauna than data from one method alone.

From the data gathered in this camera trap survey, and given the categories described, we believe the Dja Biosphere Reserve larger terrestrial vertebrate fauna falls, most likely and within the zone of the camera trap grid, in the Diminished Faunal Status category. All the larger vertebrates, except for wild felids perhaps, still occur within the Dja Reserve, albeit likely at diminished abundances. That no felids, golden cats or leopards, were documented in the survey lends support to this categorization, rather than the relatively intact fauna status, as golden cats tend to occur only in forests with little disturbance (Bahaa-el-din et al. 2015). The presence of larger-bodied duikers also supports this categorization as they often are rare or extirpated under intensive hunting. The larger landscape, such as the FMU estate surrounding the reserve, remains important for the long-term protection of vulnerable wildlife populations within the DBR and must be considered in any estimate of the trajectory of the status of the DBR's megafauna (Clark et al. 2009, Bobo et al. 2014).

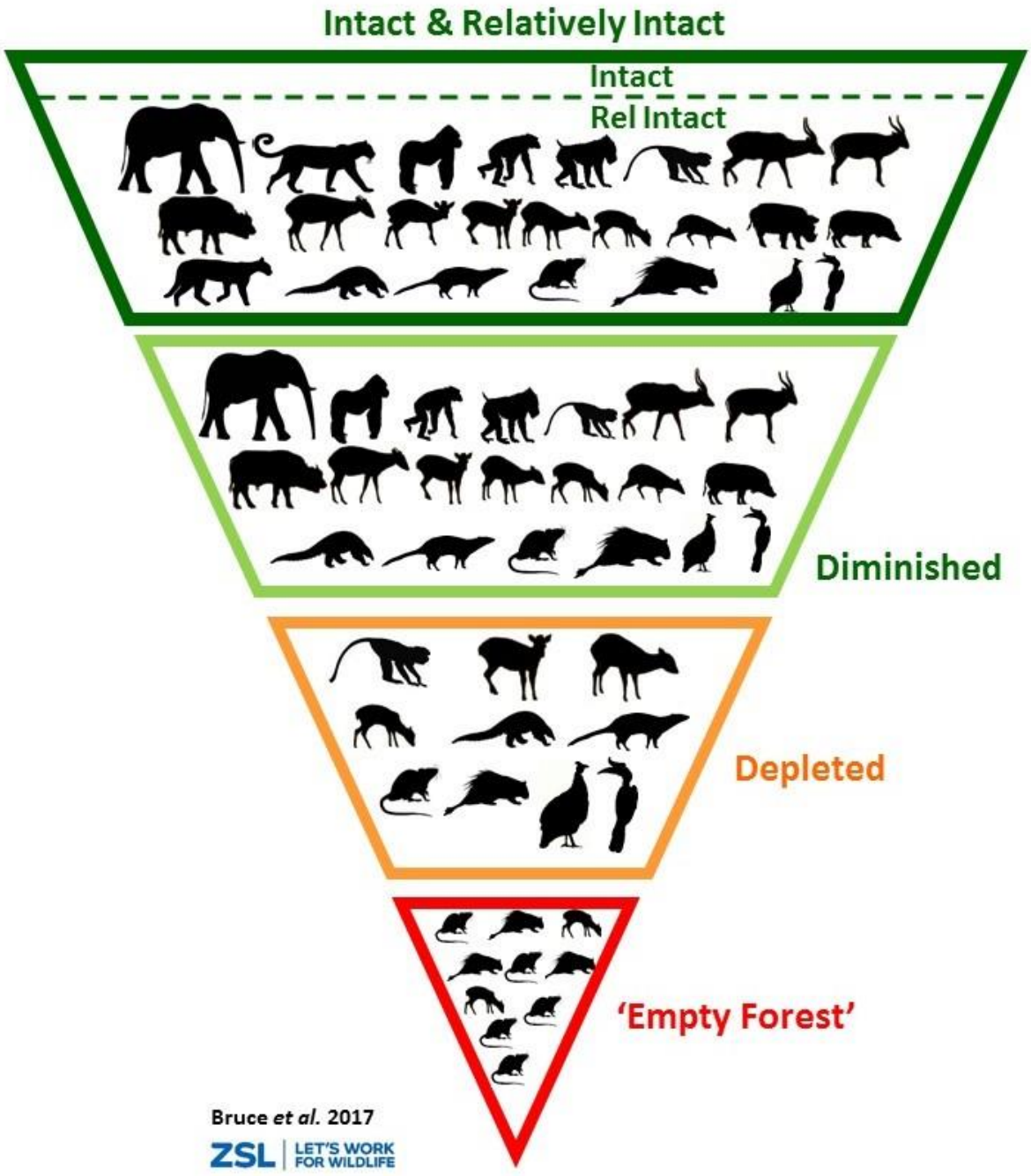


Figure 3. A conceptual model of defaunation status categories of the megafauna of tropical forests in the northwest Congo Basin. As defaunation proceeds, certain species and guilds are reduced or extirpated over time. Some species may become more prevalent. (Credits: ungulate silhouettes from www.ultimateungulate.com; golden cat silhouette from L. Bahaa-el-din imagery)

Table 3. This table presents ZSL's snapshot assessment of the status of the biodiversity and intactness of the Dja Faunal Reserve and environs (UNESCO Outstanding Universal Values for World Heritage Site status) as of April 2017. Estimates for the level of threat, trajectory of change, and priority for action are provided.

Outstanding Universal Value	*Current Status*	*Threat*	*Trajectory*	*Priority for Action*
I. HIGH BIODIVERSITY				
a. Total Species Richness	**REL. INTACT**	**LOW**	**SLOW DECLINE***	**LOW**
b. Megafauna Intactness	**DIMINISHED & THREATENED****	**HIGH**	**STEADY DECLINE**	**HIGH**
c. Keystone Species* (elephant, g pangolin, g apes)**	**THREATENED**	**V HIGH**	**RAPID DECLINE (?)****	**V HIGH**

