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RESEARCH ARTICLE

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

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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 efforts of agencies tasked with protecting threatened mammals. Reserva Natural de Río Campo (RNRC) in Equatorial Guinea 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 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, bushmeat, camera trapping, hurdle models, mammal distributions, mammal survey, protected areas, species inventory

Résumé

La Guinée équatoriale en Afrique centrale abrite une riche biodiversité et un réseau d'espaces protégés (EP). Cependant, le développement des infrastructures a facilité l'accès à des forêts autrefois éloignées. Cela a probablement accru le braconnage dans les EP, compliquant de ce fait les efforts des agences chargées de protéger les mammifères en voie de disparition. La réserve naturelle de Río Campo (RNRC) en Guinée équatoriale a été précédemment identifiée comme une zone prioritaire pour les grands mammifères en raison de la présence d'éléphants et de grands singes, et comprend un habitat pour une communauté diversifiée de mammifères d'espèces fréquemment chassées. Pour évaluer la diversité des mammifères dans la RNRC, nous avons mené une enquête par piège photographique en 2017 et 2019. Nous avons utilisé une approche de modélisation en deux étapes pour quantifier les facteurs environnementaux et anthropiques qui influencent les groupes de mammifères. Nous avons détecté 32 espèces de mammifères terrestres, dont l'éléphant de forêt, le gorille occidental, le chimpanzé, le pangolin géant et le pangolin à ventre blanc, tous en voie de disparition. Nous avons trouvé le tragélaphe rayé et le sitatunga plus près des zones dominées par l'homme, tandis que d'autres espèces courantes étaient, en général, plus éloignées du développement. L'abondance des singes et des pangolins a augmenté de la limite de la RNRC vers l'intérieur. Les espèces en voie de disparition semblent limitées au nord-est de la RNRC qui se connecte au parc national de Campo Ma'an au Cameroun. Nous recommandons l'utilisation de notre inventaire et la répartition des mammifères en voie de disparition comme points de départ pour déterminer l'efficacité des futures stratégies de lutte contre le braconnage et de gestion des populations de mammifères.

1 | 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., 2021). 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 (U.S. Fish and Wildlife Service [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 on primate hunting (Doumenge et al., 2021; INEGE, 2018). Additionally, the agency is currently undertaking surveys to determine new areas to prioritise for protection and designate as PAs. 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 (U.S. Fish and Wildlife Service [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 & Brown, 2009).

The last broad biotic survey of Equatorial Guinea's continental region was conducted in May–June 1998. The survey 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 the 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) that 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; Murai et al., 2013; Walsh et al., 2003). 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 (Fa et al., 1995, 2002, 2015; Juste et al., 1995). 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, 2002, 2015). Primates are likely consumed as a symbol of wealth and status in Equatorial Guinea, despite taboos around eating them among certain ethnic groups (Cronin et al., 2017; East et al., 2005). 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 among the most preferred wild meat species in Equatorial Guinea's markets and are often cited as the world's most trafficked mammal (East et al., 2005; Ingram et al., 2019; Juste et al., 1995). 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 & 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. We aim to use these models to facilitate conservation and monitoring in RNRC by highlighting areas for targeted protection by the government forest agency INDEFOR-AP. These models will also assist in the development of predictive mammal community models for the entire continental region of Equatorial Guinea to be used in future studies.

2 | METHODS

2.1 | 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) (UN Environment Programme World Conservation Monitoring Centre [UNEP-WCMC], 2021). The Litoral region where RNRC is located experiences an annual average temperature of 25.52°C and average annual precipitation of 2449 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 km^2 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, (Farr & Kobrick, 2000)). The reserve is located approximately 50 km north by road from Equatorial Guinea's most populous city, Bata (pop. 173046; World Population Review, 2022).

