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SPECIAL SECTION : CAMERA TRAPPING IN AFRICA

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A camera trap assessment of the forest mammal community within the transitional savannah-forest mosaic of the Batéké Plateau National Park, Gabon

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Abstract

Monitoring populations in areas of ecological transition is crucial to understanding species distributions, but also a critical conservation tool. We used camera trapping to investigate the forest mammal community in the Batéké Plateau National Park (BPNP) in Gabon, a transitional landscape that experiences severe poaching. We compiled a species inventory, investigated group sizes and activity patterns of observed species, and conducted an initial test to evaluate whether ecological gradients within this landscape influence species occurrence. Based on 6612 images and videos recorded at 40 locations during 5,902 camera days, we identified 31 mammal species, including eight classified as threatened according to the IUCN. We detected lion (Panthera leo, Linnaeus), which was thought to be extinct in Gabon, and mandrill (Mandrillus sphinx, Linnaeus), for which BPNP was thought to be outside of their natural range. Our findings suggest that BPNP supports a low species richness compared to more forested protected areas. We found no changes in species composition of the forest mammal community with increasing distance from the continuous Gabonese rainforest, but a potential decrease in abundance for some species. Continued survey efforts need to be combined with detailed ecological data collection and effective law enforcement in the region.

Résumé

Le suivi des populations vivant dans des zones de transition écologique est crucial pour comprendre la distribution des espèces ; c'est aussi un outil de conservation très utile. Nous avons utilisé des pièges photographiques pour étudier la communauté des mammifères forestiers du Parc National du Plateau des Batéké (PNPB) au Gabon, un paysage de transition qui subit un important braconnage. Nous avons dressé un inventaire des espèces, étudié la taille des groupes et les schémas d'activités des espèces observées et mené une première expérience pour évaluer si les gradients écologiques au sein de ce paysage influencent la présence des espèces. Nous basant sur 6,612 images et vidéos enregistrées sur 40 sites pendant 5 902 jours-caméra, nous avons identifié 31 espèces de mammifères dont huit sont classées comme Menacées par l'UICN. Nous avons détecté le lion (*Panthera leo*, Linnaeus), que l'on pensait éteint au Gabon, et le mandrill (*Mandrillus sphinx*, Linnaeus), alors que le PNPB était considéré comme en dehors de son aire de répartition. Nos découvertes suggèrent que le PNPB héberge une faible richesse en espèces, comparé à des zones protégées plus boisées. Nous n'avons pas trouvé de changement dans la composition des espèces de la communauté des mammifères forestiers quand augmentait la distance par rapport à la forêt pluviale continue du Gabon, mais une diminution possible de l'abondance de certaines espèces. La poursuite des efforts de surveillance doit être liée à la collecte de données écologiques détaillées et à une application efficace des lois dans la région.

KEYWORDS
lion, mandrill, monitoring, naïve occupancy, relative abundance, species richness

1 | INTRODUCTION

Terrestrial mammal communities are fundamental to the functioning of ecosystems as they play a major role in nutrient cycling (e.g. Doughty et al., 2016; Metcalfe et al., 2014), plant recruitment (Paige & Whitham, 1987; Snyder, Snyder, Finke, & Straub, 2006) and seed dispersal (Howe & Smallwood, 1982; Jordano, García, Godoy, & García-Castaño, 2007). Consequently, the decimation of mammal species through anthropogenic influences, such as poaching, can have strong consequences on ecosystems (e.g. Abernethy, Coad, Taylor, Lee, & Maisels, 2013; Ceballos, Ehrlich, & Dirzo, 2017; Dirzo et al., 2014; Peres & Palacios, 2007; Wright et al., 2000). As such, the monitoring of mammal species occurrence within and across protected areas is crucial to the implementation and evaluation of conservation management strategies (Nichols & Williams, 2006).

Monitoring of populations in transitional landscapes, where they may live at the edge of their ranges and at the extreme of their ecological niches, is not only crucial to understanding species distribution ranges, but is also a critical conservation tool. Populations in biogeographic transition zones may be increasingly maladapted to the environment (Sexton, McIntyre, Angert, & Rice, 2009), less resilient to stochastic threats than core populations (Curnutt, Pimm, & Maurer, 1996; Goodman, 1987) and susceptible to disturbances, such as human encroachment and the consequences of climate change (e.g. Parmesan, 2006), as they often exhibit low densities (Brown, 1984; Lawton, 1993) and reduced genetic variability due to a restricted gene flow (e.g. Eckert, Samis, & Lougheed, 2008). On the other hand, areas of ecological transition can constitute biodiversity hotspots (Araújo, 2002; Gaston, Rodrigues, Van Rensburg, Koleff, & Chown, 2001) and are important regions of speciation due to divergent selection, which may enrich the biodiversity of tropical rainforests (Smith, Wayne, Girman, & Bruford, 1997, 1998).