projected drier and hotter conditions will accelerate species loss through climate change over coming decades
****All megafauna species believed to still occur within reserve, though some species are declining (felids, elephant, gorilla, chimpanzee)***
*****keystone species are those species whose activities have an inordinate importance in determining ecological processes for the ecosystem and a wide range of species***
******indications of widespread and intense poaching of elephant suggest rapid declines may be occurring***

II. HABITAT INTACTNESS				
a. Forest Cover	**HIGH**	**LOW**	**STABLE**	**LOW**
b. Degree of Fragmentation within Reserve	**LOW**	**LOW**	**STABLE**	**LOW**
c. Forest Cover, Habitat Fragmentation around DBR	**MEDIUM**	**MED-HIGH**	**ONGOING**	**MED-HIGH**
d. Isolation of Dja Reserve	**MEDIUM**	**HIGH**	**HIGH ISOLATION RISK**	**HIGH***
e. Dja River Ecosystem	**MEDIUM****	**HIGH**	**DEGRADING**	**HIGH**

only one contiguous corridor of forest cover in the southeast links the Dja Reserve directly to the greater TRIDOM landscape – developing the road and more intensive logging will cause the corridor to be lost
****dams have altered water quality and flow regimes, including seasonal flood cycles, and blocked seasonal longitudinal and lateral fish migration***

Characterization of the Forest Fauna based on the Camera-Trap Survey Data

The three most frequently recorded medium-to-large mammals in this survey were blue duiker, giant pouched rat, and African-brush tailed porcupine as measured by trapping rates and occupancy values. These species are ranked as the top three species harvested for bushmeat in Cameroon (Fa et al. 2005). These top three bushmeat species all recorded occupancy values of >94% and both Peter's duiker and Bay duiker, which are both preferred species for hunters in the Congo Basin (Fa et al. 2005, Nasi et al. 2011, Yasouka et al. 2015), were highly abundant within the sample, their occupancy values were >90%. This is evidence that the Dja Reserve's northwest sector is, currently, not yet experiencing 'empty forest syndrome' (Abernethy et al. 2013, Wilkie et al. 2011, Redford 1992)—the widespread and profound loss of larger vertebrates in forest faunas, which was suggested to be case for the Dja Reserve in some recent reports (Steyn 2015).

