



**Human impacts on mammal communities in Rio Campo
Nature Reserve, Equatorial Guinea**

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Title

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Running title

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Authors

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Abstract

Equatorial Guinea in central Africa hosts rich biodiversity and a network of protected areas (PAs). However, infrastructure development has facilitated access to previously remote forests. This has likely increased poaching in PAs, thereby complicating the efforts of agencies tasked with protecting threatened mammals. Reserva Natural de Río Campo (RNRC) was previously identified as a priority area for large mammals due to the presence of elephants and great apes, and includes habitat for a diverse mammal community of commonly-hunted species. To assess mammalian diversity in RNRC, we conducted a camera trap survey in 2017 and 2019. We then used a two-step modelling approach to quantify environmental and anthropogenic factors influencing mammal groups. We detected 32 terrestrial mammal species, including endangered forest elephant, western gorilla, chimpanzee, giant pangolin, and white-bellied pangolin. We found bushbuck and sitatunga closer to human-dominated areas, while other common species were, in general, further from development. Monkey and pangolin abundance increased inward from the RNRC boundary. Endangered species appear restricted to northeast RNRC which connects to Campo Ma'an National Park in Cameroon. We recommend using our inventory and distributions of threatened mammals as starting points to determine effectiveness of future anti-

poaching and management strategies on mammal populations.

Keywords

Biodiversity assessment; mammal distributions; hurdle models; species inventory; bushmeat; mammal survey; camera trapping; protected areas

Introduction

Protected Areas (PAs) aim to conserve wildlife and ecosystems in areas threatened by human-mediated impacts (Watson et al. 2014). Despite many challenges, PAs can be instrumental in conserving wildlife in central Africa where, as urban centres grow, infrastructure development and hunting put additional pressure on wildlife (Doumenge et al. 2020). Equatorial Guinea is located in the Gulf of Guinea in central Africa, with its continental region bordered by Cameroon to the north and Gabon to the south. This region has retained forest cover and mammal diversity despite rapid infrastructure development, deforestation, and hunting (USFWS 2014). Demonstrating their dedication to protecting natural resources, the Equatoguinean government created the *Instituto Nacional de Desarrollo Forestal y Gestión del Sistema de Áreas Protegidas* (INDEFOR-AP) which oversees PA management. INDEFOR-AP has designated approximately 20% of the country's landmass into PAs and implemented legislation such as bans on hunting in PAs and of primates (Equatorial Guinea 2007, Doumenge et al. 2020). Additionally, the agency is currently undertaking surveys to determine new areas to prioritise for protection and designate as PAs (personal communication, 2021). Despite these promising measures, limited funding and capacity hinders INDEFOR-AP's effectiveness. Large mammals in Equatorial Guinea have experienced hunting pressure and habitat loss leading to dramatic population declines. At the same time, roads have expanded to meet Equatorial Guinea's national development plan Horizonte 2020, making previously remote forests more easily accessible, leading to increased human-mediated disturbance (USFWS 2014). This development has likely facilitated the transportation of wild meat (or 'bushmeat') from remote forests to urban areas, compounding the overexploitation of wildlife (Fa & Yuste 2001).

The last broad biotic survey of Equatorial Guinea's continental region was conducted in May–June 1998 and combined line transect surveys of animal signs, local community member interviews, and previous surveys to indicate the presence of mammal species in PAs, including *Reserva Natural de Río Campo* (RNRC) (Larison et al. 1999). In 2011, with international funding, researchers conducted a systematic line transect survey of mammals across continental Equatorial Guinea (Murai et al. 2013). This survey identified RNRC as a priority area for protection due to the presence of elephants and great

apes, and its connectivity with Cameroon’s neighbouring *Parc Nacional de Campo Ma’an* (PNCM). Field work for this survey took place in 2011 and included two line transects within RNRC: one passing through the centre of RNRC, and another partial transect through the easternmost portion. By exploring broad mammal diversity and factors affecting mammal group distributions throughout a larger portion of the reserve, we aim to complement this previous data collected by Murai et al. (2013) focused on elephants and great apes.

Elephants in Equatorial Guinea are likely poached extensively, leaving a remnant population in the country, and great ape populations are also dwindling, with deforestation, infrastructure development, and human population increases all likely contributing to declines (Larison et al. 1999, Walsh et al. 2003, Murai et al. 2013). Recent fine-scale spatial distribution data on other mammal species is not available for Equatorial Guinea, though several commonly-hunted and threatened species have been documented, often in the context of subsistence and commercial hunting. Duikers are common and extensively hunted, making up a large portion of wild meat available in markets, with blue duiker (*Philantomba monticola*) being one of the most prominent (Juste et al. 1995, Fa et al. 1995, Fa et al. 2002, Fa et al. 2015). Rodents, primarily African brush-tailed porcupine (*Atherurus africanus*) and Emin's pouched rat (*Cricetomys emini*), also make up a large percentage of wild meat sold in markets (Fa et al. 1995, Fa et al. 2002, Fa et al. 2015). Primates are likely consumed as a symbol of wealth and status in Equatorial Guinea, despite taboos around eating them among certain ethnic groups (East et al. 2005 Cronin et al. 2017). After a nationwide primate hunting ban was enacted, primate hunting declined dramatically, but quickly rebounded given little enforcement of the ban (Cronin et al. 2015). Pangolins are the world’s most trafficked mammal, and are among the most preferred wild meat species in Equatorial Guinea’s markets (Juste et al. 1995, East et al. 2005, Ingram et al. 2019a). Many of these commonly-hunted taxa are important sources of both local income and food security, especially as Equatorial Guinea lacks readily-available domestic protein sources due to low rates of agriculture and livestock keeping (Wilkie and Carpenter 1999).

As mammals are extracted from forests and rapid landscape change occurs in continental Equatorial Guinea, updated information on mammal communities in the region is warranted. Here we present findings from a survey of terrestrial and semi-terrestrial mammals in RNRC based on camera trap data collected in 2017 and 2019. Our objectives were to 1) quantify mammalian diversity in RNRC, and 2) develop models of mammal group presence and abundance based on human-mediated factors. These models will also assist in the development of predictive mammal community models for the entire continental region of the country in future studies. We aim to use these models to facilitate conservation and monitoring in RNRC and other PAs in continental Equatorial Guinea by highlighting areas for

targeted protection by the government forest agency INDEFOR-AP.

Methods

Study Site

RNRC was designated as a protected area in 2000 and is managed by INDEFOR-AP. The reserve is along the northernmost coastline of continental Equatorial Guinea and abuts Cameroon's Campo Ma'an National Park (PNCM) to the northeast (Figure 1, inset) (UNEP-WCMC 2021). The Litoral region where RNRC is located experiences an annual average temperature of 25.52 °C and average annual precipitation of 2,449 mm (World Bank 2021). The area experiences two periods of heavy rainfall in March–May and September–November, alternating with two periods of lighter rainfall in June–August and December–February (FNC Equatorial Guinea 2019). RNRC comprises 330 km² of tropical lowland rainforest and has an average elevation of 53 m with a range from -1 to 205 m (calculated using NASA SRTM 1 Arc-Second Global, NASA SRTM 2013). The reserve is located approximately 50 km north by road from Equatorial Guinea's most populous city, Bata (pop. 173,046) (World Population Review 2022).

Field Methods

INDEFOR-AP field teams deployed 61 Bushnell Trophycam HD (model #119836) cameras within RNRC from April to November 2017 (n=26) and March to July 2019 (n=40) (Figure 1). In 2017, to select camera stations we used QGIS to generate random points 2 km apart within a 10 km buffer of two villages which were reported to be highly populated: Punta Mbonda and Bongoro (personal communication, 2017). In 2019, we used QGIS to select random points at least 2 km apart within the boundary of RNRC for camera stations (QGIS Development Team 2017). Due to impassable or treacherous field conditions, field teams could not reach several planned camera stations during 2019, and camera traps were thus not deployed at these points or were deployed as close to the proposed points as possible. At all camera stations in both field seasons, teams were trained to fasten camera traps to trees approximately 30–45 cm above ground level, facing north or south, and angled perpendicular to and 4–8 m from a game trail within 100 m of the point, with evidence of use and limited travel alternatives when possible, in closed canopy forest, to maximise medium to large terrestrial mammal detection. Teams were also trained to clear vegetation within the camera trigger range, and camera settings were standardised as follows: mode: camera, image size: HD, sensor level: high, capture number: 3, interval: 1-second, night-vision shutter: auto. In 2017, several camera traps malfunctioned primarily due to a software bug related to the 'field scan' feature being switched 'on' in 2017. In 2019,

we turned this feature ‘off’ and malfunctions decreased, with additional camera malfunctions mainly due to weather or animal-caused damage. The total survey area between 2017 and 2019 was 296 km² (via minimum convex polygon in ArcGIS) (Meek et al. 2014).

Mammal Diversity

We collected and sorted images by species using the R package *camtrapR* (Niedballa et al. 2016). Unidentifiable images were sorted to the most descriptive taxonomic rank possible, or else labelled as ‘unidentified animal’. Trained undergraduate students at Michigan Technological University carried out sorting which was quality checked by T.L.D. To calculate camera trap nights (hereafter ‘trap nights’), we summed the number of nights a camera was active, i.e. removing dates during which detection was impossible due to human or animal-caused damage, thick condensation on the camera lens, or camera malfunctions.

To assess terrestrial mammalian diversity, we used *camtrapR* to generate a species inventory and species detection records (Niedballa et al. 2016). Detections at least 30 minutes apart were considered independent. Elephant, great ape, and hog detections were of groups of an uncounted number of individual animals; other species’ detections were generally of individuals. We generated both presence/absence and count data for all species detected at each camera station in *camtrapR*. We then created a species accumulation curve for the 2017–2019 combined camera trap data using the rarefaction method in R package *vegan* to estimate species richness of terrestrial mammals present in RNRC (Oksanen et al. 2020).

Mammal Presence/Absence and Abundance

We grouped species into taxonomic groups (hereafter ‘group’): mongooses (*Crossarchus platycephalus*, *Galerella sanguinea*, *Atilax paludinosus*, and unidentified mongooses), civets and genets (hereafter ‘viverrids’) (*Civettictis civetta*, *Nandinia binotata*, *Genetta servalina*, and unidentified viverrids), small duikers (*Cephalophus dorsalis*, *Cephalophus silvicultor*, *Philantomba monticola*, *Hyemoschus aquaticus*, and unidentified *Philantomba/Cephalophus* spp.), bushbucks and sitatungas (*Tragelaphus scriptus*, *Tragelaphus spekii*, and unidentified *Tragelaphus* spp.), hogs (*Potamochoerus porcus*), great apes (*Gorilla gorilla*, Critically Endangered and *Pan troglodytes*, Endangered) (Humble et al. 2016, Maisels et al. 2018), other primates (*Mandrillus sphinx*, Vulnerable (Abernethy & Maisels 2019); *Arctocebus calabarensis*; *Cercopithecus cephus*; *Cercopithecus nictitans*; and unidentified monkeys), pangolins (*Phataginus tricuspis*, Endangered and *Smutsia gigantea*, Endangered) (Nixon et al. 2019, Pietersen et al. 2019), forest elephants (*Loxodonta cyclotis*, Critically Endangered) (Gobush et

al, 2021), porcupines (*Atherurus africanus*), pouched rats (*Cricetomys emini*), and squirrels (Sciuridae spp.) (Figure 2). We also recorded and georeferenced human detections by camera traps or reported during camera trap recovery.

We used two-step or ‘hurdle’ models to investigate both: presence of groups in step 1 using binomial (detected/not detected) data, and an index of relative abundance in step 2, i.e. how many detections were recorded at camera stations where the group was detected, using zero-truncated count data. We used generalised linear models (GLMs) in R for both steps (R Core Team 2021), including environmental covariates as well as several covariates corresponding to human-mediated factors. All covariates were sourced from GIS data and were scaled and transformed where suggested by our data exploration (Appendix S1). Environmental covariates chosen were: distance to nearest river and elevation, and human-related covariates were: distance to road, distance to paved road, distance to RNRC boundary, distance to PNCM boundary, distance to any populated area, distance to one of RNRC’s large villages (Punta Mbonda and Bongoro), distance to human detection (see ‘human detections’), and Forest Landscape Integrity Index (FLII), which is a measure of anthropogenic forest disturbance (Grantham et al. 2020). During the initial data exploration phase, we followed recommendations in Zuur (2011), which resulted in either the removal of collinear covariates, or including them only in the separate models.

We developed a set of 25 candidate models for use in binomial GLMs in step 1, and a subset of 18 candidate models for zero-truncated Poisson GLMs in step 2 (Appendix S2). For species with low sample sizes, we further truncated the candidate model set to 12 models. All GLMs included an offset term to account for variation in survey effort (measured in trap nights) at each camera station. We averaged models within $\Delta 2$ AIC_c for both steps using the zero method, which substitutes zero for estimates and errors when a parameter is absent, effectively shrinking effect sizes in lower-weight models (Burnham and Anderson 2002). This method is often recommended for uncovering potentially important covariates on response variables (Grueber et al. 2011). For groups with only one candidate model in the top 2 Δ AIC_c, we only reported the results of the top model. We then graphed beta estimates with standard errors for significant covariates for each group to examine patterns in the direction of effects across groups using the R package *jtools* for both modelling steps (Long 2020). We also calculated detection rates at each camera station by dividing number of detections by trap nights for all species observed. We created distribution maps to visualise spatial distribution of species within groups using ArcGIS v10.7.1, including road networks, human settlements, rivers, and PA boundaries.

Human Detections

We georeferenced human detections that were not of field crews, and stolen cameras during 2017 and 2019 surveys to comprise the distance to human detection covariate that was included in candidate model sets. We also obtained the approximate location of an illegal wild meat hunting operation that was shut down during the course of field work.