Over the past years, camera trapping has developed into a well-established method to monitor mammal species. Compared to traditional methods, such as track surveys, line transects, the installation of traps or interviews with the local population, camera trapping is a cost-effective, easily employable non-invasive tool that is suitable to detect elusive as well as nocturnal species (e.g. Forrester et al., 2016; Hossain et al., 2016; O'Connell, Nichols, & Karanth, 2010; Silveira, Jácomo, & Diniz-Filho, 2003). Camera trapping allows for a diverse set of applications. Beyond the rapid assessment of species inventories (Azlan & Lading, 2006; Bowler, Toblerr, Endress, Gilmore, & Anderson, 2016; Mugerwa, Sheil, Ssekiranda, Heist, & Ezuma, 2013; Srbek-Araujo & Chiarello, 2005; Tobler, Carrillo-Percastegui, Leite Pitman, Mares, & Powell, 2008) and the long-term monitoring of changes in species occurrence and distribution (Ahumada, Hurtado, & Lizcano, 2013; King, McDonald, Martin, Tempero, & Holmes, 2007), camera trap studies can be used to investigate population size and density (Howe, Buckland, Després-Einspenner, & Kühl, 2017; Karanth & Nichols, 1998; Mace, Minta, Manley, & Aune, 1994; Noss et al., 2012; Silver et al., 2004; Sweitzer, Van Vuren, Gardner, Boyce, & Waithman, 2000; Trolle & Kéry, 2003), demographic structure (Gardner, Reppucci, Lucherini, & Royle, 2010; Karanth & Nichols, 2011), habitat use (Head, Robbins, Mundry, Makaga, & Boesch, 2012; Kelly & Holub, 2008; Rich, Miller, Robinson, McNutt, & Kelly, 2016), as well as reproductive and activity patterns (Azlan & Sharma, 2006; Gómez, Wallace, Ayala, & Tejada, 2005; Oliveira-Santos, Tortato, & Graipel, 2008; van Schaik & Griffiths, 1996). In addition, camera trap studies are increasingly employed on a large spatial scale to generate directly comparable population-level information based on the use of standardized methods across sites (Ahumada et al., 2011; Kühl et al., 2016).

The Batéké Plateau National Park (BPNP) is located in southeast Gabon, within the northern part of the Western-Congolian forest-savannah mosaic as categorized by Olson et al. (2001). Situated at the transition between the south-eastern edge of the Gabonese rainforest and the north-western limit of the savannah-dominated Batéké Plateau, BPNP comprises a transitional landscape in which forest galleries along the Mpassa River and its tributaries reach out into the savannah. In the beginning of the twentieth century, the megafauna of the Batéké Plateau was characterized both by rainforest species, such as forest elephant (*Loxodonta cyclotis*, Matschie), forest buffalo (*Syncerus caffer*, Sparrman, subsp. *nanus*), forest duikers (*Cephalophus* spp., Grey), and red river hog (*Potamochoerus porcus*, Linnaeus), as well as by a range of savannah species, including lion (*Panthera* leo, Linnaeus), spotted hyena (*Crocuta crocuta*, Erxleben), southern reedbuck (*Redunca arundinum*, Boddaert), and waterbuck (*Kobus ellipsiprymnus*, Ogilby) (King & Chamberlan, 2013; Malbrant &

Maclatchy, 1949). As a result of the bush-meat trade, the illegal hunting of elephants for ivory (e.g. Aczel, 2005) and organized eradication of large carnivores (Henschel, 2009), several species of the megafauna of the BPNP are locally extinct (King & Chamberlan, 2013). Remaining species appear restricted to the gallery forests and some may be close to the threshold of extinction. Recent survey results suggest an upsurge in poaching particularly in the south-eastern part of the national park (Fay, 2016).

We used camera traps to investigate the community of forest mammal species in the BPNP. Our goals were to (i) compile a species inventory to re-assess the presence of species, (ii) investigate group sizes and activity patterns of observed animal species, and (iii) provide an initial assessment whether ecological gradients within this transitional landscape influence species occurrence. We predicted a decrease in species richness, abundance, and occupancy with increasing distance from the Gabonese rainforest.