Comparison of Rates of Abundance Index (RAI) for Megafauna with the MINFOF & IUCN survey (2015) and surveys of other selected West and Central African Protected Areas

Due to the large variable home ranges of forest elephant (Blake 2002), chimpanzee (Newton-Fisher 2003), and gorilla (Bermejo 2004) that exceed this survey's inter-trap distances of 2 km, the positive relationship between occupancy and abundance (He & Gaston 2003, Holt et al. 2002) cannot be relied upon (Ancrenanz 2012) as with species with smaller home ranges, such as the duiker species. The relative abundance of forest elephant as measured by detection rate appears to be higher in the North Sector than those recently found by sign surveys (MINFOF & IUCN 2015). This observation may be due, in part, to forest elephants moving seasonally within the forest (Blake 2008, Mills 2017) as the MINFOF & IUCN and this survey were conducted in a different seasons. Elephant detection rates and proportion of the area used reported from this study for the DBR were lower than in Dzanga Sangha National Park and environs using the same camera-trap survey methodology (Beduels-Jamar et al. 2016). This difference may be due, in part, to lower hunting pressure and a larger population of elephants in Dzanga Sangha. However, the Dzanga Sanga conservation landscape is approximately $1/5^{th}$ the size of the DBR (African Elephant Database 2013) and, as forest elephant's ranging behaviour is altered by human disturbance, such as logging (Blake 2008), these factors could artificially increase the proportion of the habitat being used and associated detection rates.

Gorilla and chimpanzee vary in their abundance and distribution within the northern half of the DBR according to line transect and recce surveys (Latour 2010, MINFOF & IUCN 2015). Chimpanzee were found to have higher a higher concentration of nests towards the core of the North Sector (Latour 2010, MINFOF & IUCN 2015). Detection rates were greater further away from the boundary of the reserve, in general. In comparison, gorilla nests were not detected in a large area of the North Sector and, when found, occurred at low densities (MINFOF & IUCN 2015). Similarly in this study, gorilla were detected infrequently compared to chimpanzee. Both species are known to alter their ranges spatially to avoid areas of human disturbance (White & Tutin 2001, Arnhem et al. 2008, Morgan et al. 2015). The distribution of gorilla in both this survey and the MINFOF and IUCN faunal inventory could suggest that human activity is pushing both gorilla and chimpanzee towards less disturbed areas, such as the core of the reserve. Both Latour (2010) and MINFOF and IUCN (2015) suggest a concentration of both great ape species towards core habitats of the northeast section of the DBR for reasons that are not yet understood.

Giant pangolin were encountered more frequently towards the core of the reserve in this survey. Given the widespread exploitation of the species (Kingdon et al. 2013), intensive hunting pressure may be influencing their distribution within the DBR. Anecdotal reports suggest that poachers have taken to digging out giant pangolin from burrows in other protected areas in Cameroon (for example, Mbam et Djerem National Park), highlighting the increasing valuation and targeting of this species by poachers. The occupancy and trapping rates of giant pangolin in this survey were higher

than those recorded in Dzanga Sangha and at a similar level to those found in Sapo National Park, Liberia (Amin et al. in prep). The MINFOF and IUCN (2015) faunal inventory of the DBR, employing line transect and recce surveys, techniques commonly used for faunal inventories in Central African forests, failed to detect any presence of pangolin in the reserve (MINFOF & IUCN 2015).

The low detection of bongo in this survey was consistent with the findings of the faunal inventory conducted by MINFOF and IUCN (2015) and in Dzanga Sangha (Beduels-Jamar et al. 2016). Bongo are considered to occur in low numbers in large areas of closed canopy forests and favour areas of forest-savanna transition zones (Elkan & Smith 2013). However, ZSL has photographed (using camera-traps) a herd of bongo in a clearing in the South Sector of the DBR in December 2016.

Selected Species Patterns

1. A pronounced pattern within the North Sector is that the herbivore guild retains healthy populations of species as measured by two metrics, occupancy and trapping rates. However, the carnivore guild is only represented by smaller carnivores with larger carnivores being possibly extirpated from the area. Larger herbivores may be relatively abundant as a consequence of the decline or extirpation of larger carnivores, like leopard, though this remains speculative.