Results

Mammal Diversity

We recovered images from 55 camera traps between both field seasons, with an average of 48 trap nights per station (SD: 67, range: 1–230) resulting in 2,991 trap nights total. Between our 2017 and 2019 field seasons, we detected at least 32 mammal species in RNRC, including at least two mongoose species that to our knowledge have not previously been recorded in the reserve: *Atilax paludinosus*, *Galerella sanguinea*, and likely *Crossarchus platycephalus* (Appendix S3). Additionally, we detected several unidentifiable species which were placed in their most descriptive taxonomic ranks possible. The species accumulation curve produced an estimated species richness of 33 (Figure 3).

Mammal Presence/Absence and Abundance

From our two-step modelling analysis (Table 2), we uncovered six covariates that were significant predictors of group presence for common mammal species (Figure 4a). Three groups (bushbucks and sitatungas, mongooses, and squirrels) showed a negative correlation with distance to river, i.e. presence increased closer to rivers. Bushbuck and sitatunga presence also increased closer to roads, human detections, and large villages. Porcupine presence was positively correlated with increasing Forest Landscape Integrity Index (FLII) and increasing distance to populated area. Viverrid presence was negatively correlated with FLII. Mongoose presence was positively correlated with distance to human detection. Squirrel presence was positively correlated with distance to populated area, but decreased with distance to large villages. None of the model-averaged results for great apes contained significant predictors, though great ape presence increased marginally closer to the PNCM boundary (β : -0.98, CL: -2.03, 0.06) (Table 2).

Seven covariates were significant predictors of mammal group relative abundance (Figure 4b). Bushbuck and sitatunga abundance increased further from rivers, and closer to the PNCM boundary. Viverrid abundance also increased further from rivers, and with distance to large villages. Squirrel abundance increased with FLII, closer to rivers, and further from roads and populated places. Protected area boundaries were significant predictors of abundance for three groups: the abundance of cercopithecids/lorises and pangolins increased further inward from the RNRC boundary, while bushbuck

and sitatunga increased closer to the PNCR boundary.

Small sample sizes precluded us from modelling elephant presence and abundance. However, our distribution maps indicate elephant group presence was mainly in the northeast region of PNCR (Figure 5). Other threatened taxa also showed a similar pattern and were mainly detected in northeast PNCR near the PNCR border, e.g. chimpanzee, gorilla, and giant pangolin, while more common species appear to be more widely distributed across PNCR.

Human detections

Human signs were detected at five stations during this study. Additionally, INDEFOR-AP staff shut down an illegal wild meat operation that was being carried out in the eastern arm of PNCR during camera trap deployments (Figure 1). In 2017, there was one human detection at a station in the reserve's centre, approximately 0.6 km from the nearest road, and another in the eastern arm of the reserve about 0.3 km from the main road and 2.5 km from the nearest town. In 2019, there was a single human detection in the west of PNCR about 0.4 km east of the town of Machawa near the main road crossing the reserve. Two cameras in the eastern arm of PNCR were reportedly stolen during the 2017 survey; both cameras were approximately 5 km from the nearest populated area.

Discussion

Equatorial Guinea harbours both rare and common mammals that face threats from human-mediated impacts, but little information is available on fine-scale distribution of these groups, nor the factors affecting their use of forests in Equatorial Guinea's PAs. Since PNCR is located near the most populous city in the country, contains several villages within its boundaries, and is bisected by a main road, the reserve could be at risk of overexploitation of vulnerable mammals. Thus, it is important to assess patterns of mammalian diversity and factors affecting it within PNCR to optimize management and conservation efforts. During the deployment of camera traps, INDEFOR-AP staff encountered and shutdown illegal logging and commercial hunting camps within PNCR (personal communication, 2019), indicating that perhaps even the presence of INDEFOR-AP staff in the forest (such as during the deployment of camera traps) can help protect wildlife through passive protection.

This study represents the most comprehensive camera trap survey carried out in PNCR to date. We were able to identify 32 mammal species, adequately detecting the majority of medium to large terrestrial mammal diversity in PNCR (Figure 3). Of important note are several taxa we did *not* detect, including large mammals that have previously been reported in PNCR. Our camera traps failed to detect African

forest buffalo (*Syncerus caffer*), which was detected by Larison et al. (1999) and Murai et al. (2013). We did not detect Peter’s duiker (*Cephalophus callipygus*) or white-bellied duiker (*Cephalophus leucogaster*). These species were also not detected in 2011 by Murai et al. (2013), but an earlier report indicated that Peter’s duiker occurred in RNRC, and that white-bellied duiker likely occurred in RNRC (Castroviejo et al. 1990). We also did not detect black-bellied pangolin (*Phataginus tetradactyla*) and some expected monkey species (see below). Finally, we did not detect any felids; leopard (*Panthera pardus*) was reported by locals during biotic surveys in 1999, and both leopard and African golden cat (*Caracal aurata*) were reported in 1991 (Larison et al. 1999). We did however detect several species of conservation concern such as pangolins, monkeys, great apes, and elephants, as well as more common species important to local communities that rely on them as protein and income sources.

Pangolin populations in Africa have declined dramatically; their main threats are local hunting and poaching for the illegal international trade (Ingram et al. 2019). Equatorial Guinea has been implicated in the import and export of pangolin meat and scales, and pangolin products have steadily increased in the market in Equatorial Guinea’s capital, Malabo (Ingram et al. 2019). To combat threats to pangolins, the IUCN SSC Pangolin Specialist Group’s Conservation Action Plan includes better understanding pangolin ecology and identifying population strongholds for protection (Challender et al. 2014). Previously, Larison et al. (1999) neither detected nor documented reports of pangolins in RNRC, and Murai et al. (2013) detected two white-bellied pangolin signs and no giant pangolin. We detected giant pangolins in northeast RNRC and white-bellied pangolin throughout the reserve. Our models suggest that pangolins are more abundant in areas further inward from the boundary of RNRC, potentially due to hunting pressure. Additional research should compare distributions outside of RNRC’s boundary to confirm our assertion, which could indicate RNRC is a stronghold for white-bellied pangolin. We did not detect any black-bellied pangolin; this could be because they are rare, or because they are arboreal and less likely to be detected with terrestrial camera traps (Willcox et al. 2019).

A similar pattern was seen in monkeys and lorises, which were more abundant further inward from the RNRC boundary. Several primates have previously been reported in RNRC, including mandrill, guenons (Genus *Cercopithecus*), black colobus, (*Colobus satanas*, IUCN Vulnerable) (Maisels & Cronin 2020), red-capped mangabey (*Cercocebus torquatus*, IUCN Endangered) (Maisels et al. 2019), and grey-cheeked mangabey (*Lophocebus albigena*, IUCN Vulnerable) (Larison et al. 1999, Maisels et al. 2020). In this study, we detected mandrill, golden angwantibo (*Arctocebus aureus*, IUCN Least Concern) (Svensson & Nekaris 2019), moustached guenon (*Cercopithecus cephus*, IUCN Least Concern) (Abernethy & Maisels 2020), and putty-nosed guenon (*Cercopithecus nictitans*, IUCN Near Threatened) (Cronin et al. 2020). Mandrill were detected at several stations. Angwantibo and guenon

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detections were very rare, which is not unexpected for these arboreal species. Concerningly, we failed to detect any other primates, including red-capped mangabey, a semi-terrestrial species that we expected to detect with camera traps, which was previously reported in RNRC in the 1990s (Larison et al. 1999). However, red-capped mangabey was not detected during the country-wide survey by Murai et al. in 2011, despite local reports that the species was present at a few sites throughout the country (Maisels et al. 2019).

Both chimpanzee and western gorilla were previously detected by Murai et al (2013) in the eastern region of RNRC. We also detected chimpanzee and gorilla in eastern RNRC, however we also detected one gorilla group in south RNRC near the River Mbia and a chimpanzee detection in west RNRC approximately 2.5 km from the coast (Figure 5). Though the effect was marginal, our models suggest that great apes in RNRC were detected closer to the PNCM border, thus confirming the importance of eastern RNRC, though we also noted additional great ape detections in further west and south (Figure 5).

Eastern RNRC has also previously been identified as an important area for elephants that are likely entering from PNCM (Murai et al. 2013). We were unable to model elephant presence and abundance due to low sample sizes, however we similarly detected elephant groups in northeast RNRC. We detected one individual in the west less than 3 km from the main paved road and several villages, highlighting a region where INDEFOR-AP could conduct community surveys to determine potential human-elephant conflicts (Figure 5). Whether elephants currently stray into local communities in this part of RNRC is unknown, but the RNRC elephant population was reportedly culled extensively as part of a government program in the 1990s (Larison et al. 1999), and there have been reports of at least 2 elephant killings in RNRC between 2017–2019 (personal communication, 25 June 2021). Identifying potential conflict areas before local community members' livelihoods are affected could help INDEFOR-AP staff develop preventative mitigation strategies.

Three human detections occurred on camera traps during our study, close to villages and the main road crossing RNRC. This number seems low since Murai et al. (2013) found over two dozen hunting signs in RNRC in just a few kilometres of transects. However, during our study two cameras were reportedly stolen, which could indicate that hunters in RNRC are aware of camera traps and tend to avoid them. One illegal commercial hunting operation in eastern RNRC was also detected and shut down during this study. Since camera traps do not detect cable snares, gunshots, or other signs of hunting, it is likely that hunting activity was underrepresented and cameras may not be a good method for adequate detection of hunting activity.

Human-mediated factors were important predictors for several mammal groups in RNRC, though highly varied in their influence as noted elsewhere in central Africa (e.g., Vanthomme et al. 2012). For example, porcupine presence increased in higher integrity forest. This could be due to extremely high hunting pressure on porcupines in Equatorial Guinea, for instance, Fa and Juste (2001) reported that *A. africanus* made up 20.3% of all hunter captures, exceeded only by *P. monticola*. Rodents are the second-most common group to appear in markets after duikers, and thus are important sources of local income and protein (Fa & Juste 2001). Because porcupines are one of the most hunted species in central African forests, they potentially avoid low integrity forests that are more easily accessible to hunters, or are already depleted in them (Jori et al. 1998, Vanthomme et al. 2012).

Bushbuck and sitatunga were present closer to rivers, but at stations where they were present, abundance increased further from rivers. This may reflect sitatunga selection of the varied swamp and palm habitats in areas around rivers (Kingdon 2015). Bushbuck and sitatunga were also found closer to large villages, roads, and human detections. This is potentially because human-dominated areas in eastern RNRC are also closer to the Campo River, where most were detected (Figure 5). Previous studies have also suggested that sitatunga might be attracted to crops near villages (Vanthomme et al. 2012). Though we were unable to model small duiker distributions, it is also possible that bushbuck and sitatunga are closer to human-dominated areas because small duiker were depleted in these areas due to extensive hunting (Juste et al. 1995, Yasuoka et al. 2015).

Conclusion

There has been continued expansion of road networks and forest loss in continental Equatorial Guinea (Zvomuya 2014). For example, the *Machinda* region where RNRC is located lost 89.4 km² of tree cover from 2000–2019 (Global Forest Watch 2021). Despite these human-mediated impacts, RNRC is home to several endangered species, and harbours a diversity of common mammals. Eastern RNRC appears to be important for elephants and great apes as previously noted by Murai et al. (2013), and also for giant pangolins. Additionally, our models suggest interior RNRC might represent a refuge for pangolins and certain monkey species. More common but widely-hunted species, e.g. duikers, porcupines, and pouched rats were present throughout RNRC. Though we were unable to model small duiker distributions in RNRC, our models of bushbuck and sitatunga distributions suggest that they are closer to human-dominated areas in general, and thus potentially at risk of overexploitation. Since these taxa are important for local income and food security, additional research could help INDEFOR-AP staff effectively manage their populations. In the short term, we recommend that INDEFOR-AP uses our mammal inventory and distribution maps to prioritise anti-poaching efforts in RNRC’s eastern

region. Longer term, we also recommend conducting targeted camera trap surveys in the north-western portion of RNRC, which was underrepresented in this study.

To effectively manage and conserve mammals, INDEFOR-AP needs comprehensive biodiversity surveys and robust analyses conducted to assess mammal abundance in relation to both human-mediated factors, e.g. distance to roads, villages and cities, as well as environmental factors, e.g. forest structure. This could be particularly useful in recently developed areas, such as the new capital Ciudad de la Paz (previously Oyala) which is being built in the centre of the country. By surveying mammals across both highly-disturbed and less-disturbed regions of Equatorial Guinea, we can begin to disentangle drivers of mammal diversity and distribution at a country-wide scale. This project represents the first step in assessing these larger, important research questions.

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Conflict of interest statement:

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Data availability

The data supporting the findings of this study are available from the corresponding author, T.L.D., upon reasonable request.