2 | METHODS

Since 1998, The Aspinall Foundation (TAF) and the Gabonese authorities have worked together to facilitate the re-establishment of mammal species in the BPNP, particularly through the re-introduction of the western lowland gorilla (*Gorilla gorilla*, Savage, subsp. *gorilla*) (King, Chamberlan, & Courage, 2012; Pearson, Aczel, Mahé, Courage, & King, 2007; Pearson & King, 2008). The data presented here mark the starting point of a long-term camera trap-based monitoring programme conducted by TAF. Data were collected in collaboration with the Pan African Program of the Max Planck Institute for Evolutionary Anthropology, which conducted a survey investigating various aspects of the behaviour of chimpanzees (*Pan troglodytes*, Blumenbach, subspec. *troglodytes*) in the BPNP from 2014 to 2016 (e.g. Kühl et al., 2016).

2.1 | Survey design

We conducted a camera trap survey in the northern sector of BPNP for eleven months from June 2014 to May 2015 (Figure 1). The study area was situated largely outside the heavily poached region in the southeast of the park (see Fay, 2016), which allowed us to investigate species presence largely in the absence of ongoing poaching. We installed 40 camera traps across a grid covering approximately 174 km^2 with a cell size of 1 km^2. We chose one camera trap location within every second grid cell containing forest habitat. Camera trap locations within a given cell were chosen along animal trails and close to fruit trees, to maximize capture probability. This resulted in an average minimum distance of 1.3 km between cameras (min = 0.5 km, max = 2.8 km). We mounted camera traps on trees

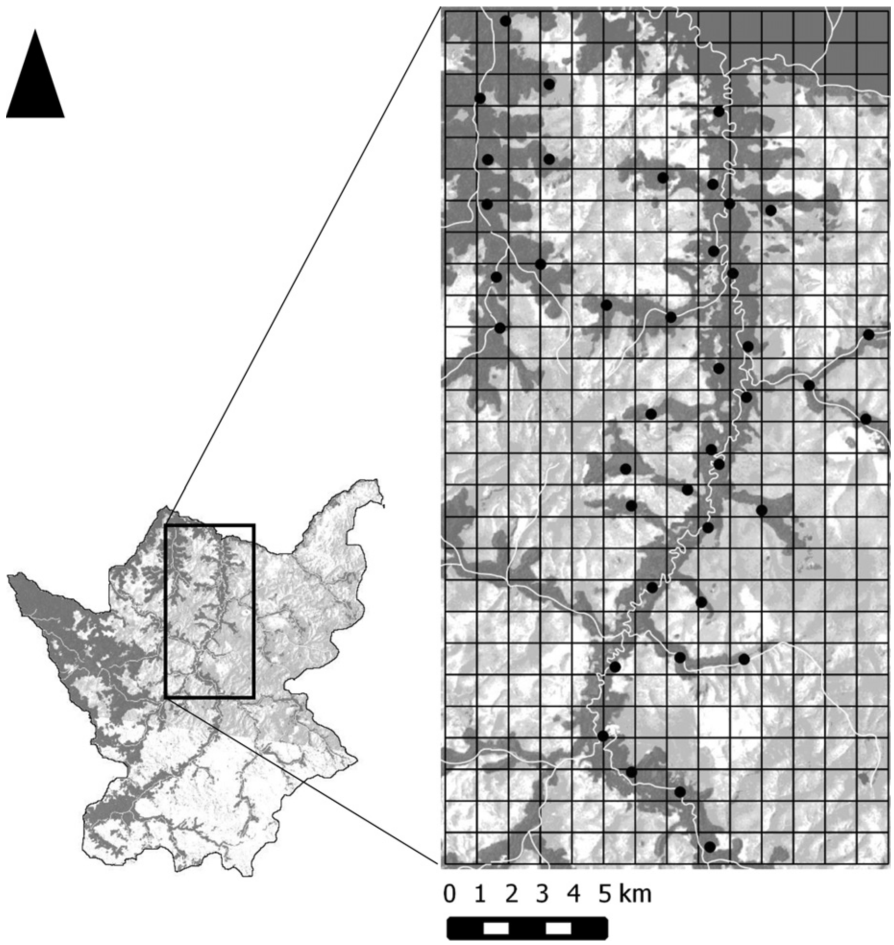

FIGURE 1 Location of the study area within Batéké Plateau National Park and the 40 camera traps within the 1 km^2 sampling grid. Black dots indicate camera trap locations. White lines indicate the Mpassa River and its tributaries. Areas in dark grey along the rivers show gallery forest, white and bright grey areas savannah. GIS data on land cover and watercourses were obtained from the US-GS and DIVA-GIS geospatial database

at a mean height of 0.6 m above the ground (median = 0.6 m, range = 0.4–1.1 m). The mean camera detection area was 9.6 m^2 (median = 8.6 m^2, range = 2–27.5 m^2). We used motion-triggered camera traps (Bushnell Trophy Cam 119405, 119436; Bushnell Trophy Cam HD 119547, 119437, 119476, 119676, 119678, 119776; Bushnell Trophy Cam Security 119466; Reconyx HC 500 hyperfire semi-covert IR), which were active for 24 hr per day with motion sensors set to trigger immediately when movement was detected. Depending on the camera type, we programmed them to film for 60 s or to take ten photographs with a three-second interval between photos, and to continue recording in case the animal stayed in front of the camera. We excluded days when a camera trap was not filming due to technical problems from analysis. In total, the cameras at the 40 locations were functional for 5,902 camera days.