2. Eight species (for example, black-legged mongoose, red river hog, Bate's pygmy antelope, Peter's duiker) displayed a trend of increasing occupancy towards the interior of the reserve (that is further from human habitation). Among these, only three were statistically significant. This suggests that, although a majority of the trends lacked significance, the core area of the reserve furthest away from the boundary and human populations could act as a refuge for species vulnerable to disturbance, such as red river hog and yellow-backed duiker.

3. The black-footed mongoose was the second most frequently detected carnivore during the survey, despite being thought to occur in low abundance in Cameroon (Van Rompaey & Colyn 2013). The species is not often found in disturbed forests. The probability of a site being occupied increased significantly as distance to the boundary increased, which could be due to hunting intensity (guns, snares, other traps) within the core of the reserve being lower than the habitat closer to the boundary (Muchaal & Ngandjui 1999).

4. The detection of mandrill for the first time east of the Dja River inside the reserve represents a minor range extension of approximately 20 km for the species, but one that crosses a possible major barrier of the Dja River (Ngo Bata *in press).*

5. The first observations of Peters' duiker being active nocturnally in 25 separate events (out of 524 events) were recorded in this survey. Previous studies on their ecology have only recorded strictly diurnal activity that is assumed to provide niche separation with the similarly-sized duiker (Feer 1989, Newing 2001, Feer & Mockrin 2013). Peter's duiker were observed foraging and investigating the camera at night.

6. The probability of a site being occupied by Bate's pygmy antelope increased significantly with distance to the boundary. As the species in known to be tolerant of disturbed habitat (Feer 2013), the more intense hunting pressures closer to the boundary of the reserve (Muchaal & Ngandjui 1999) could be affecting the distribution of Bate's pygmy antelope within the reserve.

7. The absence of aardvark (*Orycteropus afer*) from this survey, combined with no records or reports from local villagers or guides of an aardvark being seen in the Dja for several years (T. Smith per. comm.) suggests they may be rare or absent within the reserve.

8. Several species of larger cursorial bird were frequently detected, including Nukulengu rail (*Himantornis haemotopus* – 31% occupancy), plumed guineafowl (*Guttera plumifera* – 27% occupancy), and black guineafowl (*Agelestes niger* – 55% occupancy), and Latham's forest francolin (*Peleperdix lathami* – 73% occupancy). Larger cursorial birds tend to decline when hunting is intense.

9. Six medium to large terrestrial mammals expected to occur in the DBR were not detected in this survey: giant forest hog, white-bellied duiker, leopard, golden cat, large-spotted genet (possible detection), and aardvark. Spotted hyena is known to occur at a locality roughly 90 km to the southeast of the DBR.

Camera-Trap Surveys Complement Other Wildlife Survey Methods

The survey has demonstrated the particular effectiveness of camera-trapping as a method for monitoring medium-to-large mammals (and cursorial birds) within the reserve. This is highlighted by the detection of the six small carnivores and two pangolin species (as well as several larger cursorial bird species) that are frequently missed or grouped together at a familial level in analyses of line transect and recce surveys (MINFOF & IUCN 2015). The cryptic and shy nature, rarity, or nocturnal activity of such species makes them commonly missed or not targeted in transect surveys (Silveira et al. 2003, Tobler 2008, Nakashima 2015).

Camera-trap surveys record a much greater proportion of the larger vertebrate fauna than do line transect and recce surveys that are best-suited for gathering data (direct observations and sign) for larger-bodied species that leave noticeable sign, such as nests and dung (Walker 2010, Bahaa-el-din et al. 2015, Nakashima 2015). Thus, the overall 'intactness' status of the larger cursorial vertebrate fauna within a protected area can be better estimated using camera-trap surveys. However, transect data is superior for gathering data on arboreal primates and avian species. And the distance sampling data obtained through line transect and recce encounter rate surveys also allows for abundance estimates for gorilla, chimpanzee, and forest elephant whose sign (dung and nests) can be aged (see White & Edwards 2001, Maisels et al. 2008, Latour 2010, Thomas et al. 2010, MINFOF & IUCN 2015). An outstanding question is whether modelling camera-trap data using novel approaches, such as the gas dispersion models of Rowcliffe et al. (2008) that incorporate empirical metrics on the movements of certain species over time, can provide estimates of the relative abundance and changes in numbers over time of great apes and forest elephant with as much accuracy as can data derived from distance sampling (see Denes et al. 2015).