2.2 | 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. 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

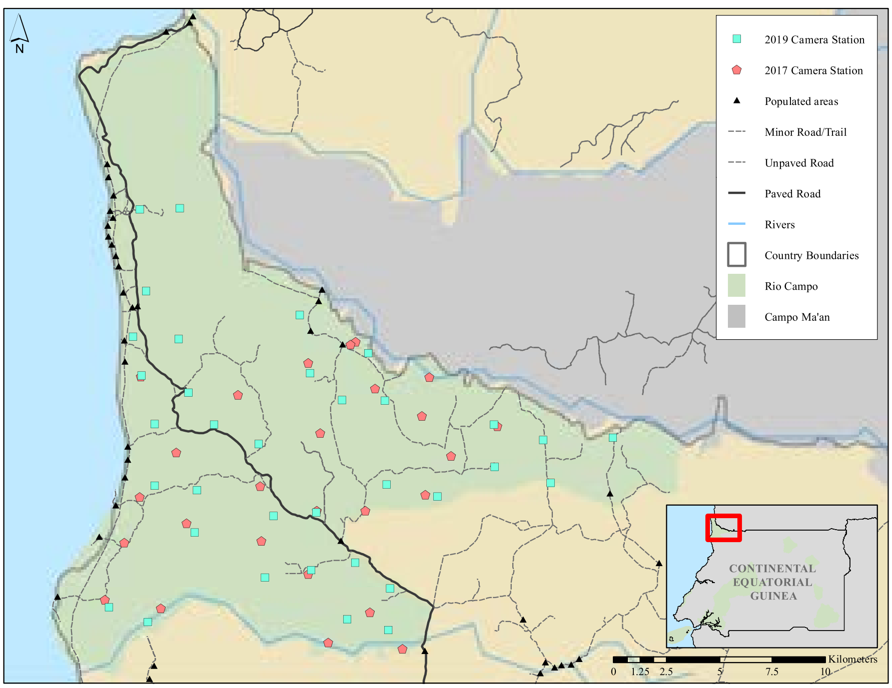

FIGURE 1 Study area and study design for remote camera trap deployment in Rio Campo Nature Reserve, Equatorial Guinea in 2017 and 2019, showing populated places (red triangles), main roads and secondary roads/trails (black solid and dotted lines, respectively), rivers (blue lines) and camera stations 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.

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 to standardise camera settings as follows: mode: camera, image size: HD, sensor level: high, capture number: 3, interval: 1-s, 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 km^2 (via minimum convex polygon in ArcGIS; Meek et al., 2014).

2.3 | 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'. 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, that is 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 min 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).

2.4 | Mammal presence/absence and abundance

We grouped species into taxonomic groups (hereafter 'groups'): 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; Humle 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, that is 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 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 & 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 ΔAIC_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 each 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.

2.5 | Human detections

We georeferenced human detections that were not of field crews, and stolen cameras during 2017 and 2019 surveys, to comprise the distance