References

Abernethy, K. & Maisels, F. (2019). *Mandrillus sphinx*. The IUCN Red List of Threatened Species

- 2019: e.T12754A17952325. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12754A17952325.en>.
- Abernethy, K. & Maisels, F. (2020). *Cercopithecus cephus* (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T4214A166614362. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T4214A166614362.en>.
- Burnham, K., & Anderson, D. (2002). *Model selection and multimodel inference* - 2nd ed.. New York, NY: Springer-verlag new York Inc.
- Castroviejo, J. B., Blom, A., & Alers, M. P. T. (1990). Equatorial Guinea In R. East (compiler) *Antelopes: Global Survey and Regional Action Plans, Part 3: West and Central Africa*, (pp. 167-171). IUCN, Gland, Switzerland.
- Challender, D., Waterman, C., & Baillie, J. (2014). *Scaling up pangolin conservation*. IUCN SSC Pangolin Specialist Group Conservation Action Plan. Zoological Society of London, London, UK.
- Cronin, D., Woloszynek, S., Morra, W., Honarvar, S., Linder, J., & Gonder, M. et al. (2015). Long-Term Urban Market Dynamics Reveal Increased Bushmeat Carcass Volume despite Economic Growth and Proactive Environmental Legislation on Bioko Island, Equatorial Guinea. *PLOS ONE*, 10(7), e0134464. doi: 10.1371/journal.pone.0134464
- Cronin, D., Sesink Clee, P., Mitchell, M., Bocuma Meñe, D., Fernández, D., & Riaco, C. et al. (2017). Conservation strategies for understanding and combating the primate bushmeat trade on Bioko Island, Equatorial Guinea. *American Journal Of Primatology*, 79(11), 22663. doi: 10.1002/ajp.22663
- Cronin, D.T., Maisels, F., Gadsby, E., Gonedelé Bi, S., Ikemeh, R. & Imong, I. (2020). *Cercopithecus nictitans* (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T4224A166615169. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T4224A166615169.en>.
- Doumenge C., Palla F., Itsoua Madzous G-L. (Eds.) (2021). *State of Protected Areas in Central Africa 2020*. OFAC-COMIFAC, Yaounde, Cameroon & IUCN, Gland, Switzerland: 400p.
- East, T., Kumpel, N., Milner-Gulland, E., & Rowcliffe, J. (2005). Determinants of urban bushmeat consumption in Río Muni, Equatorial Guinea. *Biological Conservation*, 126(2), 206-215. doi: 10.1016/j.biocon.2005.05.012
- Equatorial Guinea (2007). *Hunting and consumption of monkeys and other primates in the republic of Equatorial Guinea is prohibited*. Law num. 72/2007, Government of Equatorial Guinea.
- Fa, J., & Juste, J. (2001). Commercial bushmeat hunting in the Monte Mitra forests, Equatorial Guinea: extent and impact. *Animal Biodiversity and Conservation* 24(1), 31-52.
- Fa, J., Juste, J., Burn, R., & Broad, G. (2002). Bushmeat Consumption and Preferences of Two Ethnic Groups in Bioko Island, West Africa. *Human Ecology* 30(3), 397-416.
- Fa, J., & Brown, D. (2009). Impacts of hunting on mammals in African tropical moist forests: a review and synthesis. *Mammal Review*, 39(4), 231-264. doi: 10.1111/j.1365-2907.2009.00149.x
- Fa, J., Olivero, J., Farfán, M., Márquez, A., Duarte, J., & Nackoney, J. et al. (2015). Correlates of bushmeat in markets and depletion of wildlife. *Conservation Biology*, 29(3), 805-815. doi: 10.1111/cobi.12441
- FNC Equatorial Guinea (2019). *First National Communication to the United Nations Framework Convention on Climate Change*. Republic of Equatorial Guinea, Ministry of Agriculture, Livestock, Forests and Environment (MAGBMA), Malabo, Equatorial Guinea, First Edition 2019.
- Global Forest Watch, n.d. *Equatorial Guinea Deforestation Rates & Statistics*. Retrieved 31 August 2021, from <https://www.globalforestwatch.org/dashboards/country/GNQ/>
- Gobush, K.S., Edwards, C.T.T., Maisels, F., Wittemyer, G., Balfour, D. & Taylor, R.D. (2021). *Loxodonta cyclotis* (errata version published in 2021). The IUCN Red List of Threatened Species 2021: e.T181007989A204404464. Retrieved 24 February 2022, from:

- <https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T181007989A204404464.en>.
- Grantham, H., Duncan, A., Evans, T., Jones, K., Beyer, H., & Schuster, R. et al. (2020). Anthropogenic modification of forests means only 40% of remaining forests have high ecosystem integrity. *Nature Communications*, 11(1). doi: 10.1038/s41467-020-19493-3
- Grueber, C., Nakagawa, S., Laws, R. & Jamieson, I. (2011). Multimodel inference in ecology and evolution: challenges and solutions. *Journal of Evolutionary Biology*, 24(4), 699-711.
- Humle, T., Maisels, F., Oates, J.F., Plumptre, A. & Williamson, E.A. (2016). Pan troglodytes (errata version published in 2018). The IUCN Red List of Threatened Species 2016: e.T15933A129038584. Retrieved 22 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2016-2.RLTS.T15933A17964454.en>.
- Jori, F., Lopez-Bejar, M., & Houben, P. (1998) The biology and use of the African brush-tailed porcupine (*Atherurus africanus*, Gray, 1842) as a food animal. A review. *Biodiversity and Conservation* 7, 1417-1426
- Juste, J., Fa, J., Val, J., & Castroviejo, J. (1995). Market Dynamics of Bushmeat Species in Equatorial Guinea. *The Journal Of Applied Ecology*, 32(3), 454. doi: 10.2307/2404644
- Instituto Nacional de Estadística de Guinea Ecuatorial (INEGE) (2018). Anuario estadístico de Guinea Ecuatorial 2018. Retrieved 1 July 2021, from <https://www.inege.gq/wp-content/uploads/2019/03/anuario-estadistico-de-guinea-ecuatorial-2018-.pdf>.
- Ingram, D., Cronin, D., Challender, D., Venditti, D., & Gonder, M. (2019). Characterising trafficking and trade of pangolins in the Gulf of Guinea. *Global Ecology And Conservation*, 17, e00576. doi: 10.1016/j.gecco.2019.e00576
- Kingdon, J. (2015). *The Kingdon field guide to African mammals* (2nd ed.). Princeton, New Jersey: Princeton University Press.
- Larison, B., Smith, T. B., Girman, D., Stauffer, D., Mila, B., Drewes, R.C., Griswold, C.E., Vindum, J.V., Ubick, D., O'Keefe, K., Nguema, J. & Henwood, L. (1999). Biotic surveys of Bioko and Rio Muni, Equatorial Guinea. Central Africa Regional Program for the Environment (CARPE), Washington DC.
- Long, J. A. (2020). jtools: Analysis and Presentation of Social Scientific Data. R package version 2.1.0. <https://cran.r-project.org/package=jtools>
- Maisels, F., Bergl, R.A. & Williamson, E.A. (2018). Gorilla gorilla (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2018: e.T9404A136250858. Retrieved 22 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T9404A136250858.en>.
- Maisels, F., Oates, J.F., Linder, J., Ikemeh, R., Imong, I. & Etiendem, D. (2019). Cercopithecus torquatus (errata version published in 2019). The IUCN Red List of Threatened Species 2019: e.T4201A154210757. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-1.RLTS.T4201A154210757.en>.
- Maisels, F. & Cronin, D.T. (2020). Colobus satanas. The IUCN Red List of Threatened Species 2020: e.T5145A17944405. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T5145A17944405.en>.
- Maisels, F., Hart, J., Olupot, W. & Oates, J.F. (2020). Lophocebus albigena (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T12309A166607033. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T12309A166607033.en>.
- Murai, M., Ruffler, H., Berlemont, A., Campbell, G., Esono, F., & Agbor, A. et al. (2013). Priority Areas for Large Mammal Conservation in Equatorial Guinea. *Plos ONE*, 8(9), e75024. doi: 10.1371/journal.pone.0075024
- NASA Shuttle Radar Topography Mission (SRTM) (2013). Shuttle Radar Topography Mission (SRTM) Global. Distributed by OpenTopography. Doi: 10.5069/G9445JDF Accessed: 2021-12-16
- Niedballa, J., Sollmann, R., Courtiol, A., & Wilting, A. (2016). camtrapR: an R package for

efficient camera trap data management. *Methods In Ecology And Evolution*, 7(12), 1457-1462. doi: 10.1111/2041-210x.12600

Nixon, S., Pietersen, D., Challender, D., Hoffmann, M., Godwill Ichu, I., Bruce, T., Ingram, D.J., Matthews, N. & Shirley, M.H. (2019). *Smutsia gigantea*. The IUCN Red List of Threatened Species 2019: e.T12762A123584478. Retrieved 22 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12762A123584478.en>.

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., et al. (2020). *vegan: Community Ecology Package*. R package version 2.5-7. <https://CRAN.R-project.org/package=vegan>

Pietersen, D., Moumbolou, C., Ingram, D.J., Soewu, D., Jansen, R., Sodeinde, O., Keboy Mov Linkey Iflankoy, C., Challender, D. & Shirley, M.H. (2019). *Phataginus tricuspidis*. The IUCN Red List of Threatened Species 2019: e.T12767A123586469. Retrieved 22 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12767A123586469.en>.

QGIS Development Team (2017). QGIS Geographic Information System. Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>

Redford, K. (1992). The Empty Forest. *Bioscience*, 42(6), 412-422. doi: 10.2307/1311860

Svensson, M. & Nekaris, K.A.I. (2019). *Arctocebus aureus*. The IUCN Red List of Threatened Species 2019: e.T2053A17969875. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T2053A17969875.en>.

Thouless, C., Dublin, H. Blanc, J., Skinner, D., Daniel, T., Taylor, R., Maisels, F., Frederick, H., & Bouché, P. (2016). African Elephant Status Report 2016: an update from the African Elephant Database. Occasional Paper Series of the IUCN Species Survival Commission, No. 60 IUCN / SSC African Elephant Specialist Group, Gland, Switzerland.

Walsh, P., Abernethy, K., Bermejo, M., Beyers, R., De Wachter, P., & Akou, M. et al. (2003). Catastrophic ape decline in western equatorial Africa. *Nature*, 422(6932), 611-614. doi: 10.1038/nature01566

Watson, J., Dudley, N., Segan, D., & Hockings, M. (2014). The performance and potential of protected areas. *Nature*, 515(7525), 67-73. doi: 10.1038/nature13947,

Willcox, D., Nash, H., Trageser, S., Kim, H., Hywood, L., & Connelly, E. et al. (2019). Evaluating methods for detecting and monitoring pangolin (Pholidata: Manidae) populations. *Global Ecology And Conservation*, 17, e00539. doi: 10.1016/j.gecco.2019.e00539

World Population Review (2022). Population of Cities in Equatorial Guinea (2022). Retrieved 17 February 2022, from <https://worldpopulationreview.com/countries/cities/equatorial-guinea>

UNEP-WCMC (2021). Protected Area Profile for Rio Campo from the World Database of Protected Areas, August 2021. Available at: www.protectedplanet.net

U.S. Fish and Wildlife Service (USFWS) (2014). Equatorial Guinea Fact Sheet.

Vanthomme, H., Kolowski, J., Korte, L., & Alonso, A. (2013). Distribution of a Community of Mammals in Relation to Roads and Other Human Disturbances in Gabon, Central Africa. *Conservation Biology*, 27(2), 281-291. doi: 10.1111/cobi.12017

World Bank (2021). Climate Change Knowledge Portal. Retrieved 20 December 2021, from <https://climateknowledgeportal.worldbank.org/country/equatorial-guinea/climate-data-historical>

World Wide Fund for Nature (WWF) Cameroon, n.d., Kudu Zombo. Retrieved 16 July 2020, from https://cameroon.panda.org/places_landscapes/kudu_zombo/.

Yasuoka, H., M. Hirai, T. O. W. Kamgaing, Z. C. B. Dzefack, E. C. B. Kamdoum, and K. S. Bobo. 2015. Changes in the composition of hunting catches in southeastern Cameroon: a promising approach for collaborative wildlife management between ecologists and local hunters. *Ecology and Society* 20(4):25. <http://dx.doi.org/10.5751/ES-08041-200425>

Zuur, A. (2011). *Mixed effects models and extensions in ecology with R*. New York, NY:

Springer.

Zvomuya, F. (2014). On a whim: Equatorial Guinea building new capital city in the middle of the Rainforest. Retrieved 16 July 2020, from <https://news.mongabay.com/2014/07/on-a-whim-equatorial-guinea-building-new-capital-city-in-the-middle-of-the-rainforest>

Figure & table captions

Figure 1. Study area and study design for remote camera trap deployment in Rio Campo Nature Reserve, Equatorial Guinea in 2017 and 2019, showing populated places (red triangles), main roads and secondary roads/trails (black solid and dotted lines, respectively), rivers (blue lines), and camera stations in 2017 and 2019 (pink pentagons and teal squares, respectively). Rio Campo Nature Reserve is shaded green, and nearby Campo Ma'an National Park is shaded grey. The inset map shows Rio Campo Nature Reserve's location within continental Equatorial Guinea. A total of 66 camera traps were deployed during this study.

Figure 2. Camera trap images of wildlife and human activity detected during our 2017 and 2019 mammal survey in Rio Campo Nature Reserve, Equatorial Guinea. Images included are representative of **a.** threatened taxa (left to right: African forest elephant, tree pangolin, giant pangolin, western mountain gorilla, chimpanzee, mandrill), **b.** common taxa (left to right: yellow-backed duiker, water chevrotain, blue duiker, Emin's pouched rat, African brush-tailed porcupine) and **c.** hunters.

Figure 3. Species accumulation curve (black, confidence intervals light blue) of terrestrial mammal species detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments using rarefaction.

Figure 4. Forest plots showing beta-estimates for presence (a) and relative abundance (b) of terrestrial mammal groups detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments. [†]square-root transformed, [‡]log-transformed, [§]cubed.

Figure 5. Distribution and detection rates of species and groups of particular conservation or hunting concern detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments. Detection rates for taxa are symbolised with proportionally-sized circles.

Title

Human impacts on mammal communities in Rio Campo Nature Reserve, Equatorial Guinea

Running title

Human impacts on mammals in Rio Campo, EG

Authors

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Abstract

Equatorial Guinea in central Africa hosts rich biodiversity and a network of protected areas (PAs). However, infrastructure development has facilitated access to previously remote forests. This has likely increased poaching in PAs, thereby complicating the efforts of agencies tasked with protecting threatened mammals. Reserva Natural de Río Campo (RNRC) was previously identified as a priority area for large mammals due to the presence of elephants and great apes, and includes habitat for a diverse mammal community of commonly-hunted species. To assess mammalian diversity in RNRC, we conducted a camera trap survey in 2017 and 2019. We then used a two-step modelling approach to quantify environmental and anthropogenic factors influencing mammal groups. We detected 32 terrestrial mammal species, including endangered forest elephant, western gorilla, chimpanzee, giant pangolin, and white-bellied pangolin. We found bushbuck and sitatunga closer to human-dominated areas, while other common species were, in general, further from development. Monkey and pangolin abundance increased inward from the RNRC boundary. Endangered species appear restricted to northeast RNRC which connects to Campo Ma'an National Park in Cameroon. We recommend using our inventory and distributions of threatened mammals as starting points to determine effectiveness of future anti-

poaching and management strategies on mammal populations.