Recommended Wildlife Monitoring Program for the DBR

Presently, given a review of past and current efforts and an evaluation of the strengths and limitations of different survey methods as we now know them, we recommend that the wildlife monitoring program for the DBR should consist of the following (this recommendation is provided here for review and revision by MINFOF, partners, and specialists):

1. **Distance Sampling & Encounter Rates** – A full DBR inventory using distance sampling based on line transect and recce encounter rate survey methods for the full set of 5 x 5 km grids for the DBR every four years. Within each sector, select 5 permanent grid blocks towards the core of the reserve for line transects/recces annually and track changes over time. We recommend that grey parrot and species of hornbill be included within the target species of these surveys.

2. **Ecoguard Patrols** – Ongoing direct encounter data for target species (elephant, great apes, bongo, mandrill, felids, pangolin spp.) obtained during regular MINFOF ecoguard patrols (see ZSL & MINFOF 2016).
3. **Bouamir Long-term Monitoring** – Periodically repeated wildlife surveys around Bouamir Field Station that have been run since the early 1990's (Whitney & Smith 1998, Magurran et al. 2010, Campell et al. 2011, Chen et al. in prep).
4. **Camera-Trap Surveys** – Deploy ZSL/MINFOF standard camera trap surveys on permanently established grids in each sector at least once every two years, during the dry season for each grid, wherever possible. The grids should encompass primarily core habitat, that is, they should not be too close to the reserve boundary. Each sector should have 10 permanently running cameras placed in favourable sites in the core habitat (for example, bais [cleared areas]), waterholes, and game trails to track presence or absence of vulnerable species (for example, forest elephant, great apes, giant pangolin, bongo) over time.

Key Questions for DBR Wildlife Monitoring

Future camera-trap surveys within the reserve are recommended to gain further baseline data on medium-to-large mammal distribution and abundance in other sectors. Such surveys can also provide data to help answer several important and outstanding questions and challenges related to wildlife monitoring for the DBR:

1. **Close tracking of the status of DBR's forest elephants and great apes (The Big 3)** – Close tracking of forest elephant and great ape populations is desirable as these species are globally threatened, heavily poached, sensitive to human disturbance, and are demographically sensitive to even low to moderate levels of loss. Presently, distance sampling through line transects and recce encounter rate surveys is the method used to track the status of and shifts in populations within the reserve as a whole and within different areas of the reserve over time. Patrol-based direct encounter rates are also used, but these are not systematically obtained and do not provide a robust population metrics, though long-term data over large areas may indicate real changes in abundance over time. Camera-trap surveys (the standard approach recommended here) are reliable at providing direct confirmation of the presence of elephant, chimpanzee, and gorilla, as opposed to sign-based assessments. Comparing camera trap metrics of occupancy and detection with distance sampling metrics for the abundance and population changes in these species for similar areas may also provide confirmation of trends. However, an outstanding question is whether camera trap data can provide confident insights into status and distribution trends of elephant, chimpanzee, and gorilla, with the same demographic, spatial, and temporal resolution as can distance sampling. Understanding the strengths and limitations of each survey method is important to assess the cost-effectiveness of different wildlife monitoring strategies.
2. **Identifying Refugia within the DBR for Wildlife** – Camera traps can provide direct and supporting (that is, along with distance sampling results) evidence as to whether factors, such as habitat type, terrain, swamps, and distance from park boundaries influence mammal distribution and abundance within the reserve. Some areas within the DBR may have conditions that enable certain wildlife populations to find refuge from intense hunting pressure or find more favourable habitats. Camera trap surveys can provide data that confirms any such patterns suggested by distance sampling surveys.
3. **Attribution of Conservation Impacts to Conservation Actions** – Though it remains challenging to attribute changes in wildlife metrics to management activity (Ferraro & Pattanayak 2000, Sutherland et al. 2004, Plumptre et al. 2014, Dhanjal-Adams et al. 2015, Critchlow et al. 2016), camera-trap survey data provides important information on the status of the reserve's megafauna as a whole, not just the 'Big 3' species of conservation concern (forest elephant, gorilla, chimpanzee), and can help highlight candidate areas within

the reserve or species and guilds deserving of increased management action. For example, giant pangolin can only be adequately surveyed using camera-trap surveys, as direct encounters are rare and there remains an unacceptable level of uncertainty with pangolin sign data.