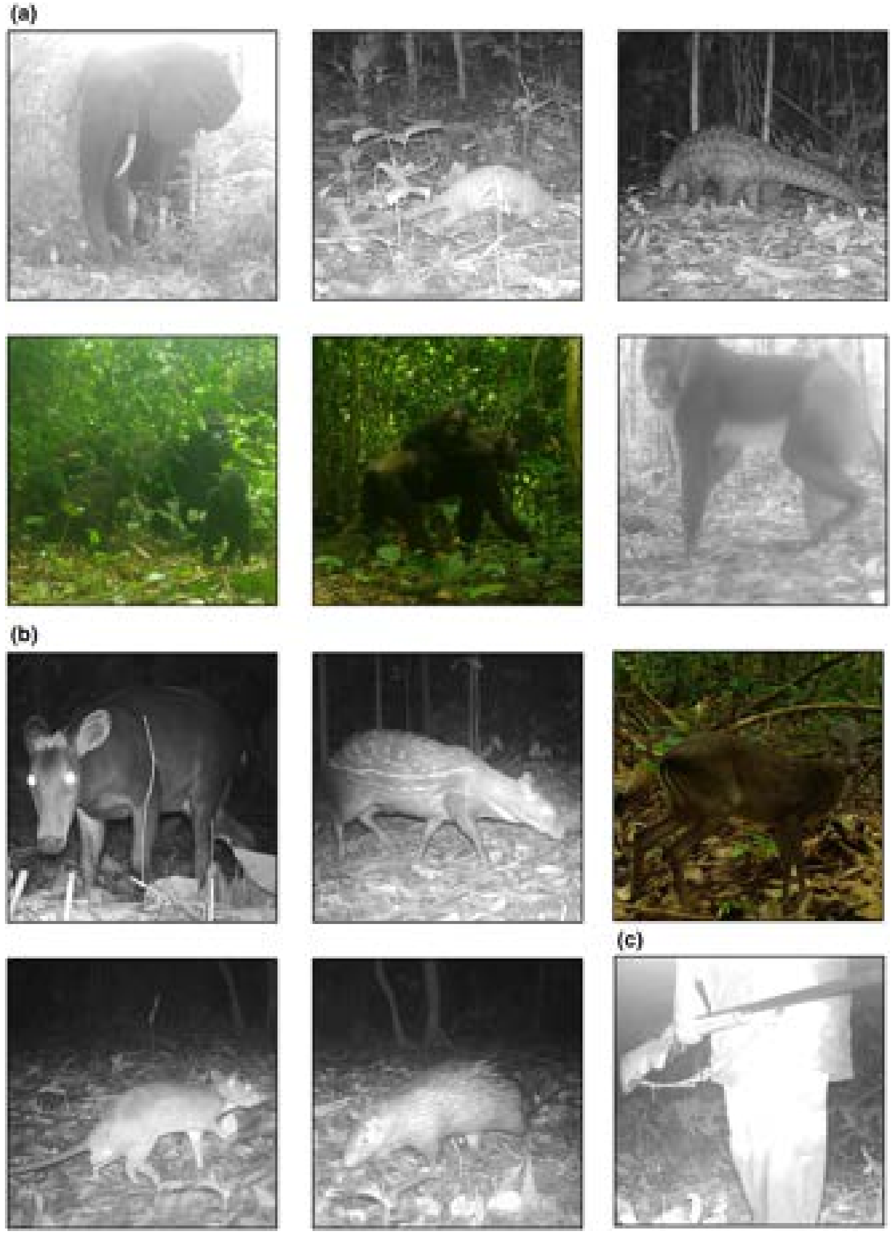

FIGURE 2 Camera trap images of wildlife and human activity detected during our 2017 and 2019 mammal survey in Rio Campo Nature Reserve, Equatorial Guinea. Images included are representative of (a) threatened taxa (left to right: African forest elephant, tree pangolin, giant pangolin, western mountain 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

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.

3 | RESULTS

3.1 | 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 2991 trap nights total. Between our 2017 and 2019 field seasons, we detected at least 32 mammal species in RNRC (Table 1). This includes 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). We also 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).

3.2 | 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, that is 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