2.2 | Data analysis

We considered a single camera event to be all recordings of one or more animals of the same species taken within less than 5 min of each other at the same location. We used this threshold to avoid artificially inflated capture frequencies as animals often remained in front of the camera, resulting in multiple triggers for the same individual (e.g. Mugerwa et al., 2013; Tobler et al., 2008). For each camera event, we noted the date and time of day, species and the number of individuals. Species identification was based on Kingdon (2015) and was conducted by Daniela Hedwig and Ivonne Kienast. In case of doubt, we consulted experts for the respective taxa (Philipp Henschel of Panthera for small carnivores and David Mallon of the IUCN Antelope Specialist Group for forest duikers). In case we were unable to identify an animal to the species level, we present the next possible taxonomic level or the generic trivial name (i.e. “mongoose” or “cat”). In case no identification was possible, we counted the event as “unidentified.”

Three taxonomic groups posed particular challenges. First, crested genet (*Genetta cristata*, Hayman) and servaline genet (*Genetta servalina*, Pucheran) are morphologically similar and hybridization has been suggested (Gaubert, Papeş, & Peterson, 2006). It is possible that observations identified here as servaline genet include crested genets, or hybrids between these, similar to Bahaa-el-din et al. (2013). Second, as marsh mongoose (*Atilax paludinosus*, Cuvier) and long-nosed mongoose (*Herpestes naso*, de Winton) are difficult to distinguish in the field (Ray, 1997), events presented here as “mongoose” are either only one or both of the two species. Third, white-legged duiker (*Cephalophus ogilbyi*, Waterhouse, subsp. *crusalbum*) and Peters’ duiker (*Cephalophus callipygus*, Peters) are phenotypically similar and may hybridize (Kingdon, 2015). Individuals which were clearly either white-legged or Peters’ duiker but a discrimination was not possible were registered as “red duiker.” Other species of the genus *Cephalophus* that we were unable to identify were labelled as “unidentified forest duiker.”

For each species, we calculated the relative abundance index (RAI) as the number of captures divided by the sampling effort (i.e. number of camera days) multiplied by 100, indicating the number of captures per 100 days of camera trapping (O’Brien, 2011). In addition, we computed the naïve occupancy as the number of camera trap locations at which we detected each species divided by the total number of camera trap locations (e.g. Jenks et al., 2011; Rovero, Martin, Rosa, Ahumada, & Spitale, 2014). Bearing in mind that both the RAI and naïve occupancy are influenced by sampling design, such as the detailed set-up and location of camera traps as well as a species’ behaviour (e.g. Sollmann, Mohamed, Samejima, & Wilting, 2013), they are nevertheless useful measures to monitor the occurrence of a given species.

To investigate changes in species occurrence with increasing distance from the continuous rainforest, we divided the study area into two sections, to the west and to the east of the Mpassa River, the former section being closer to the continuous Gabonese rainforest. We calculated species richness, RAI and naïve occupancy for the entire study area, and for each of the two sections. To test whether species showed larger naïve occupancy values and RAIs to the west as compared to the east of the river we used Wilcoxon tests applied to the most frequently observed species (N = 16 species with RAI ≥ 0.5, excluding the western lowland gorilla because it was reintroduced only to the east of the river).

2.3 | Sampling coverage

We evaluated the completeness of our inventory, for each camera trap location, the entire study area, and for the two sections on either side of the river, using two complementary methods. First, we inspected species accumulation curves plotting the cumulative number of species detected against the number of camera days (Fisher, Corbet, & Williams, 1943). If the number of species reaches asymptote, it means it is unlikely that more camera events will lead to the identification of new species and that we were able to compile a full species inventory. Second, we calculated the sampling coverage $Q = 1-(N_1/I)$ where N_1 is the number of species captured once and I the total number of camera events (Fagen & Goldman, 1977). A Q close to one means that the probability of observing a novel species in an additional camera event is low and that we largely captured all species. Sampling effort was comparable between the two sections to either side of the river, each with twenty camera trap locations and approximately 2950 camera days (west: 2947 days (range: 34–230 across all locations), east: 2955 (11–249)). These methods can only assess completeness of the inventory given the applied data collection method, and it cannot be ruled out that further species will be detected with other methods.