Keywords

Biodiversity assessment; mammal distributions; hurdle models; species inventory; bushmeat; mammal survey; camera trapping; protected areas

Introduction

Protected Areas (PAs) aim to conserve wildlife and ecosystems in areas threatened by human-mediated impacts (Watson et al. 2014). Despite many challenges, PAs can be instrumental in conserving wildlife in central Africa where, as urban centres grow, infrastructure development and hunting put additional pressure on wildlife (Doumenge et al. 2020). Equatorial Guinea is located in the Gulf of Guinea in central Africa, with its continental region bordered by Cameroon to the north and Gabon to the south. This region has retained forest cover and mammal diversity despite rapid infrastructure development, deforestation, and hunting (USFWS 2014). Demonstrating their dedication to protecting natural resources, the Equatoguinean government created the *Instituto Nacional de Desarrollo Forestal y Gestión del Sistema de Áreas Protegidas* (INDEFOR-AP) which oversees PA management. INDEFOR-AP has designated approximately 20% of the country's landmass into PAs and implemented legislation such as bans on hunting in PAs and of primates (Equatorial Guinea 2007, Doumenge et al. 2020). Additionally, the agency is currently undertaking surveys to determine new areas to prioritise for protection and designate as PAs (personal communication, 2021). Despite these promising measures, limited funding and capacity hinders INDEFOR-AP's effectiveness. Large mammals in Equatorial Guinea have experienced hunting pressure and habitat loss leading to dramatic population declines. At the same time, roads have expanded to meet Equatorial Guinea's national development plan Horizonte 2020, making previously remote forests more easily accessible, leading to increased human-mediated disturbance (USFWS 2014). This development has likely facilitated the transportation of wild meat (or 'bushmeat') from remote forests to urban areas, compounding the overexploitation of wildlife (Fa & Yuste 2001).

The last broad biotic survey of Equatorial Guinea's continental region was conducted in May–June 1998 and combined line transect surveys of animal signs, local community member interviews, and previous surveys to indicate the presence of mammal species in PAs, including *Reserva Natural de Río Campo* (RNRC) (Larison et al. 1999). In 2011, with international funding, researchers conducted a systematic line transect survey of mammals across continental Equatorial Guinea (Murai et al. 2013). This survey identified RNRC as a priority area for protection due to the presence of elephants and great

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3 apes, and its connectivity with Cameroon’s neighbouring *Parc Nacional de Campo Ma’an* (PNCM).
4 Field work for this survey took place in 2011 and included two line transects within RNRC: one passing
5 through the centre of RNRC, and another partial transect through the easternmost portion. By exploring
6 broad mammal diversity and factors affecting mammal group distributions throughout a larger portion of
7 the reserve, we aim to complement this previous data collected by Murai et al. (2013) focused on
8 elephants and great apes.
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14 Elephants in Equatorial Guinea are likely poached extensively, leaving a remnant population in the
15 country, and great ape populations are also dwindling, with deforestation, infrastructure development,
16 and human population increases all likely contributing to declines (Larison et al. 1999, Walsh et al.
17 2003, Murai et al. 2013). Recent fine-scale spatial distribution data on other mammal species is not
18 available for Equatorial Guinea, though several commonly-hunted and threatened species have been
19 documented, often in the context of subsistence and commercial hunting. Duikers are common and
20 extensively hunted, making up a large portion of wild meat available in markets, with blue duiker
21 (*Philantomba monticola*) being one of the most prominent (Juste et al. 1995, Fa et al. 1995, Fa et al.
22 2002, Fa et al. 2015). Rodents, primarily African brush-tailed porcupine (*Atherurus africanus*) and
23 Emin's pouched rat (*Cricetomys emini*), also make up a large percentage of wild meat sold in markets
24 (Fa et al. 1995, Fa et al. 2002, Fa et al. 2015). Primates are likely consumed as a symbol of wealth and
25 status in Equatorial Guinea, despite taboos around eating them among certain ethnic groups (East et al.
26 2005 Cronin et al. 2017). After a nationwide primate hunting ban was enacted, primate hunting declined
27 dramatically, but quickly rebounded given little enforcement of the ban (Cronin et al. 2015). Pangolins
28 are the world’s most trafficked mammal, and are among the most preferred wild meat species in
29 Equatorial Guinea’s markets (Juste et al. 1995, East et al. 2005, Ingram et al. 2019a). Many of these
30 commonly-hunted taxa are important sources of both local income and food security, especially as
31 Equatorial Guinea lacks readily-available domestic protein sources due to low rates of agriculture and
32 livestock keeping (Wilkie and Carpenter 1999).
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45 As mammals are extracted from forests and rapid landscape change occurs in continental Equatorial
46 Guinea, updated information on mammal communities in the region is warranted. Here we present
47 findings from a survey of terrestrial and semi-terrestrial mammals in RNRC based on camera trap data
48 collected in 2017 and 2019. Our objectives were to 1) quantify mammalian diversity in RNRC, and 2)
49 develop models of mammal group presence and abundance based on human-mediated factors. These
50 models will also assist in the development of predictive mammal community models for the entire
51 continental region of the country in future studies. We aim to use these models to facilitate conservation
52 and monitoring in RNRC and other PAs in continental Equatorial Guinea by highlighting areas for
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targeted protection by the government forest agency INDEFOR-AP.

Methods

Study Site

RNRC was designated as a protected area in 2000 and is managed by INDEFOR-AP. The reserve is along the northernmost coastline of continental Equatorial Guinea and abuts Cameroon's Campo Ma'an National Park (PNCM) to the northeast (Figure 1, inset) (UNEP-WCMC 2021). The Litoral region where RNRC is located experiences an annual average temperature of 25.52 °C and average annual precipitation of 2,449 mm (World Bank 2021). The area experiences two periods of heavy rainfall in March–May and September–November, alternating with two periods of lighter rainfall in June–August and December–February (FNC Equatorial Guinea 2019). RNRC comprises 330 km² of tropical lowland rainforest and has an average elevation of 53 m with a range from -1 to 205 m (calculated using NASA SRTM 1 Arc-Second Global, NASA SRTM 2013). The reserve is located approximately 50 km north by road from Equatorial Guinea's most populous city, Bata (pop. 173,046) (World Population Review 2022).

Field Methods

INDEFOR-AP field teams deployed 61 Bushnell Trophycam HD (model #119836) cameras within RNRC from April to November 2017 (n=26) and March to July 2019 (n=40) (Figure 1). In 2017, to select camera stations we used QGIS to generate random points 2 km apart within a 10 km buffer of two villages which were reported to be highly populated: Punta Mbonda and Bongoro (personal communication, 2017). In 2019, we used QGIS to select random points at least 2 km apart within the boundary of RNRC for camera stations (QGIS Development Team 2017). Due to impassable or treacherous field conditions, field teams could not reach several planned camera stations during 2019, and camera traps were thus not deployed at these points or were deployed as close to the proposed points as possible. At all camera stations in both field seasons, teams were trained to fasten camera traps to trees approximately 30–45 cm above ground level, facing north or south, and angled perpendicular to and 4–8 m from a game trail within 100 m of the point, with evidence of use and limited travel alternatives when possible, in closed canopy forest, to maximise medium to large terrestrial mammal detection. Teams were also trained to clear vegetation within the camera trigger range, and camera settings were standardised as follows: mode: camera, image size: HD, sensor level: high, capture number: 3, interval: 1-second, night-vision shutter: auto. In 2017, several camera traps malfunctioned primarily due to a software bug related to the 'field scan' feature being switched 'on' in 2017. In 2019,

we turned this feature ‘off’ and malfunctions decreased, with additional camera malfunctions mainly due to weather or animal-caused damage. The total survey area between 2017 and 2019 was 296 km² (via minimum convex polygon in ArcGIS) (Meek et al. 2014).

Mammal Diversity

We collected and sorted images by species using the R package *camtrapR* (Niedballa et al. 2016). Unidentifiable images were sorted to the most descriptive taxonomic rank possible, or else labelled as ‘unidentified animal’. Trained undergraduate students at Michigan Technological University carried out sorting which was quality checked by T.L.D. To calculate camera trap nights (hereafter ‘trap nights’), we summed the number of nights a camera was active, i.e. removing dates during which detection was impossible due to human or animal-caused damage, thick condensation on the camera lens, or camera malfunctions.

To assess terrestrial mammalian diversity, we used *camtrapR* to generate a species inventory and species detection records (Niedballa et al. 2016). Detections at least 30 minutes apart were considered independent. Elephant, great ape, and hog detections were of groups of an uncounted number of individual animals; other species’ detections were generally of individuals. We generated both presence/absence and count data for all species detected at each camera station in *camtrapR*. We then created a species accumulation curve for the 2017–2019 combined camera trap data using the rarefaction method in R package *vegan* to estimate species richness of terrestrial mammals present in RNRC (Oksanen et al. 2020).

Mammal Presence/Absence and Abundance

We grouped species into taxonomic groups (hereafter ‘group’): mongooses (*Crossarchus platycephalus*, *Galerella sanguinea*, *Atilax paludinosus*, and unidentified mongooses), civets and genets (hereafter ‘viverrids’) (*Civettictis civetta*, *Nandinia binotata*, *Genetta servalina*, and unidentified viverrids), small duikers (*Cephalophus dorsalis*, *Cephalophus silvicultor*, *Philantomba monticola*, *Hyemoschus aquaticus*, and unidentified *Philantomba/Cephalophus* spp.), bushbucks and sitatungas (*Tragelaphus scriptus*, *Tragelaphus spekii*, and unidentified *Tragelaphus* spp.), hogs (*Potamochoerus porcus*), great apes (*Gorilla gorilla*, Critically Endangered and *Pan troglodytes*, Endangered) (Humble et al. 2016, Maisels et al. 2018), other primates (*Mandrillus sphinx*, Vulnerable (Abernethy & Maisels 2019); *Arctocebus calabarensis*; *Cercopithecus cephus*; *Cercopithecus nictitans*; and unidentified monkeys), pangolins (*Phataginus tricuspis*, Endangered and *Smutsia gigantea*, Endangered) (Nixon et al. 2019, Pietersen et al. 2019), forest elephants (*Loxodonta cyclotis*, Critically Endangered) (Gobush et

al, 2021), porcupines (*Atherurus africanus*), pouched rats (*Cricetomys emini*), and squirrels (Sciuridae spp.) (Figure 2). We also recorded and georeferenced human detections by camera traps or reported during camera trap recovery.

We used two-step or ‘hurdle’ models to investigate both: presence of groups in step 1 using binomial (detected/not detected) data, and an index of relative abundance in step 2, i.e. how many detections were recorded at camera stations where the group was detected, using zero-truncated count data. We used generalised linear models (GLMs) in R for both steps (R Core Team 2021), including environmental covariates as well as several covariates corresponding to human-mediated factors. All covariates were sourced from GIS data and were scaled and transformed where suggested by our data exploration (Appendix S1). Environmental covariates chosen were: distance to nearest river and elevation, and human-related covariates were: distance to road, distance to paved road, distance to RNRC boundary, distance to PNCM boundary, distance to any populated area, distance to one of RNRC’s large villages (Punta Mbonda and Bongoro), distance to human detection (see ‘human detections’), and Forest Landscape Integrity Index (FLII), which is a measure of anthropogenic forest disturbance (Grantham et al. 2020). During the initial data exploration phase, we followed recommendations in Zuur (2011), which resulted in either the removal of collinear covariates, or including them only in the separate models.

We developed a set of 25 candidate models for use in binomial GLMs in step 1, and a subset of 18 candidate models for zero-truncated Poisson GLMs in step 2 (Appendix S2). For species with low sample sizes, we further truncated the candidate model set to 12 models. All GLMs included an offset term to account for variation in survey effort (measured in trap nights) at each camera station. We averaged models within $\Delta 2$ AIC_c for both steps using the zero method, which substitutes zero for estimates and errors when a parameter is absent, effectively shrinking effect sizes in lower-weight models (Burnham and Anderson 2002). This method is often recommended for uncovering potentially important covariates on response variables (Grueber et al. 2011). For groups with only one candidate model in the top 2 Δ AIC_c, we only reported the results of the top model. We then graphed beta estimates with standard errors for significant covariates for each group to examine patterns in the direction of effects across groups using the R package *jtools* for both modelling steps (Long 2020). We also calculated detection rates at each camera station by dividing number of detections by trap nights for all species observed. We created distribution maps to visualise spatial distribution of species within groups using ArcGIS v10.7.1, including road networks, human settlements, rivers, and PA boundaries.

Human Detections

We georeferenced human detections that were not of field crews, and stolen cameras during 2017 and 2019 surveys to comprise the distance to human detection covariate that was included in candidate model sets. We also obtained the approximate location of an illegal wild meat hunting operation that was shut down during the course of field work.

Results

Mammal Diversity

We recovered images from 55 camera traps between both field seasons, with an average of 48 trap nights per station (SD: 67, range: 1–230) resulting in 2,991 trap nights total. Between our 2017 and 2019 field seasons, we detected at least 32 mammal species in RNRC, including ~~three~~ at least two mongoose species that to our knowledge have not previously been recorded in the reserve (~~–~~ *Atilax paludinosus*, *Galerella sanguinea*, and likely *Crossarchus platycephalus*, ~~and~~ *Galerella sanguinea*) (Appendix S3). Additionally, we detected several unidentifiable species which were placed in their most descriptive taxonomic ranks possible. The species accumulation curve produced an estimated species richness of 33 (Figure 3).