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

Order	Family	Species name	English name	Spanish name	*n*	Detection Rate
Carnivora	Herpestidae	*Atilax paludinosus*	Marsh mongoose	*Mangosta de los pantanos*	3	0.0010
		Crossarchus platycephalus	Cusimanse	*Cusimanse común*	8	0.0027
		Galerella sanguinea	Slender mongoose	*Mangosta esbelta*	1	0.0003
		Herpestidae spp.	Unidentified Mongoose	*Mangosta*	7	0.0024
	Viverridae	*Civettictis civetta*	African civet	*Civeta africana*	10	0.0034
		Genetta servalina	Servaline genet	*Jineta servalina*	23	0.0078
	Nandiniidae	*Nandinia binotata*	African palm civet	*Civeta africana de las palmeras*	5	0.0017
Cetartiodactyla	Bovidae	*Cephalophus dorsalis*	Bay duiker	*Duiker bayo*	7	0.0024
		Cephalophus silvicultor	Yellow-backed duiker	*Cefalofo silvicultor*	8	0.0027
		Hyemoschus aquaticus	Water chevrotain	*Cervatillo de agua*	3	0.0010
		Philantomba monticola	Blue duiker	*Cefalofo azul*	338	0.1154
		Tragelaphus scriptus	Bushbuck	*Bushbuck*	7	0.0023
		Tragelaphus spekii	Sitatunga	*Sitatunga*	2	0.0007
		Tragelaphus spp.	Unidentified Tragelaphus	*Antílope grande*	1	0.0003
		Philantomba/Cephalophus spp.	Unidentified small duiker	*Antílope pequeño*	21	0.0072
	Suidae	*Potamochoerus porcus*	Red river hog	*Potamoquero rojo*	11	0.0038
Chiroptera	–		Unidentified bat	*Murciélago*	2	0.0007
Hyracoidea	Procaviidae	*Dendrohyrax dorsalis*	Western tree hyrax	*Damán arborícola occidental*	1	0.0003
Primates	Cercopithecidae	*Cercopithecus cephus*	Moustached guenon	*Cercopiteco de hocico azul*	3	0.0010
		Cercopithecus nictitans	Putty-nosed guenon	*Cercopiteco de nariz blanca*	2	0.0007
		Mandrillus sphinx	Mandrill	*Mandril*	19	0.0065
	Hominidae	*Gorilla gorilla*	Western gorilla	*Gorila occidental*	5	0.0017
		Pan troglodytes	Common chimpanzee	*Chimpancé*	5	0.0017
	Lorisidae	*Arctocebus aureus*	Golden angwantibo	*Poto dorado*	7	0.0024
	–		Unidentified monkey	*Mono no identificado*	3	0.0010
Pholidota	Manidae	*Phataginus tricuspis*	Tree pangolin	*Pangolín arborícola*	34	0.0116
		Smutsia gigantea	Giant pangolin	*Pangolín gigante*	2	0.0007
Proboscidea	Elephantidae	*Loxodonta cyclotis*	Forest elephant	*Elefante del bosque*	20	0.0068

TABLE 1 (Continued)

Order	Family	Species name	English name	Spanish name	*n*	Detection Rate
Rodentia	Hystricidae	*Atherurus africanus*	African brush-tailed porcupine	*Puercoespín*	484	0.1652
	Muridae	Murinae spp.	Unidentified mouse	*Ratón*	171	0.0584
	Nesomyidae	*Cricetomys emini*	Emin's pouched rat	*Rata gigante de Gambia*	921	0.3143
	Sciuridae	*Funisciurus lemniscatus*	Ribboned rope squirrel	-	90	0.0307
		Funisciurus anerythrus	Thomas's rope squirrel	-	1	0.0003
		Funisciurus isabella	Lady Burton's rope squirrel	-	8	0.0027
		Funisciurus pyrrhopus	Fire-footed rope squirrel	-	18	0.0061
		Heliosciurus rufobrachium	Red-legged sun squirrel	-	14	0.0048
		Paraxerus poensis	Green bush squirrel	-	1	0.0003
		Funisciurus Spp.	Unidentified rope squirrel	*Ardilla listada africana*	29	0.0099
		Sciuridae spp.	Unidentified squirrel	*Ardilla*	13	0.0044
			Unidentified small mammal	*Mamífero pequeño*	2	0.0007
			Unidentified animal	*Animal no identificado*	214	0.0730

Note: Detections were considered independent if they were at least 30 min apart.

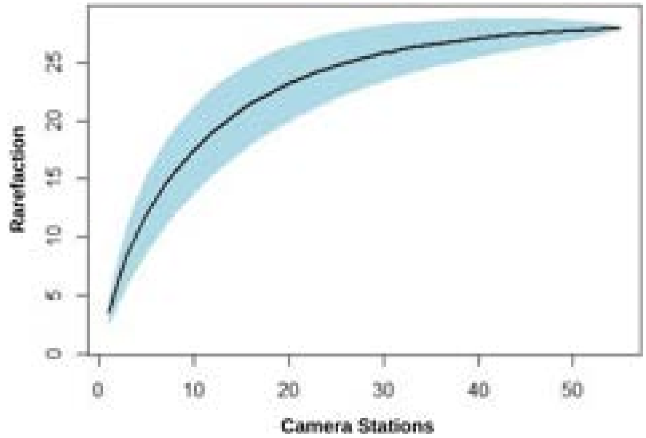

FIGURE 3 Species accumulation curve (black, confidence intervals light blue) of terrestrial mammal species detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments using rarefaction.