3 | RESULTS

3.1 | Sampling coverage

We assessed our species inventory for the entire study area as close to complete, given the applied data collection method, based on a sampling coverage of one and the cumulative number of species having reached asymptote after about 200 camera days (Figure 2).

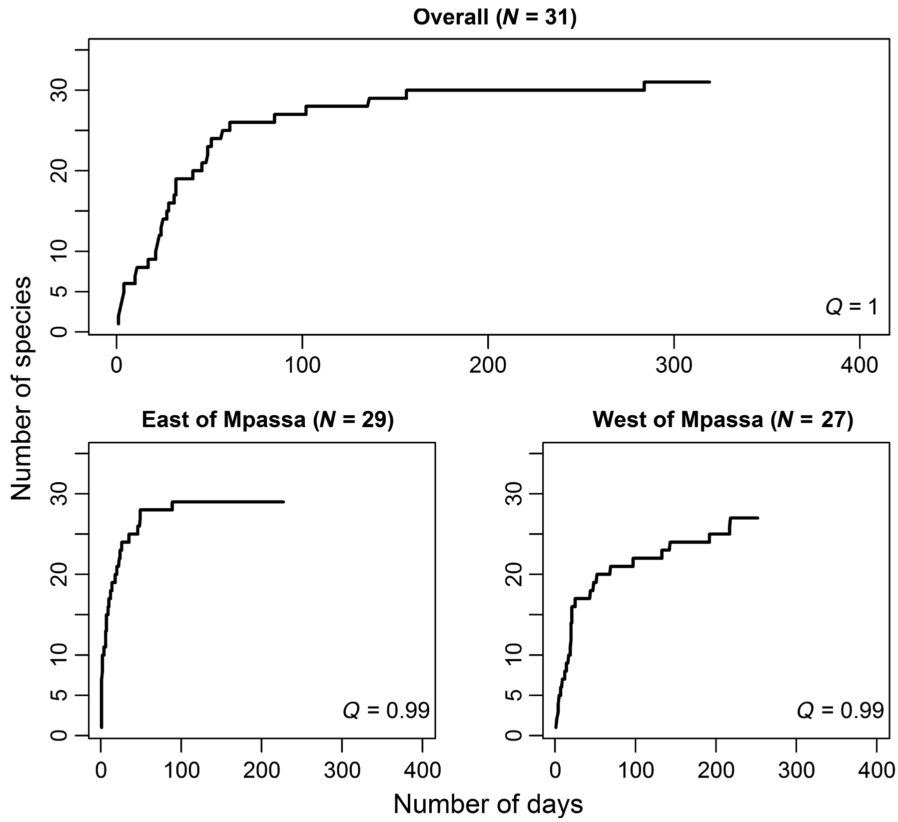

FIGURE 2 Cumulative sum of the number of identified species over the number of camera days, as well as sampling coverage Q based on $N = 6{,}612$ camera events across the entire study area as well as for the twenty camera traps in the sections to the east and west of the Mpassa River

We likely compiled a complete species inventory for the eastern section and were close to a full species inventory for the section west of the Mpassa River (Figure 2). Our analysis indicated that we did not compile full inventories at most camera trap locations. Sampling coverage Q and cumulative species numbers indicated a full inventory for only three camera trap locations based on a criterion of both a $Q > 0.98$ and the cumulative number of species having reached a clear asymptote (Data S1).

3.2 | Species richness, RAI and naïve occupancy

We identified 31 mammal species belonging to seven taxonomic groups across the entire study area. The number of detected species differed only slightly between the two sections, with 27 species detected west and 29 species east of the Mpassa River (Table 1, Figure 3). We recorded bushbuck (*Tragelaphus scriptus*, Pallas), bush duiker (*Sylvicapra grimmia*, Linnaeus), western lowland gorilla, northern talapoin monkey (*Miopithecus ogouensis*, Kingdon) and an unidentified species of bush squirrel (*Paraxerus* spp., Forsyth Major) in the eastern section only, and lion, African palm civet (*Nandinia binotata*, Grey) and an unidentified cane rat species (*Thryonomys spp*., Fitzinger) only to the west of the Mpassa.