Mammal Presence/Absence and Abundance

From our two-step modelling analysis (Table 2), we uncovered six covariates that were significant predictors of group presence for common mammal species (Figure 4a). Three groups (bushbucks and sitatungas, mongooses, and squirrels) showed a negative correlation with distance to river, i.e. presence increased closer to rivers. Bushbuck and sitatunga presence also increased closer to roads, human detections, and large villages. Porcupine presence was positively correlated with increasing Forest Landscape Integrity Index (FLII) and increasing distance to populated area. Viverrid presence was negatively correlated with FLII. Mongoose presence was positively correlated with distance to human detection. Squirrel presence was positively correlated with distance to populated area, but decreased with distance to large villages. None of the model-averaged results for great apes contained significant predictors, though great ape presence increased marginally closer to the PNCM boundary (β : -0.98, CL: -2.03, 0.06) (Table 2).

Seven covariates were significant predictors of mammal group relative abundance (Figure 4b). Bushbuck and sitatunga abundance increased further from rivers, and closer to the PNCM boundary. Viverrid abundance also increased further from rivers, and with distance to large villages. Squirrel abundance increased with FLII, closer to rivers, and further from roads and populated places. Protected area boundaries were significant predictors of abundance for three groups: the abundance of

cercopithecids/lorises and pangolins increased further inward from the RNRC boundary, while bushbuck and sitatunga increased closer to the PNCM boundary.

Small sample sizes precluded us from modelling elephant presence and abundance. However, our distribution maps indicate elephant group presence was mainly in the northeast region of RNRC (Figure 5). Other threatened taxa also showed a similar pattern and were mainly detected in northeast RNRC near the PNCM border, e.g. chimpanzee, gorilla, and giant pangolin, while more common species appear to be more widely distributed across RNRC.

Human detections

Human signs were detected at five stations during this study. Additionally, INDEFOR-AP staff shut down an illegal wild meat operation that was being carried out in the eastern arm of RNRC during camera trap deployments (Figure 1). In 2017, there was one human detection at a station in the reserve's centre, approximately 0.6 km from the nearest road, and another in the eastern arm of the reserve about 0.3 km from the main road and 2.5 km from the nearest town. In 2019, there was a single human detection in the west of RNRC about 0.4 km east of the town of Machawa near the main road crossing the reserve. Two cameras in the eastern arm of RNRC were reportedly stolen during the 2017 survey; both cameras were approximately 5 km from the nearest populated area.

Discussion

Equatorial Guinea harbours both rare and common mammals that face threats from human-mediated impacts, but little information is available on fine-scale distribution of these groups, nor the factors affecting their use of forests in Equatorial Guinea's PAs. Since RNRC is located near the most populous city in the country, contains several villages within its boundaries, and is bisected by a main road, the reserve could be at risk of overexploitation of vulnerable mammals. Thus, it is important to assess patterns of mammalian diversity and factors affecting it within RNRC to optimize management and conservation efforts. During the deployment of camera traps, INDEFOR-AP staff encountered and shutdown illegal logging and commercial hunting camps within RNRC (personal communication, 2019), indicating that perhaps even the presence of INDEFOR-AP staff in the forest (such as during the deployment of camera traps) can help protect wildlife through passive protection.

This study represents the most comprehensive camera trap survey carried out in RNRC to date. We were able to identify 32 mammal species, adequately detecting the majority of medium to large terrestrial mammal diversity in RNRC (Figure 3). Of important note are several taxa we did *not* detect, including

large mammals that have previously been reported in RNRC. Our camera traps failed to detect African forest buffalo (*Syncerus caffer*), which was detected by Larison et al. (1999) and Murai et al. (2013). We did not detect Peter’s duiker (*Cephalophus callipygus*) or white-bellied duiker (*Cephalophus leucogaster*). These species were also not detected in 2011 by Murai et al. (2013), but an earlier report indicated that Peter’s duiker occurred in RNRC, and that white-bellied duiker likely occurred in RNRC (Castroviejo et al. 1990). We also did not detect black-bellied pangolin (*Phataginus tetradactyla*) and some expected monkey species (see below). Finally, we did not detect any felids; leopard (*Panthera pardus*) was reported by locals during biotic surveys in 1999, and both leopard and African golden cat (*Caracal aurata*) were reported in 1991 (Larison et al. 1999). We did however detect several species of conservation concern such as pangolins, monkeys, great apes, and elephants, as well as more common species important to local communities that rely on them as protein and income sources.

Pangolin populations in Africa have declined dramatically; their main threats are local hunting and poaching for the illegal international trade (Ingram et al. 2019). Equatorial Guinea has been implicated in the import and export of pangolin meat and scales, and pangolin products have steadily increased in the market in Equatorial Guinea’s capital, Malabo (Ingram et al. 2019). To combat threats to pangolins, the IUCN SSC Pangolin Specialist Group’s Conservation Action Plan includes better understanding pangolin ecology and identifying population strongholds for protection (Challender et al. 2014). Previously, Larison et al. (1999) neither detected nor documented reports of pangolins in RNRC, and Murai et al. (2013) detected two white-bellied pangolin signs and no giant pangolin. We detected giant pangolins in northeast RNRC and white-bellied pangolin throughout the reserve. Our models suggest that pangolins are more abundant in areas further inward from the boundary of RNRC, potentially due to hunting pressure. Additional research should compare distributions outside of RNRC’s boundary to confirm our assertion, which could indicate RNRC is a stronghold for white-bellied pangolin. We did not detect any black-bellied pangolin; this could be because they are rare, or because they are arboreal and less likely to be detected with terrestrial camera traps (Willcox et al. 2019).

A similar pattern was seen in monkeys and lorises, which were more abundant further inward from the RNRC boundary. Several primates have previously been reported in RNRC, including mandrill, guenons (Genus *Cercopithecus*), black colobus, (*Colobus satanas*, IUCN Vulnerable) (Maisels & Cronin 2020), red-capped mangabey (*Cercocebus torquatus*, IUCN Endangered) (Maisels et al. 2019), and grey-cheeked mangabey (*Lophocebus albigena*, IUCN Vulnerable) (Larison et al. 1999, Maisels et al. 2020). In this study, we detected mandrill, golden angwantibo (*Arctocebus aureus*, IUCN Least Concern) (Svensson & Nekaris 2019), moustached guenon (*Cercopithecus cephus*, IUCN Least Concern) (Abernethy & Maisels 2020), and putty-nosed guenon (*Cercopithecus nictitans*, IUCN Near

Threatened) (Cronin et al. 2020). Mandrill were detected at several stations. Angwantibo and guenon detections were very rare, which is not unexpected for these arboreal species. Concerningly, we failed to detect any other primates, including red-capped mangabey, a semi-terrestrial species that we expected to detect with camera traps, which was previously reported in RNRC in the 1990s (Larison et al. 1999). However, red-capped mangabey was not detected during the country-wide survey by Murai et al. in 2011, despite local reports that the species was present at a few sites throughout the country (Maisels et al. 2019).

Both chimpanzee and western gorilla were previously detected by Murai et al (2013) in the eastern region of RNRC. We also detected chimpanzee and gorilla in eastern RNRC, however we also detected one gorilla group in south RNRC near the River Mbia and a chimpanzee detection in west RNRC approximately 2.5 km from the coast (Figure 5). Though the effect was marginal, our models suggest that great apes in RNRC were detected closer to the PNCM border, thus confirming the importance of eastern RNRC, though we also noted additional great ape detections in further west and south (Figure 5).

Eastern RNRC has also previously been identified as an important area for elephants that are likely entering from PNCM (Murai et al. 2013). We were unable to model elephant presence and abundance due to low sample sizes, however we similarly detected elephant groups in northeast RNRC. We detected one individual in the west less than 3 km from the main paved road and several villages, highlighting a region where INDEFOR-AP could conduct community surveys to determine potential human-elephant conflicts (Figure 5). Whether elephants currently stray into local communities in this part of RNRC is unknown, but the RNRC elephant population was reportedly culled extensively as part of a government program in the 1990s (Larison et al. 1999), and there have been reports of at least 2 elephant killings in RNRC between 2017–2019 (personal communication, 25 June 2021). Identifying potential conflict areas before local community members' livelihoods are affected could help INDEFOR-AP staff develop preventative mitigation strategies.

Three human detections occurred on camera traps during our study, close to villages and the main road crossing RNRC. This number seems low since Murai et al. (2013) found over two dozen hunting signs in RNRC in just a few kilometres of transects. However, during our study two cameras were reportedly stolen, which could indicate that hunters in RNRC are aware of camera traps and tend to avoid them. One illegal commercial hunting operation in eastern RNRC was also detected and shut down during this study. Since camera traps do not detect cable snares, gunshots, or other signs of hunting, it is likely that hunting activity was underrepresented and cameras may not be a good method

for adequate detection of hunting activity.

Human-mediated factors were important predictors for several mammal groups in RNRC, though highly varied in their influence as noted elsewhere in central Africa (e.g., Vanthomme et al. 2012). For example, porcupine presence increased in higher integrity forest. This could be due to extremely high hunting pressure on porcupines in Equatorial Guinea, for instance, Fa and Juste (2001) reported that *A. africanus* made up 20.3% of all hunter captures, exceeded only by *P. monticola*. Rodents are the second-most common group to appear in markets after duikers, and thus are important sources of local income and protein (Fa & Juste 2001). Because porcupines are one of the most hunted species in central African forests, they potentially avoid low integrity forests that are more easily accessible to hunters, or are already depleted in them (Jori et al. 1998, Vanthomme et al. 2012).

Bushbuck and sitatunga were present closer to rivers, but at stations where they were present, abundance increased further from rivers. This may reflect sitatunga selection of the varied swamp and palm habitats in areas around rivers (Kingdon 2015). Bushbuck and sitatunga were also found closer to large villages, roads, and human detections. This is potentially because human-dominated areas in eastern RNRC are also closer to the Campo River, where most were detected (Figure 5). Previous studies have also suggested that sitatunga might be attracted to crops near villages (Vanthomme et al. 2012). Though we were unable to model small duiker distributions, it is also possible that bushbuck and sitatunga are closer to human-dominated areas because small duiker were depleted in these areas due to extensive hunting (Juste et al. 1995, Yasuoka et al. 2015).

Conclusion

There has been continued expansion of road networks and forest loss in continental Equatorial Guinea (Zvomuya 2014). For example, the *Machinda* region where RNRC is located lost 89.4 km² of tree cover from 2000–2019 (Global Forest Watch 2021). Despite these human-mediated impacts, RNRC is home to several endangered species, and harbours a diversity of common mammals. Eastern RNRC appears to be important for elephants and great apes as previously noted by Murai et al. (2013), and also for giant pangolins. Additionally, our models suggest interior RNRC might represent a refuge for pangolins and certain monkey species. More common but widely-hunted species, e.g. duikers, porcupines, and pouched rats were present throughout RNRC. Though we were unable to model small duiker distributions in RNRC, our models of bushbuck and sitatunga distributions suggest that they are closer to human-dominated areas in general, and thus potentially at risk of overexploitation. Since these taxa are important for local income and food security, additional research could help INDEFOR-AP

staff effectively manage their populations. In the short term, we recommend that INDEFOR-AP uses our mammal inventory and distribution maps to prioritise anti-poaching efforts in RNRC's eastern region. Longer term, we also recommend conducting targeted camera trap surveys in the north-western portion of RNRC, which was underrepresented in this study.

To effectively manage and conserve mammals, INDEFOR-AP needs comprehensive biodiversity surveys and robust analyses conducted to assess mammal abundance in relation to both human-mediated factors, e.g. distance to roads, villages and cities, as well as environmental factors, e.g. forest structure. This could be particularly useful in recently developed areas, such as the new capital Ciudad de la Paz (previously Oyala) which is being built in the centre of the country. By surveying mammals across both highly-disturbed and less-disturbed regions of Equatorial Guinea, we can begin to disentangle drivers of mammal diversity and distribution at a country-wide scale. This project represents the first step in assessing these larger, important research questions.

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Conflict of interest statement:

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Data availability

The data supporting the findings of this study are available from the corresponding author, T.L.D., upon reasonable request.

References

Abernethy, K. & Maisels, F. (2019). *Mandrillus sphinx*. The IUCN Red List of Threatened Species 2019: e.T12754A17952325. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12754A17952325.en>.

Abernethy, K. & Maisels, F. (2020). *Cercopithecus cephus* (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T4214A166614362. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T4214A166614362.en>.

Burnham, K., & Anderson, D. (2002). *Model selection and multimodel inference* - 2nd ed.. New York, NY: Springer-verlag new York Inc.

Castroviejo, J. B., Blom, A., & Alers. M. P. T. (1990). Equatorial Guinea In R. East (compiler) *Antelopes: Global Survey and Regional Action Plans, Part 3: West and Central Africa*, (pp. 167-171). IUCN, Gland, Switzerland.

Challender, D., Waterman, C., & Baillie, J. (2014). *Scaling up pangolin conservation*. IUCN SSC Pangolin Specialist Group Conservation Action Plan. Zoological Society of London, London, UK.

Cronin, D., Woloszynek, S., Morra, W., Honarvar, S., Linder, J., & Gonder, M. et al. (2015). Long-Term Urban Market Dynamics Reveal Increased Bushmeat Carcass Volume despite Economic Growth and Proactive Environmental Legislation on Bioko Island, Equatorial Guinea. *PLOS ONE*, 10(7), e0134464. doi: 10.1371/journal.pone.0134464

Cronin, D., Sesink Clee, P., Mitchell, M., Bocuma Meñe, D., Fernández, D., & Riaco, C. et al. (2017). Conservation strategies for understanding and combating the primate bushmeat trade on Bioko Island, Equatorial Guinea. *American Journal Of Primatology*, 79(11), 22663. doi: 10.1002/ajp.22663

Cronin, D.T., Maisels, F., Gadsby, E., Gonedelé Bi, S., Ikemeh, R. & Imong, I. (2020). *Cercopithecus nictitans* (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T4224A166615169. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T4224A166615169.en>.