(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 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, for example chimpanzee, gorilla and giant pangolin, while more common species appear to be more widely distributed across RNRC.

3.3 | 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

TABLE 2 Top model-averaged results of two-step models of mammal group presence and abundance in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments in 2017 and 2019

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	N/A				
		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[a]	−0.41	0.21	−1.33, 0.51	0.12						
		Large Village[b]	−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[a]	**−0.81**	**0.38**	**−1.57, −0.05**	0.84		**Large Village[b]**	**0.53**	**0.23**	**0.04, 1.03**	0.48
		RNRC Boundary[c]	−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[b]	−0.28	0.15	−0.59, 0.03	0.19
Small Duikers	26	**Intercept**	**−3.16**	**0.35**	**−3.86, −2.47**		18	N/A				
		Populated Place[c]	0.38	0.34	−0.30, 1.06	0.26						
		Large Village[b]	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[b]	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[b]	**−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[b]	−0.35	0.15	−0.68, −0.01	0
		Road[b]	**−0.91**	**0.44**	**−1.80, −0.03**	0.24		Large Village[b]	0.51	0.31	−0.17, 1.19	0.03
		Populated Place[c]	−0.20	0.38	−0.95, 0.56	0.24		RNRC Boundary[c]	0.42	0.26	−0.14, 0.98	0.03
								FLII[a]	0.21	0.35	−0.55, 0.98	0.01
								Paved Road[b]	−0.21	0.35	−0.99, 0.56	0.01
								Populated Place[c]	0.03	0.19	−0.39, 0.45	0.01
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[b]	0.41	0.83	−0.55, 3.79	0.26
		River	−0.31	0.48	−1.26, 0.65	0.29		FLII[a]	−0.20	0.43	−1.99, 0.11	0.22
								Road[b]	−0.08	0.19	−1.06, 0.16	0.17
								River	0.09	0.30	−0.6, 2.17	0.11

TABLE 2 (Continued)

Taxonomic Group	Step 1 models	Explanatory variables	β	SE	CL	RI	Step 2 models	Explanatory variables	β	SE	CL	RI
Monkeys	26	**Intercept**	**−4.35**	**0.36**	**−5.08, −3.62**		12	**Intercept**	**−3.96**	**0.18**	**−4.33, −3.63**	
		Road[b]	0.62	0.38	−0.15, 1.38	0.66		**RNRC Boundary[c]**	**0.41**	**0.15**	**0.12, 0.70**	1
		Populated Place[c]	0.24	0.36	−0.49, 0.97	0.19						
Pangolins	26	**Intercept**	**−4.51**	**0.38**	**−5.26, −3.75**		12	**Intercept**	**−3.6**	**0.16**	**−3.94, −3.29**	
		FLII[a]	0.66	0.44	−0.22, 1.54	0.43		**RNRC Boundary[c]**	**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	N/A				
		Road[b]	0.55	0.36	−0.17, 1.27	0.18						
		Populated Place[c]	**0.80**	**0.36**	**0.08, 1.52**	0.59						
		FLII[a]	**0.88**	**0.40**	**0.09, 1.67**	0.4						
		RNRC Boundary[c]	0.49	0.36	−0.24, 1.22	0.15						
		River	−0.37	0.37	−1.12, 0.38	0.2						
		Large Village[b]	−0.40	0.33	−1.07, 0.27	0.11						
Pouched rats	26	**Intercept**	**−0.97**	**0.41**	**−1.8, −0.14**		18	N/A				
		RNRC Boundary[c]	−0.84	0.43	−1.71, 0.03	0.84						
		Paved Road[b]	−0.33	0.40	−1.13, 0.47	0.21						
		Large Village[b]	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[b]**	**0.35**	**0.08**	**0.18, 0.52**	0.64
		Large Village[b]	**−1.24**	**0.39**	**−2.03, −0.45**	1		**Populated Place[c]**	**0.31**	**0.07**	**0.16, 0.46**	0.64
		Human	−0.81	0.44	−1.7, 0.08	0.59		**FLII[a]**	**0.50**	**0.10**	**0.29, 0.71**	0.36
		Road[b]	−0.76	0.43	−1.62, 0.09	0.59		**River**	**−0.29**	**0.10**	**−0.49, −0.09**	0.36
		Populated Place[c]	**1.07**	**0.42**	**0.23, 1.90**	1						

Note: Covariates with confidence limits that do not overlap zero are bolded.