In both sections, ungulates were the most frequently observed taxonomic group, followed by elephants and rodents. The blue duiker (*Philantomba monticola*, Thunberg) was the most frequently captured species, followed by the yellow-backed duiker (*Cephalophus silvicultor*, Afzelius) and the white-legged duiker. In contrast to our prediction, we did not find overall larger relative abundance indices in the section to the west as compared to the east of the river (Wilcoxon test; $N = 16$ species, $V = 91$, $p = .252$). However, among the sixteen most frequently observed species (RAI ≥ 0.5, excluding the western lowland gorilla), ten species showed higher RAIs in the western as compared to the eastern section. These included four of the seven recorded forest duiker species, as well as the red river hog, forest buffalo, elephant, leopard (*Panthera pardus*, Linnaeus), African civet (*Civettictis civetta*, Schreber) and the chimpanzee. White-legged duiker, water chevrotain (*Hyemoschus aquaticus*, Ogilby), brush-tailed porcupine (*Atherurus africanus*, Grey) and African golden cat (*Caracal aurata*, Temminck) had higher RAIs in the eastern section, while aardvark (*Orycteropus afer*, Pallas) and black-fronted duiker (*Cephalophus nigrifrons*, Grey) showed similar values in both sections (Table 1).

The majority of species were detected at a similar number of locations in the two sections. In contrast to our prediction, we only found a trend for a larger naïve occupancy in the section to the west as compared to the east of the river (Wilcoxon test; $N = 16$ species, $V = 53$, $p = .083$). However, we found some species at more locations on one side of the river. Blue duiker, bay duiker (*Cephalophus dorsalis*, Grey), white-bellied duiker (*Cephalophus leucogaster*, Grey), chimpanzee, as well as leopard and African civet were detected on at least three locations more in the west as compared to the east. Water chevrotain, sitatunga (*Tragelaphus spekii*, Speke) and brush-tailed porcupine were found on at least three more locations in the eastern section (Table 1).

TABLE 1 Overview of species identified from June 2014 to May 2015 in Batéké Plateau National Park based on a total of 40 camera trap locations and 5902 camera days. Indicated is the number of captures of a given species per 100 camera days (relative abundance index; RAI) and the proportion of locations at which a species was recorded (naïve occupancy) in the overall study area, as well as in the sections west and east to the Mpassa River. Note that the western lowland gorillas constitute a reintroduced population

Species		RAI			Naïve Occupancy			Animals per event
		Overall	West	East	Overall	West	East	
Cetartiodactyla		71.7	77.3	66.1	1	1	1	
Blue duiker	*Philantomba monticola*, Thunberg	24.0	25.9	22.1	0.875	0.95	0.8	1–5
Yellow-backed duiker [NT]	*Cephalophus silvicultor*, Afzelius	14.3	16.7	11.9	0.925	0.95	0.9	1–2
White-legged duiker [NT]	*Cephalophus ogilbyi*, Waterhouse subsp., *crusalbum*	8.9	8.5	9.3	0.6	0.6	0.6	1–3
Red river hog	*Potamochoerus porcus*, Linnaeus	6.4	7.2	5.7	0.9	0.9	0.9	1–23
Water chevrotain	*Hyemoschus aquaticus*, Ogilby	6.2	4.8	7.5	0.5	0.4	0.6	1–2
Bay duiker [NT]	*Cephalophus dorsalis*, Grey	2.5	2.7	2.3	0.375	0.55	0.2	1–2
Peters' duiker	*Cephalophus callipygus*, Peters	2.1	3.4	0.7	0.275	0.3	0.25	1–3
Forest buffalo	*Syncerus caffer*, Sparrman subsp., *nanus*	0.7	0.8	0.5	0.35	0.35	0.35	1–8
Black-fronted duiker	*Cephalophus nigrifrons*, Grey	0.6	0.6	0.6	0.25	0.25	0.25	1–2
White-bellied duiker [NT]	*Cephalophus leucogaster*, Grey	0.2	0.2	0.1	0.175	0.25	0.1	1
Sitatunga	*Tragelaphus spekii*, Speke	0.2	<0.01	0.3	0.15	0.05	0.25	1–2
Bushbuck	*Tragelaphus scriptus*, Pallas	<0.01	–	0.1	0.025	–	0.05	1
Bush duiker	*Sylvicapra grimmia*, Linnaeus	<0.01	–	0.1	0.025	–	0.05	1
Red duiker	*Cephalophus o. crusalbum* or *C. callipygus*	5.4	6.3	4.5	0.75	0.7	0.8	–
Unidentified spiral-horned bovine	*Tragelaphus* spp., de Blainville	0.1	0.1	0.1	0.075	0.05	0.1	–
Unidentified forest duiker	*Cephalophus* spp., Grey	0.1	–	0.1	0.025	–	0.05	–
Proboscidea								
Forest elephant [VU]	*Loxodonta cyclotis*, Matschie	6.0	6.4	5.6	0.875	0.9	0.85	1–6
Rodentia		5.6	2.5	8.8	0.725	0.65	0.8	
Brush-tailed porcupine	*Atherurus africanus*, Grey	2.8	0.8	4.7	0.425	0.35	0.5	1–2
Bush squirrel	*Paraxerus* spp., Forsyth Major	0.3	–	0.7	0.025	–	0.05	–
Giant pouched rat	*Cricetomys* spp., Waterhouse	0.3	<0.01	0.5	0.1	0.05	0.15	–
Cane rat	*Thryonomys* spp., Fitzinger	<0.01	<0.01	–	0.025	0.05	–	–
Unidentified squirrel		0.1	0.2	0.1	0.15	0.25	0.05	–
Primates		3.6	1.1	6.1	0.65	0.45	0.85	
Western lowland gorilla[a,CR]	*Gorilla gorilla*, Savage, subsp. *gorilla*	2.8	–	5.5	0.35	–	0.7	1–14
Central African chimpanzee [EN]	*Pan troglodytes*, Blumenbach, subsp. *troglodytes*	0.6	1.0	0.2	0.325	0.45	0.2	1–5
Northern talapoin	*Miopithecus ogouensis*, Kingdon	0.1	–	0.2	0.075	–	0.15	1–3
Moustached monkey	*Cercopithecus cephus*, Linnaeus	0.1	0.1	0.1	0.1	0.05	0.15	1
Mandrill [VU]	*Mandrillus sphinx*, Linnaeus	<0.01	<0.01	<0.01	0.05	0.05	0.05	1
Unidentified great ape		<0.01	–	<0.01	0.025	–	0.05	–
Carnivora		3.5	3.6	3.4	0.85	0.9	0.8	
Felidae		1.2	1.1	1.4	0.575	0.7	0.45	
Leopard [VU]	*Panthera pardus*, Linnaeus	0.7	0.7	0.6	0.475	0.6	0.35	1–3
African golden cat [VU]	*Caracal aurata*, Temminck	0.5	0.2	0.8	0.225	0.25	0.2	1–2
Lion [VU]	*Panthera leo*, Linnaeus	<0.01	0.1	–	0.05	0.1	–	1
Unidentified cat		<0.01	<0.01	–	0.025	0.05	–	–