2017 Cost Estimate for Standard Camera Trap Survey

Costs of the ZSL standard camera trap survey in the DBR can be estimated as follows (2017 costings):

40 Cuddeback Attack IR E2, memory cards (one time purchase)	*$7,200*
Batteries, locks for each deployment	*$580*
Replacement cameras for each grid	*$850*
Camera deployment & retrieval costs (approximately 6 weeks for both) (16 people required for deployment or retrieval)	*$4,000*
Data analysis (2 months)	*$4,000*

In summary, startup costs are roughly $7,780. Each camera-trap grid deployment and analysis is roughly $9,430. ZSL and MINFOF are presently evaluating the relative costs of transect/recce surveys presently so the cost-effectiveness of different survey methods can be assessed.

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Annex I. AIC values for covariate models

nPars is the number of parameters estimated by a model;
delta is the difference in AIC relative to the top ranked model;
AICcwt is the probability that a given model is the best given the candidate models under consideration.

African brush-tailed porcupine *	**nPars**	**AIC**	**delta**	**AICwt**
Distance to the reserve boundary	3	601.51	0	0.71
Null model	2	603.93	2.42	0.21
Distance to nearest water source	3	605.81	4.31	0.08

Bates' pygmy antelope *	**nPars**	**AIC**	**delta**	**AICwt**
Distance to the reserve boundary	3	93.43	0	0.78
Null model	2	96.61	3.18	0.16
Distance to nearest water source	3	98.59	5.16	0.06

Bay duiker †	**nPars**	**AIC**	**delta**	**AICwt**
Distance to nearest water source	3	550.8	0	0.87
Null model	2	555.2	4.4	0.09
Distance to the reserve boundary	3	557.2	6.4	0.04

Black fronted duiker	**nPars**	**AIC**	**delta**	**AICwt**
Null model	2	106.59	0	0.46
Distance to nearest water source	3	107.34	0.75	0.31
Distance to the reserve boundary	3	107.93	1.35	0.23

Black-legged mongoose *	**nPars**	**AIC**	**delta**	**AICwt**
Distance to nearest water source	3	257.42	0	0.53
Distance to the reserve boundary	3	258.67	1.25	0.28
Null model	2	259.51	2.09	0.19

Blue duiker	**nPars**	**AIC**	**delta**	**AICwt**
Null model	2	431.2	0	0.53
Distance to nearest water source	3	432.56	1.36	0.27
Distance to the reserve boundary	3	433.11	1.91	0.20

Cameroon cusimanse *	**nPars**	**AIC**	**delta**	**AICwt**
Distance to nearest water source	3	319.41	0	0.44
Null model	2	319.83	0.43	0.36
Distance to the reserve boundary	3	320.98	1.57	0.20

Emin's giant pouched rat	nPars	AIC	delta	AICwt
Null model	2	540.56	0	0.58
Distance to nearest water source	3	542.56	2	0.21
Distance to the reserve boundary	3	542.56	2	0.21

Peters' duiker	nPars	AIC	delta	AICwt
Null model	2	593.17	0	0.42
Distance to the reserve boundary	3	593.2	0.028	0.42
Distance to nearest water source	3	595.1	1.929	0.16

Red river hog *	nPars	AIC	delta	AICwt
Distance to nearest water source	3	291.38	0	0.99
Null model	2	302.17	10.78	0.01
Distance to the reserve boundary	3	304.13	12.74	0.01

Servaline genet	nPars	AIC	delta	AICwt
Null model	2	471.2	0	0.58
Distance to the reserve boundary	3	473.2	2	0.21
Distance to nearest water source	3	473.2	2	0.21

Yellow-backed duiker †	nPars	AIC	delta	AICwt
Distance to the reserve boundary	3	442.26	0	0.72
Null model	2	444.8	2.54	0.2
Distance to nearest water source	3	446.8	4.54	0.08

* Indicates that any model with a smaller AIC than the null met all three criteria for covariate model selection and can be considered significant.
† Indicates the model with the smallest AIC improved efficiency over the null, but had overlapping standard errors so could not be considered significant.