Abbreviations: River, Distance to nearest river (m); 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; FLII, Forest Landscape Integrity Index (factor, range 1–10).

[a]Cubed.

[b]Log-transformed.

[c]Square-root transformed.

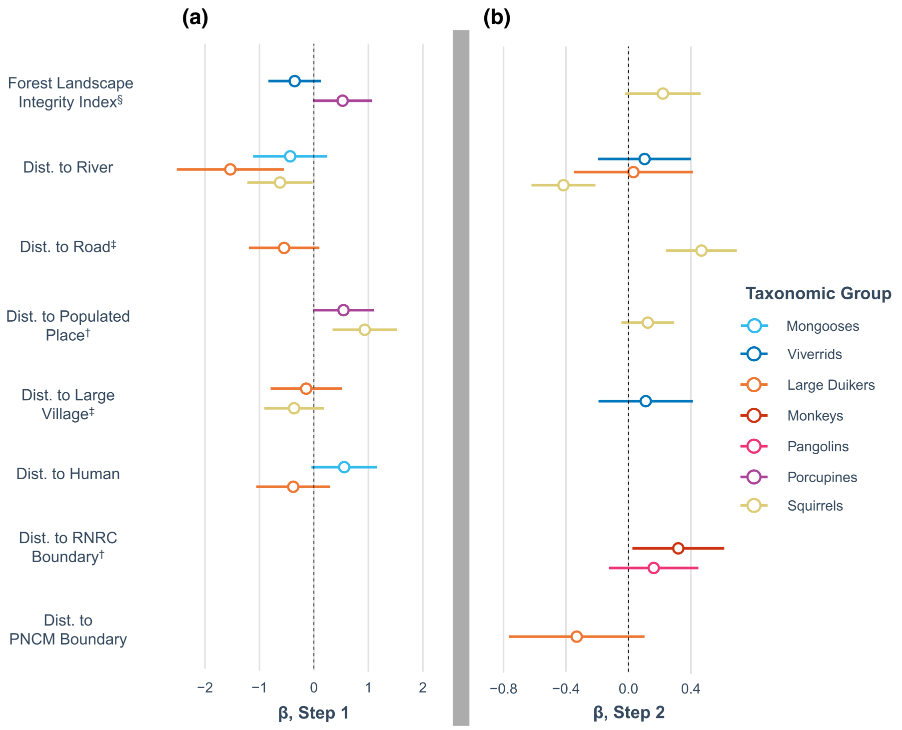

FIGURE 4 Forest plots showing beta-estimates for presence (a) and relative abundance (b) of terrestrial mammal groups detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments. †Square-root transformed, ‡log-transformed, §cubed

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.

4 | 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 optimise management and conservation efforts. During the deployment of camera traps, INDEFOR-AP staff encountered and shutdown illegal logging and commercial hunting camps within RNRC, 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