Doumenge C., Palla F., Itsoua Madzous G-L. (Eds.) (2021). *State of Protected Areas in Central Africa 2020*. OFAC-COMIFAC, Yaounde, Cameroon & IUCN, Gland, Switzerland: 400p.

East, T., Kümpel, N., Milner-Gulland, E., & Rowcliffe, J. (2005). Determinants of urban bushmeat consumption in Río Muni, Equatorial Guinea. *Biological Conservation*, 126(2), 206-215. doi: 10.1016/j.biocon.2005.05.012

Equatorial Guinea (2007). *Hunting and consumption of monkeys and other primates in the republic of Equatorial Guinea is prohibited*. Law num. 72/2007, Government of Equatorial Guinea.

Fa, J., & Juste, J. (2001). Commercial bushmeat hunting in the Monte Mitra forests, Equatorial Guinea: extent and impact. *Animal Biodiversity and Conservation* 24(1), 31-52.

Fa, J., Juste, J., Burn, R., & Broad, G. (2002). Bushmeat Consumption and Preferences of Two Ethnic Groups in Bioko Island, West Africa. *Human Ecology* 30(3), 397-416.

Fa, J., & Brown, D. (2009). Impacts of hunting on mammals in African tropical moist forests: a review and synthesis. *Mammal Review*, 39(4), 231-264. doi: 10.1111/j.1365-2907.2009.00149.x

Fa, J., Olivero, J., Farfán, M., Márquez, A., Duarte, J., & Nackoney, J. et al. (2015). Correlates of bushmeat in markets and depletion of wildlife. *Conservation Biology*, 29(3), 805-815. doi: 10.1111/cobi.12441

FNC Equatorial Guinea (2019). *First National Communication to the United Nations Framework Convention on Climate Change*. Republic of Equatorial Guinea, Ministry of Agriculture, Livestock, Forests and Environment (MAGBMA), Malabo, Equatorial Guinea, First Edition 2019.

Global Forest Watch, n.d. *Equatorial Guinea Deforestation Rates & Statistics*. Retrieved 31 August 2021, from <https://www.globalforestwatch.org/dashboards/country/GNQ/>

- Gobush, K.S., Edwards, C.T.T., Maisels, F., Wittemyer, G., Balfour, D. & Taylor, R.D. (2021). *Loxodonta cyclotis* (errata version published in 2021). The IUCN Red List of Threatened Species 2021: e.T181007989A204404464. Retrieved 24 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T181007989A204404464.en>.
- Grantham, H., Duncan, A., Evans, T., Jones, K., Beyer, H., & Schuster, R. et al. (2020). Anthropogenic modification of forests means only 40% of remaining forests have high ecosystem integrity. *Nature Communications*, 11(1). doi: 10.1038/s41467-020-19493-3
- Grueber, C., Nakagawa, S., Laws, R. & Jamieson, I. (2011). Multimodel inference in ecology and evolution: challenges and solutions. *Journal of Evolutionary Biology*, 24(4), 699-711.
- Humle, T., Maisels, F., Oates, J.F., Plumptre, A. & Williamson, E.A. (2016). *Pan troglodytes* (errata version published in 2018). The IUCN Red List of Threatened Species 2016: e.T15933A129038584. Retrieved 22 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2016-2.RLTS.T15933A17964454.en>.
- Jori, F., Lopez-Bejar, M., & Houben, P. (1998) The biology and use of the African brush-tailed porcupine (*Atherurus africanus*, Gray, 1842) as a food animal. A review. *Biodiversity and Conservation* 7, 1417-1426
- Juste, J., Fa, J., Val, J., & Castroviejo, J. (1995). Market Dynamics of Bushmeat Species in Equatorial Guinea. *The Journal Of Applied Ecology*, 32(3), 454. doi: 10.2307/2404644
- Instituto Nacional de Estadística de Guinea Ecuatorial (INEGE) (2018). Anuario estadístico de Guinea Ecuatorial 2018. Retrieved 1 July 2021, from <https://www.inege.gq/wp-content/uploads/2019/03/anuario-estadistico-de-guinea-ecuatorial-2018-.pdf>.
- Ingram, D., Cronin, D., Challender, D., Venditti, D., & Gonder, M. (2019). Characterising trafficking and trade of pangolins in the Gulf of Guinea. *Global Ecology And Conservation*, 17, e00576. doi: 10.1016/j.gecco.2019.e00576
- Kingdon, J. (2015). *The Kingdon field guide to African mammals* (2nd ed.). Princeton, New Jersey: Princeton University Press.
- Larison, B., Smith, T. B., Gorman, D., Stauffer, D., Mila, B., Drewes, R.C., Griswold, C.E., Vindum, J.V., Ubick, D., O'Keefe, K., Nguema, J. & Henwood, L. (1999). Biotic surveys of Bioko and Rio Muni, Equatorial Guinea. Central Africa Regional Program for the Environment (CARPE), Washington DC.
- Long, J. A. (2020). jtools: Analysis and Presentation of Social Scientific Data. R package version 2.1.0. <https://cran.r-project.org/package=jtools>
- Maisels, F., Bergl, R.A. & Williamson, E.A. (2018). *Gorilla gorilla* (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2018: e.T9404A136250858. Retrieved 22 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T9404A136250858.en>.
- Maisels, F., Oates, J.F., Linder, J., Ikemeh, R., Imong, I. & Etiendem, D. (2019). *Cercocebus torquatus* (errata version published in 2019). The IUCN Red List of Threatened Species 2019: e.T4201A154210757. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-1.RLTS.T4201A154210757.en>.
- Maisels, F. & Cronin, D.T. (2020). *Colobus satanas*. The IUCN Red List of Threatened Species 2020: e.T5145A17944405. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T5145A17944405.en>.
- Maisels, F., Hart, J., Olupot, W. & Oates, J.F. (2020). *Lophocebus albigena* (amended version of 2019 assessment). The IUCN Red List of Threatened Species 2020: e.T12309A166607033. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2020-1.RLTS.T12309A166607033.en>.
- Murai, M., Ruffler, H., Berlemont, A., Campbell, G., Esono, F., & Agbor, A. et al. (2013). Priority Areas for Large Mammal Conservation in Equatorial Guinea. *Plos ONE*, 8(9), e75024. doi: 10.1371/journal.pone.0075024
- NASA Shuttle Radar Topography Mission (SRTM) (2013). Shuttle Radar Topography Mission

- (SRTM) Global. Distributed by OpenTopography. Doi: 10.5069/G9445JDF Accessed: 2021-12-16
- Niedballa, J., Sollmann, R., Courtiol, A., & Wilting, A. (2016). camtrapR: an R package for efficient camera trap data management. *Methods In Ecology And Evolution*, 7(12), 1457-1462. doi: 10.1111/2041-210x.12600
- Nixon, S., Pietersen, D., Challender, D., Hoffmann, M., Godwill Ichu, I., Bruce, T., Ingram, D.J., Matthews, N. & Shirley, M.H. (2019). *Smutsia gigantea*. The IUCN Red List of Threatened Species 2019: e.T12762A123584478. Retrieved 22 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12762A123584478.en>.
- Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., et al. (2020). *vegan: Community Ecology Package*. R package version 2.5-7. <https://CRAN.R-project.org/package=vegan>
- Pietersen, D., Moumbolou, C., Ingram, D.J., Soewu, D., Jansen, R., Sodeinde, O., Keboy Mov Linkey Iflankoy, C., Challender, D. & Shirley, M.H. (2019). *Phataginus tricuspidis*. The IUCN Red List of Threatened Species 2019: e.T12767A123586469. Retrieved 22 February 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T12767A123586469.en>.
- QGIS Development Team (2017). QGIS Geographic Information System. Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>
- R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- Redford, K. (1992). The Empty Forest. *Bioscience*, 42(6), 412-422. doi: 10.2307/1311860
- Svensson, M. & Nekaris, K.A.I. (2019). *Arctocebus aureus*. The IUCN Red List of Threatened Species 2019: e.T2053A17969875. Retrieved 14 April 2022, from: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T2053A17969875.en>.
- Thouless, C., Dublin, H. Blanc, J., Skinner, D., Daniel, T., Taylor, R., Maisels, F., Frederick, H., & Bouché, P. (2016). African Elephant Status Report 2016: an update from the African Elephant Database. Occasional Paper Series of the IUCN Species Survival Commission, No. 60 IUCN / SSC African Elephant Specialist Group, Gland, Switzerland.
- Walsh, P., Abernethy, K., Bermejo, M., Beyers, R., De Wachter, P., & Akou, M. et al. (2003). Catastrophic ape decline in western equatorial Africa. *Nature*, 422(6932), 611-614. doi: 10.1038/nature01566
- Watson, J., Dudley, N., Segan, D., & Hockings, M. (2014). The performance and potential of protected areas. *Nature*, 515(7525), 67-73. doi: 10.1038/nature13947,
- Willcox, D., Nash, H., Trageser, S., Kim, H., Hywood, L., & Connelly, E. et al. (2019). Evaluating methods for detecting and monitoring pangolin (Pholidata: Manidae) populations. *Global Ecology And Conservation*, 17, e00539. doi: 10.1016/j.gecco.2019.e00539
- World Population Review (2022). Population of Cities in Equatorial Guinea (2022). Retrieved 17 February 2022, from <https://worldpopulationreview.com/countries/cities/equatorial-guinea>
- UNEP-WCMC (2021). Protected Area Profile for Rio Campo from the World Database of Protected Areas, August 2021. Available at: www.protectedplanet.net
- U.S. Fish and Wildlife Service (USFWS) (2014). Equatorial Guinea Fact Sheet.
- Vanthomme, H., Kolowski, J., Korte, L., & Alonso, A. (2013). Distribution of a Community of Mammals in Relation to Roads and Other Human Disturbances in Gabon, Central Africa. *Conservation Biology*, 27(2), 281-291. doi: 10.1111/cobi.12017
- World Bank (2021). Climate Change Knowledge Portal. Retrieved 20 December 2021, from <https://climateknowledgeportal.worldbank.org/country/equatorial-guinea/climate-data-historical>
- World Wide Fund for Nature (WWF) Cameroon, n.d., Kudu Zombo. Retrieved 16 July 2020, from https://cameroon.panda.org/places_landscapes/kudu_zombo/.
- Yasuoka, H., M. Hirai, T. O. W. Kamgaing, Z. C. B. Dzefack, E. C. B. Kamdoun, and K. S. Bobo. 2015. Changes in the composition of hunting catches in southeastern Cameroon: a

promising approach for collaborative wildlife management between ecologists and local hunters. *Ecology and Society* 20(4):25. <http://dx.doi.org/10.5751/ES-08041-200425>

Zuur, A. (2011). *Mixed effects models and extensions in ecology with R*. New York, NY: Springer.

Zvomuya, F. (2014). On a whim: Equatorial Guinea building new capital city in the middle of the Rainforest. Retrieved 16 July 2020, from <https://news.mongabay.com/2014/07/on-a-whim-equatorial-guinea-building-new-capital-city-in-the-middle-of-the-rainforest>

Figure & table captions

Figure 1. Study area and study design for remote camera trap deployment in Rio Campo Nature Reserve, Equatorial Guinea in 2017 and 2019, showing populated places (red triangles), main roads and secondary roads/trails (black solid and dotted lines, respectively), rivers (blue lines), and camera stations in 2017 and 2019 (pink pentagons and teal squares, respectively). Rio Campo Nature Reserve is shaded green, and nearby Campo Ma'an National Park is shaded grey. The inset map shows Rio Campo Nature Reserve's location within continental Equatorial Guinea. A total of 66 camera traps were deployed during this study.

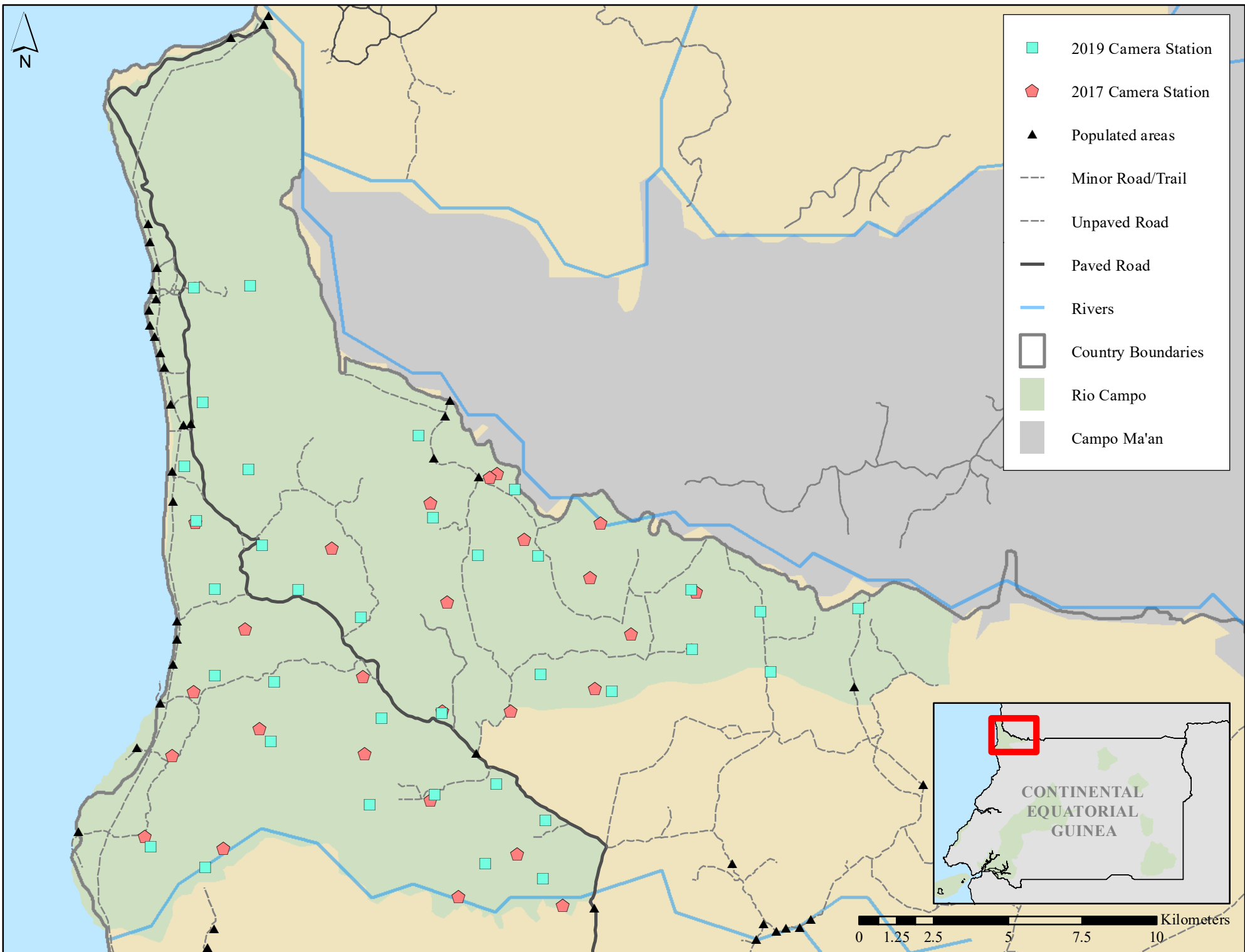
Figure 2. Camera trap images of wildlife and human activity detected during our 2017 and 2019 mammal survey in Rio Campo Nature Reserve, Equatorial Guinea. Images included are representative of **a.** threatened taxa (left to right: African forest elephant, tree pangolin, giant pangolin, western mountain gorilla, chimpanzee, mandrill), **b.** common taxa (left to right: yellow-backed duiker, water chevrotain, blue duiker, Emin's pouched rat, African brush-tailed porcupine) and **c.** hunters.