(Continues)

TABLE 1 (Continued)

Species		RAI Overall	RAI West	RAI East	Naïve Occupancy Overall	Naïve Occupancy West	Naïve Occupancy East	Animals per event
Herpestidae		1.0	1.1	1.0	0.45	0.4	0.5	
Black-legged mongoose	*Bdeogale nigripes*, Pucheran	0.2	0.2	0.3	0.175	0.2	0.15	1
Long-nosed mongoose	*Herpestes naso*, de Winton	0.1	0.1	0.1	0.125	0.15	0.1	1
Marsh mongoose	*Atilax paludinosus*, Cuvier	<0.01	<0.01	<0.01	0.05	0.05	0.05	1
Unidentified mongoose		0.7	0.7	0.6	0.4	0.35	0.45	–
Nandiniidae								
African palm civet	*Nandinia binotata*, Grey	<0.01	0.1	–	0.025	0.05	–	1–4
Viverridea		1.2	1.4	0.9	0.45	0.55	0.35	
African civet	*Civettictis civetta*, Schreber	0.7	0.8	0.6	0.325	0.5	0.15	1–4
Servaline genet	*Genetta servalina*, Pucheran	0.3	0.4	0.2	0.175	0.15	0.2	1–2
Genet	*Genetta* spp., Cuvier	0.2	0.2	0.1	0.125	0.1	0.15	–
Tubulidentata								
Aardvark	*Orycteropus afer*, Pallas	0.8	0.8	0.8	0.6	0.6	0.6	1
Pholidota		0.4	0.3	0.5	0.35	0.35	0.35	
Giant pangolin [VU]	*Smutsia gigantea*, Illiger	0.3	0.2	0.4	0.3	0.25	0.35	1
Unidentified pangolin		0.1	0.1	0.1	0.125	0.15	0.1	–
Other								
Unidentified rat		2.1	1.4	2.8	0.6	0.55	0.65	–
Unidentified		5.2	7.2	3.2	0.9	0.95	0.85	–

NT, near threatened; VU, vulnerable; EN, endangered; CR, critically endangered according to the IUCN (2017).
[a]Reintroduced population.

3.3 | Group sizes and activity patterns

We counted the largest number of individuals per camera event for the red river hog (23 animals), followed by the western lowland gorilla (14), forest buffalo (8), forest elephant (6), chimpanzee (5) and blue duiker (5) (Table 1).