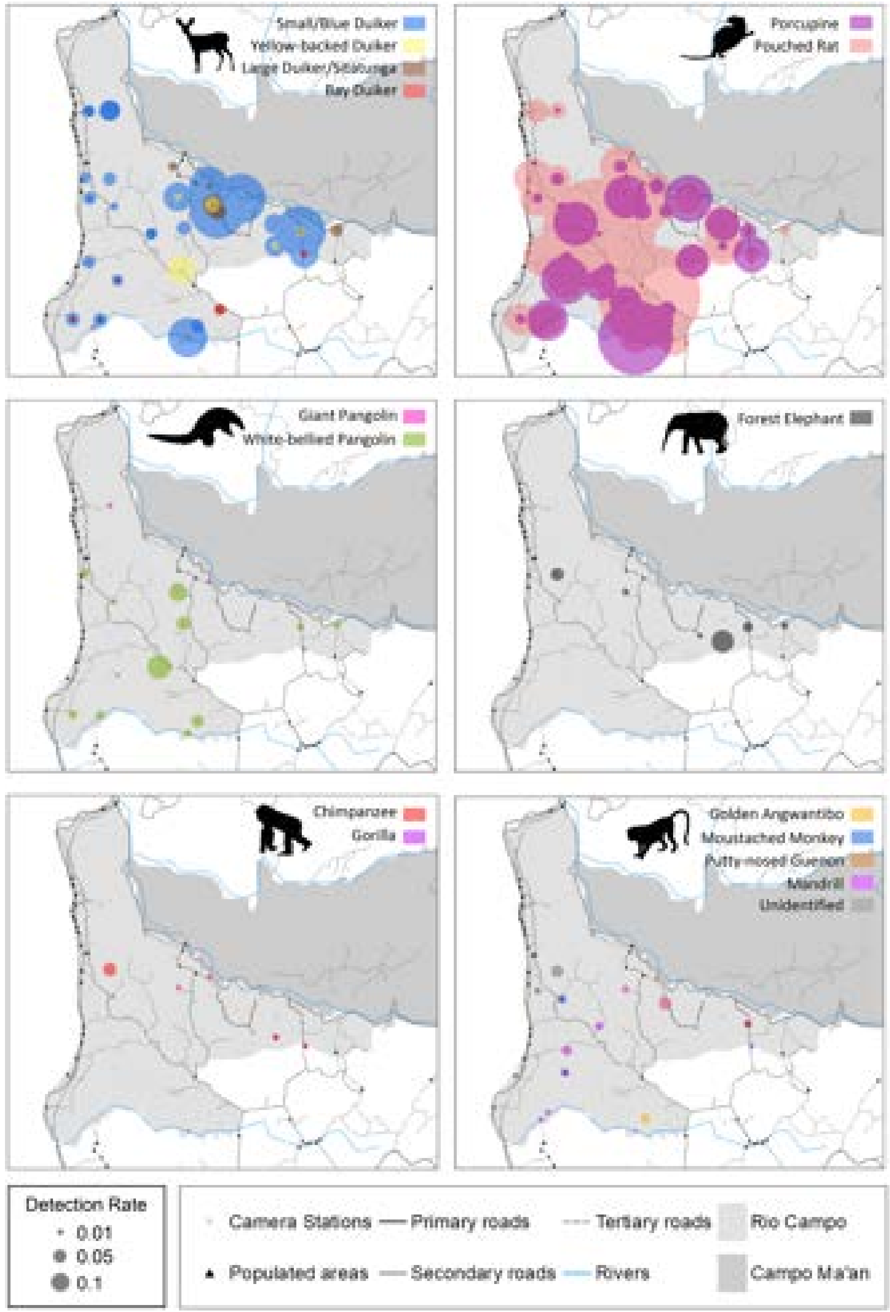

FIGURE 5 Distribution and detection rates of species and groups of particular conservation or hunting concern detected in 2017 and 2019 in Rio Campo Nature Reserve, Equatorial Guinea based on remote camera deployments. Detection rates for taxa are symbolised with proportionally sized circles.

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 was 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. conducted in 2011, despite local reports that the species was present at a few sites throughout the country (Maisels et al., 2019; Murai et al., 2013).

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 in Cameroon (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 programme in the 1990s (Larison et al., 1999), and there have been reports of at least two elephant killings in RNRC between 2017 and 2019. 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., 2013). 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., 2013).

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., 2013). 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 are depleted in these areas due to extensive hunting (Juste et al., 1995; Yasuoka et al., 2015).

5 | 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 km^2 of tree cover from 2000 to 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, for example 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, for example distance to roads, villages and cities, as well as environmental factors, for example forest structure. This could be particularly useful in recently developed areas, such as the new capital Ciudad de la Paz (previously the village of 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

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

DATA AVAILABILITY STATEMENT

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

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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