Figure 3. Species accumulation curve (black, confidence intervals light blue) of terrestrial mammal species detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments using rarefaction.

Figure 4. Forest plots showing beta-estimates for presence (a) and relative abundance (b) of terrestrial mammal groups detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments. †square-root transformed, ‡log-transformed, §cubed.

Figure 5. Distribution and detection rates of species and groups of particular conservation or hunting concern detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments. Detection rates for taxa are symbolised with proportionally-sized circles.

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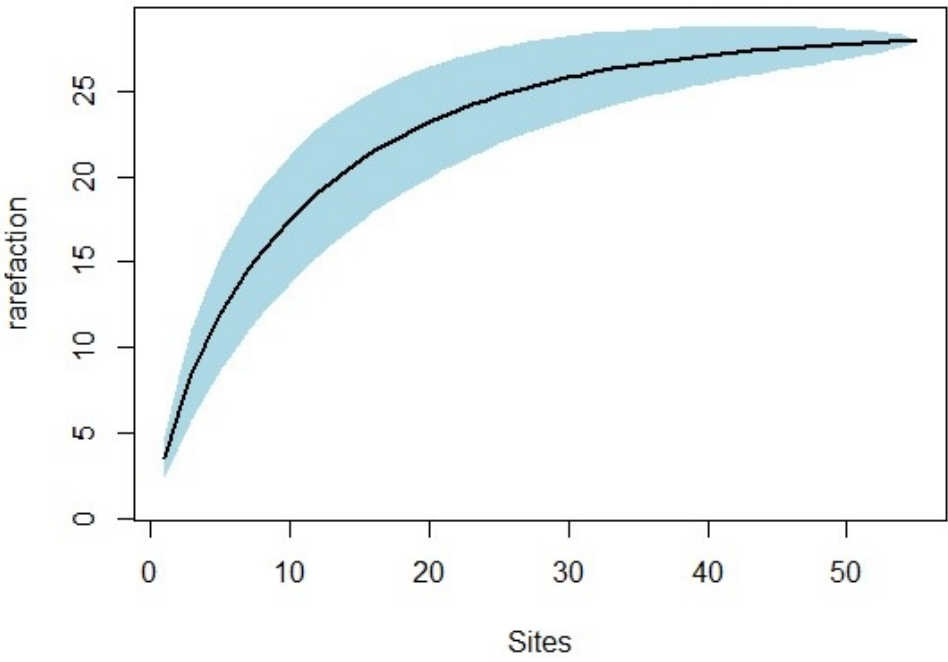


b.



c.





Species accumulation curve (black, confidence intervals light blue) of terrestrial mammal species detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments using rarefaction.

147x103mm (96 x 96 DPI)

a.

Forest Landscape
Integrity Index^s

Dist. to River

Dist. to Road[‡]Dist. to Populated
Place[†]Dist. to Large
Village[‡]

Dist. to Human

Dist. to RNRC
Boundary[†]Dist. to
PNCM Boundary β , Step 1

b.

 β , Step 2

Taxonomic Group

- Mongooses
- Viverrids
- Large Duikers
- Monkeys
- Pangolins
- Porcupines
- Squirrels

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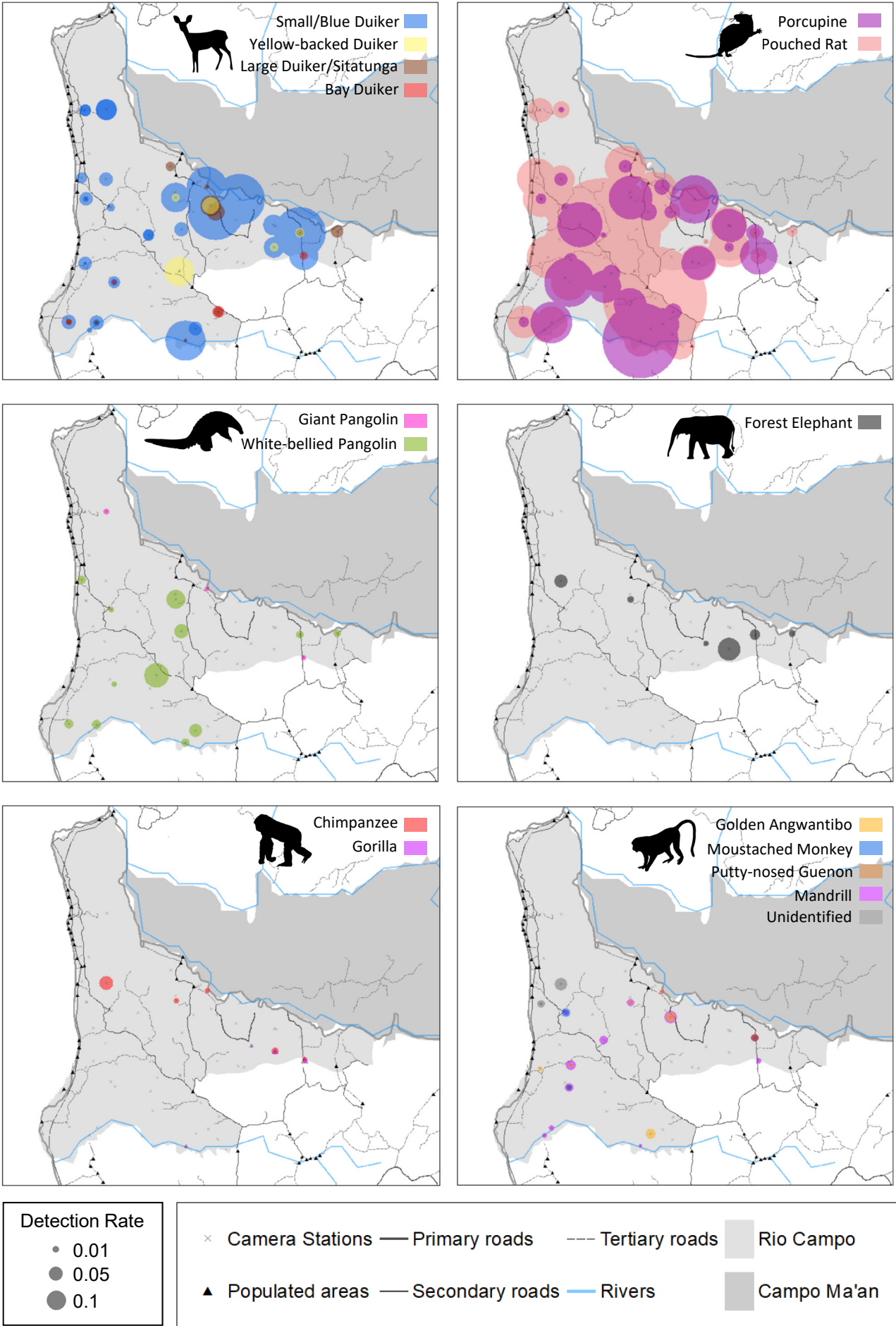


Table 1. Taxa detected, number of independent detections (n), and overall detection rates of taxa recorded by camera traps in Rio Campo Nature Reserve, Equatorial Guinea in 2017 and 2019. Detections were considered independent if they were at least 30 minutes apart.

Order	Family	Species name	English name	Spanish name	n	Detection Rate
Carnivora	Herpestidae	Herpestidae spp.	Mongoose	<i>Mangosta</i>	7	0.0024
		<i>Atilax paludinosus</i>	Marsh mongoose	<i>Mangosta de los pantanos</i>	3	0.0010
		<i>Crossarchus platycephalus</i>	Cusimanse	<i>Cusimanse común</i>	8	0.0027
		<i>Galerella sanguinea</i>	Slender mongoose	<i>Mangosta esbelta</i>	1	0.0003
	Viverridae	<i>Civettictis civetta</i>	African civet	<i>Civeta africana</i>	10	0.0034
		<i>Genetta servalina</i>	Servaline genet	<i>Jineta servalina</i>	23	0.0078
	Nandiniidae	<i>Nandinia binotata</i>	African palm civet	<i>Civeta africana de las palmeras</i>	5	0.0017
Cetartiodactyla	Bovidae	<i>Cephalophus dorsalis</i>	Bay duiker	<i>Duiker bayo</i>	7	0.0024
		<i>Cephalophus silvicultor</i>	Yellow-backed duiker	<i>Cefalofo silvicultor</i>	8	0.0027
		<i>Hyemoschus aquaticus</i>	Water chevrotain	<i>Cervatillo de agua</i>	3	0.0010
		<i>Philantomba monticola</i>	Blue duiker	<i>Cefalofo azul</i>	338	0.1154
		<i>Tragelaphus scriptus</i>	Bushbuck	<i>Bushbuck</i>	7	0.0023
		<i>Tragelaphus spekii</i>	Sitatunga	<i>Sitatunga</i>	2	0.0007
		<i>Tragelaphus</i> spp.	Unidentified <i>Tragelaphus</i>	<i>Antilope grande</i>	1	0.0003
		<i>Philantomba/Cephalophus</i> spp.	Unidentified small duiker	<i>Antilope pequeño</i>	21	0.0072
	Suidae	<i>Potamochoerus porcus</i>	Red river hog	<i>Potamoquero rojo</i>	11	0.0038
Chiroptera	–		Bat	<i>Murciélago</i>	2	0.0007
Hyracoidea	Procaviidae	<i>Dendrohyrax dorsalis</i>	Western tree hyrax	<i>Damán arborícola occidental</i>	1	0.0003
Primates	Cercopithecidae	<i>Cercopithecus cephus</i>	Moustached guenon	<i>Cercopiteco de hocico azul</i>	3	0.0010
		<i>Cercopithecus nictitans</i>	Putty-nosed guenon	<i>Cercopiteco de nariz blanca</i>	2	0.0007
		<i>Mandrillus sphinx</i>	Mandrill	<i>Mandrill</i>	19	0.0065
	Hominidae	<i>Gorilla gorilla</i>	Western gorilla	<i>Gorila occidental</i>	5	0.0017
		<i>Pan troglodytes</i>	Common chimpanzee	<i>Chimpancé</i>	5	0.0017
	Lorisidae	<i>Arctocebus aureus</i>	Golden angwantibo	<i>Poto dorado</i>	7	0.0024
		–	Unidentified monkey	<i>Mono no identificado</i>	3	0.0010
Pholidota	Manidae	<i>Phataginus tricuspis</i>	Tree pangolin	<i>Pangolín arborícola</i>	34	0.0116
		<i>Smutsia gigantea</i>	Giant pangolin	<i>Pangolín gigante</i>	2	0.0007
Proboscidea	Elephantidae	<i>Loxodonta cyclotis</i>	Forest elephant	<i>Elefante del bosque</i>	20	0.0068
Rodentia	Hystriidae	<i>Atherurus africanus</i>	African brush-tailed porcupine	<i>Puercoespín</i>	484	0.1652
	Muridae	Murinae spp.	Unidentified mouse	<i>Ratón</i>	171	0.0584
	Nesomyidae	<i>Cricetomys emini</i>	Emin's pouched rat	<i>Rata gigante de Gambia</i>	921	0.3143
	Sciuridae	Sciuridae spp.	Unidentified squirrel	<i>Ardilla</i>	13	0.0044
		<i>Funisciurus</i> Spp.	Unidentified rope squirrel	<i>Ardilla listada africana</i>	29	0.0099
		<i>Funisciurus lemniscatus</i>	Ribboned rope squirrel	–	90	0.0307
		<i>Funisciurus anerythrus</i>	Thomas's rope squirrel	–	1	0.0003
		<i>Funisciurus isabella</i>	Lady Burton's rope squirrel	–	8	0.0027
		<i>Funisciurus pyrrhopus</i>	Fire-footed rope squirrel	–	18	0.0061
		<i>Heliosciurus rufobrachium</i>	Red-legged sun squirrel	–	14	0.0048
		<i>Paraxerus poensis</i>	Green bush squirrel	–	1	0.0003
		Rodentia spp.	Unidentified small mammal	<i>Mamífero pequeño</i>	2	0.0007
			Unidentified animal	<i>Animal no identificado</i>	214	0.0730

Table 2. Top model-averaged results of two-step models of mammal group presence and abundance in in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments in 2017 and 2019. Covariates with confidence limits that do not overlap zero are bolded. River: Distance to nearest river (m); FLII: Forest Landscape Integrity Index (factor, range 1-10); Road: Distance to nearest road (m); Paved Road: Distance to nearest paved road (m); Populated Place: Distance to nearest populated place (m); Large Village: Distance to nearest of two villages, Mbonda or Bongoro (m); Human: Distance to nearest human detection or stolen camera trap (m); RNRC Boundary: Distance to nearest boundary of Rio Campo Nature Reserve (m); PNCM Boundary: Distance to nearest boundary of Campo Ma'an National Park in Cameroon; β : beta-estimate, SE: standard error, CL: confidence limits, RI: relative importance of variable. \dagger square-root transformed; \ddagger Log-transformed; \S cubed.

Taxonomic Group	Step 1 models	Explanatory Variables	β	SE	CL	RI	Step 2 models	Explanatory Variables	β	SE	CL	RI
Mongooses	26	Intercept	-4.61	0.39	-5.40, -3.83		12					
		River	-0.87	0.52	-1.73, -0.02	0.78						
		PNCM Boundary	0.59	0.34	-0.19, 1.36	0.28						
		Human	0.83	0.39	0.01, 1.65	0.22						
		FLII \S	-0.41	0.21	-1.33, 0.51	0.12						
		Large Village \ddagger	-0.36	0.19	-1.26, 0.53	0.12						
Viverrids	26	Intercept	-4.19	0.37	-4.92, -3.45		12	Intercept	-3.91	0.19	-4.32, -3.51	
		FLII \S	-0.81	0.38	-1.57, -0.05	0.84		Large Village \ddagger	0.53	0.23	0.04, 1.03	0.48
		RNRC Boundary \dagger	-0.62	0.38	-1.38, 0.14	0.54		River	0.30	0.14	0.00, 0.60	0.32
		River	-0.37	0.39	-1.16, 0.42	0.15		Road \ddagger	-0.28	0.15	-0.59, 0.03	0.19
Small Duikers	26	Intercept	-3.16	0.35	-3.86, -2.47		18					
		Populated Place \dagger	0.38	0.34	-0.30, 1.06	0.26						
		Large Village \ddagger	0.44	0.42	-0.40, 1.28	0.25						
		Human	-0.25	0.34	-0.92, 0.43	0.11						
		PNCM Boundary	-0.22	0.35	-0.91, 0.47	0.11						
		Road \ddagger	0.20	0.33	-0.45, 0.86	0.11						
Large Duikers	26	Intercept	-5.03	0.48	-5.99, -4.07		12	Intercept	-3.77	0.41	-4.61, -2.93	
		River	-1.58	0.67	-2.92, -0.24	1		PNCM Boundary	-0.51	0.19	-0.94, -0.09	0.5
		PNCM Boundary	-0.67	0.36	-1.39, 0.06	0.49		River	0.88	0.32	0.17, 1.59	0.23
		Large Village \ddagger	-1.05	0.47	-2.0, -0.11	0.24		Human	-0.43	0.19	-0.85, -0.01	0.1
		Human	-1.21	0.46	-2.13, -0.28	0.24		Road \ddagger	-0.35	0.15	-0.68, -0.01	0
		Road \ddagger	-0.91	0.44	-1.80, -0.03	0.24		Large Village \ddagger	0.51	0.31	-0.17, 1.19	0.03
		Populated Place \dagger	-0.20	0.38	-0.95, 0.56	0.24		RNRC Boundary \dagger	0.42	0.26	-0.14, 0.98	0.03
								FLII \S	0.21	0.35	-0.55, 0.98	0.01
								Paved Road \ddagger	-0.21	0.35	-0.99, 0.56	0.01
								Populated Place \dagger	0.03	0.19	-0.39, 0.45	0.01

Taxonomic Group	Step 1 models	Explanatory Variables	β	SE	CL	RI	Step 2 models	Explanatory Variables	β	SE	CL	RI
Great Apes	26	Intercept	-5.89	0.51	-6.92, -4.85		12	Intercept	-4.54	0.61	-5.92, -3.17	
		PNCM Boundary	-0.98	0.52	-2.03, 0.06	1		Large Village [‡]	0.41	0.83	-0.55, 3.79	0.26
		River	-0.31	0.48	-1.26, 0.65	0.29		FLII [§]	-0.20	0.43	-1.99, 0.11	0.22
								Road [‡]	-0.08	0.19	-1.06, 0.16	0.17
Monkeys	26	Intercept	-4.35	0.36	-5.08, -3.62		12	Intercept	-3.96	0.18	-4.33, -3.63	
		Road [‡]	0.62	0.38	-0.15, 1.38	0.66		RNRC Boundary [†]	0.41	0.15	0.12, 0.70	1
		Populated Place [†]	0.24	0.36	-0.49, 0.97	0.19						
Pangolins	26	Intercept	-4.51	0.38	-5.26, -3.75		12	Intercept	-3.601	0.16	-3.94, -3.29	
		FLII [§]	0.66	0.44	-0.22, 1.54	0.43		RNRC Boundary [†]	0.43	0.16	0.12, 0.75	1
		River	-0.45	0.38	-1.22, 0.32	0.33						
		Human	0.51	0.38	-0.25, 1.26	0.18						
Porcupines	26	Intercept	-2.73	0.36	-3.44, -2.02		18					
		Road [‡]	0.55	0.36	-0.17, 1.27	0.18						
		Populated Place [†]	0.80	0.36	0.08, 1.52	0.59						
		FLII [§]	0.88	0.40	0.09, 1.67	0.4						
		RNRC Boundary [†]	0.49	0.36	-0.24, 1.22	0.15						
		River	-0.37	0.37	-1.12, 0.38	0.2						
Pouched rats	26	Intercept	-0.97	0.41	-1.8, -0.14		18					
		RNRC Boundary [†]	-0.84	0.43	-1.71, 0.03	0.84						
		Paved Road [‡]	-0.33	0.40	-1.13, 0.47	0.21						
		Large Village [‡]	0.24	0.39	-0.53, 1.01	0.18						
Squirrels	26	Intercept	-3.98	0.39	-4.77, -3.2		18	Intercept	-2.50	0.12	-2.75, -2.25	
		River	-1.37	0.53	-2.43, -0.31	0.59		Road [‡]	0.35	0.08	0.18, 0.52	0.64
		Large Village [‡]	-1.24	0.39	-2.03, -0.45	1		Populated Place [†]	0.31	0.07	0.16, 0.46	0.64
		Human	-0.81	0.44	-1.7, 0.08	0.59		FLII [§]	0.50	0.10	0.29, 0.71	0.36
		Road [‡]	-0.76	0.43	-1.62, 0.09	0.59		River	-0.29	0.10	-0.49, -0.09	0.36
		Populated Place [†]	1.07	0.42	0.23, 1.90	1						

Appendix S1: Covariates included in initial data exploration to model mammal group presence and abundance in Rio Campo Nature Reserve, Equatorial Guinea. all covariate units are in meters (m) except for Forest Landscape Integrity Index, which is a factor from 1-10. † not included in analyses due to collinearity with other covariates

Covariate Name	Description	Transformation	Source
Road	Distance to road neared road in Equatorial Guinea, including primary, secondary, private roads, and trails	Log	INDEFOR-AP
Rio Campo Boundary	Distance to nearest point of Rio Campo's boundary	Square-root	INDEFOR-AP
River	Distance to nearest river	N/A	Lehner, B., Verdin, K., Jarvis, A. (2006): HydroSHEDS Technical Documentation. World Wildlife Fund US, Washington, DC. Available at http://hydrosheds.cr.usgs.gov . Please also visit http://www.worldwildlife.org/hydrosheds and http://hydrosheds.cr.usgs.gov for information on data download and status reports.
Large Village	Distance to the nearest of two large villages in Rio Campo: Punta Mbonda, and Bongoro	Log	INDEFOR-AP
Forest Landscape Integrity Index	Factor, Index of forest integrity based on human pressure and loos of forest connectivity ranging from 0 (low) to 10 (high)	Cube	Grantham, H., Duncan, A., Evans, T., Jones, K., Beyer, H., & Schuster, R. et al. (2020). Anthropogenic modification of forests means only 40% of remaining forests have high ecosystem integrity. Nature Communications, 11(1). doi: 10.1038/s41467-020-19493-3
Campo Ma'an Boundary	Distance to nearest point of Campo Ma'an's boundary	N/A	IUCN and UNEP-WCMC (2016), The World Database on Protected Areas (WDPA) [On-line], [April 2017], Cambridge, UK: UNEP-WCMC. Available at: www.protectedplanet.net .
Populated Area	Distance to nearest populated area	Log	INDEFOR-AP
Human Detection	Distance to nearest human detection recorded within the survey period	N/A	The authors
Paved Road	Distance to nearest paved road	Log	INDEFOR-AP
Elevation†	Elevation calculated from ASTER Global Digital Elevation Model 1 arc second image	N/A	Terra ASTER Global Digital Elevation Model (GDEM) DEM data was retrieved on 2021_10_04 from https://lpdaac.usgs.gov , maintained by the NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC) at the USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota. 2018, https://lpdaac.usgs.gov/resources/data-action/aster-ultimate-2018-winter-olympics-observer/ .

Appendix S2: Candidate model sets used to model mammal group presence and abundance in Rio Campo, Equatorial Guinea, from camera trap deployments in 2017 and 2019.

Step 1 models: Binomial GLM	
fit1	Road + Offset term (trap nights)
fit2	Rio Campo Boundary + Offset term (trap nights)
fit3	River + Offset term (trap nights)
fit4	Large Village + Offset term (trap nights)
fit5	Forest Integrity Index + Offset term (trap nights)
fit6	Campo Ma'an Boundary + Offset term (trap nights)
fit7	Populated Area + Offset term (trap nights)
fit8	Human Detection + Offset term (trap nights)
fit9	Paved Road + Offset term (trap nights)
fit10	Road + Populated Area + Offset term (trap nights)
fit11	Road + Rio Campo Boundary + Offset term (trap nights)
fit12	Road + Large Village + Offset term (trap nights)
fit13	River + Road + Offset term (trap nights)
fit14	Forest Integrity Index + River + Offset term (trap nights)
fit15	Forest Integrity Index + Rio Campo Boundary + Offset term (trap nights)
fit16	River + Large Village + Offset term (trap nights)
fit17	River + Campo Ma'an Boundary + Offset term (trap nights)
fit18	River + Populated Area + Offset term (trap nights)
fit19	Large Village + Rio Campo Boundary + Offset term (trap nights)
fit20	Large Village + Populated Area + Offset term (trap nights)
fit21	Paved Road + Populated Area + Offset term (trap nights)
fit22	Paved Road + Rio Campo Boundary + Offset term (trap nights)
fitNull	1 + Offset term (trap nights)
fitGlobal1	River + Large Village + Human Detection + Road + Populated Area + Offset term (trap nights)
fitGlobal2	Rio Campo Boundary + Campo Ma'an Boundary + Forest Integrity Index + Paved Road + Offset term (trap nights)

Full model set: small duikers, porcupines, rats, squirrels

Step 2 models: Poisson GLM	
fit1	Road + Offset term (trap nights)
fit2	Rio Campo Boundary + Offset term (trap nights)
fit3	River + Offset term (trap nights)
fit4	Large Village + Offset term (trap nights)
fit5	Forest Integrity Index + Offset term (trap nights)
fit6	Campo Ma'an Boundary + Offset term (trap nights)
fit7	Populated Area + Offset term (trap nights)
fit8	Human Detection + Offset term (trap nights)
fit9	Paved Road + Offset term (trap nights)
fit10	River + Road+ Offset term (trap nights)
fit11	River + Populated Area + Offset term (trap nights)
fit12	Forest Integrity Index + River + Offset term (trap nights)
fit13	Road + Rio Campo Boundary + Offset term (trap nights)
fit14	Forest Integrity Index + Rio Campo Boundary + Offset term (trap nights)
fit15	Road + Populated Area + Offset term (trap nights)
fitNull	1 + Offset term (trap nights)
fitGlobal1	River + Large Village + Human Detection + Road + Populated Area + Offset term (trap nights)
fitGlobal2	Rio Campo Boundary + Campo Ma'an Boundary + Forest Integrity Index + Paved Road + Offset term (trap nights)

Reduced model set: mongooses, viverrids, large duikers, hogs, apes, monkeys, pangolins, elephants	
Step 2 models: Poisson GLM, small sample size	
fit1	Road + Offset term (trap nights)
fit2	Rio Campo Boundary + Offset term (trap nights)
fit3	River + Offset term (trap nights)
fit4	Large Village + Offset term (trap nights)
fit5	Forest Integrity Index + Offset term (trap nights)
fit6	Campo Ma'an Boundary + Offset term (trap nights)
fit7	Populated Area + Offset term (trap nights)
fit8	Human Detection + Offset term (trap nights)
fit9	Paved Road + Offset term (trap nights)
fitNull	1 + Offset term (trap nights)
fitGlobal1	River + Large Village + Human Detection + Road + Populated Area + Offset term (trap nights)
fitGlobal2	Rio Campo Boundary + Campo Ma'an Boundary + Forest Integrity Index + Paved Road + Offset term (trap nights)

Appendix S3: Camera trap images of mongoose species that, to the authors' knowledge, have not been recorded in Rio Campo Nature Reserve, Equatorial Guinea.

a. Atilax paludinosus





b. *Crossarchus platycephalus* (likely)





c. *Galerella sanguinea*