The distribution of the number of captures across the hours of the day indicated clear diurnal activity patterns for Peters' duiker, white-legged duiker and white-bellied duiker; nocturnal activity patterns for the bay duiker, yellow-backed duiker, forest buffalo, aardvark, giant pangolin (*Smutsia gigantea*, Illiger), African civet, brush-tailed porcupine and servaline genet, and diurnal to crepuscular activity patterns for the blue duiker. Forest elephant, red river hog and the two top predator species, leopard and African golden cat, appeared to be cathemeral, whereby leopard seems to show activity peaks in the early morning and evening (Figure 4).

4 | DISCUSSION

Previously, 40 species of large to medium-sized mammal species have been reported to occur in the BPNP (excluding bats, insectivores and rodents; Pearson et al., 2007), of which two were known to be extirpated (hippopotamus (*Hippopotamus amphibius*, Linnaeus), reedbuck). In this study, five of these species could not be confirmed neither with camera traps nor with opportunistic observations by TAF staff (de Brazza's monkey (*Cercopithecus neglectus*, Schlegel), crowned monkey (*Cercopithecus pogonias*, Bennett), Demidoff's galago (*Galagoides demidoff*, Fischer), spotted-necked otter (*Hydrictis maculicollis*, Lichtenstein), honey badger (*Mellivora capensis*, Schreber). However, using camera traps allowed us to detect three species that had not been previously described (mandrill (*Mandrillus sphinx*, Linnaeus), black-legged mongoose (*Bdeogale nigripes*, Pucheran) and long-nosed mongoose). These combined observations result in a total number of 36 medium to large-sized (i.e. excluding bats, insectivores and rodents) mammal species confirmed to be currently occurring in the BPNP (Data S2 provides an overview of species detected in this and previous surveys).

Taking both historical and current observations into account, the transitional landscape within BPNP appears to support a low species richness of large-sized mammals compared to more forested protected areas in West-central Africa, but similar to areas that encompass both savannah and forest habitats, such as Moukalaba-Doudou (Nakashima (2015): Moukalaba-Doudou: 39; Lopé 44; Campo-Ma'an: 46; Ipassa-Makokou: 48; Odzala-Kokoua: 51). This stands in contrast to findings that heterogeneous landscapes exhibit a larger species diversity (e.g. Tews et al., 2004). The transitional landscape in the BPNP may contain the extremes of the ecological conditions under which true forest and savannah specialists can exist. Striking is the low number of diurnal primate species, particularly the absence of

FIGURE 3 Camera trap images of species identified in the Batéké Plateau National Park. Shown are species with special conservation status according to IUCN, which have previously been thought to be extinct or not occurring in BPNP (*Mandrillus sphinx*, Linnaeus; *Panthera leo*, Linnaeus; *Bdeogale nigripes*, Pucheran; *Herpestes naso*, de Winton) [Colour figure can be viewed at wileyonlinelibrary.com]

mangabey and colobine species, which are characteristic for the African rainforest (Chapman, Gautier-Hion, Oates, & Onderdonk, 1999). Lower productivity of the forest habitat in this transitional landscape may be a constraining factor for these species (e.g. Korstjens, Lehmann, & Dunbar, 2010). While comparing the species inventories of the sections west and east of the Mpassa River suggests that potential ecological gradients may not have an impact on species richness, the gallery forests in the study area are narrow and their area may be too low to maintain populations of some true forest specialists. Future studies will also need to take into account factors, such as altitude and abiotic characteristics influencing plant productivity and food availability, to better understand such local variation in species richness.

A major contribution of our camera trap survey is the discovery of lion and mandrill in the BPNP, as both are classified as Vulnerable according to the IUCN (Bauer, Packer, Funston, Henschel, & Nowell, 2016; Oates & Butynski, 2008). The presence of lions in the Western-Congolian savannah-forest mosaic is significant for the conservation of lions in Central Africa. While East and Southern Africa provide population strongholds, population models indicate a 67% chance of lions in West and Central Africa to decline by one half in just two decades (Bauer et al., 2015). The last direct observation of lions in the Batéké area in Gabon was in 1996 (Henschel, 2006), and in Odzala-Kokoua National Park in Congo in 1994 (Dowsett, 1995; Dowsett & Dowsett-Lemaire, 1997). Lions were therefore thought to be extinct in the northern part of the Western-Congolian savannah-forest mosaic (Henschel, 2009). Big cat tracks were found in the BPNP in 2004 and attributed to lion (Bout, 2006), but our footage provides the first indisputable evidence of the presence of lions in the area in twenty years (Figure 3). The Batéké Plateau is separated from the closest known lion populations in Cameroon by a 1,000-km stretch of rainforest, and from those in Angola or in the Central African Republic by an equal distance and by the Congo River (IUCN, 2017). Given that lions generally avoid forest habitats, the individual could be a remnant of the historical lion population of the savannah regions of Gabon and the Republic

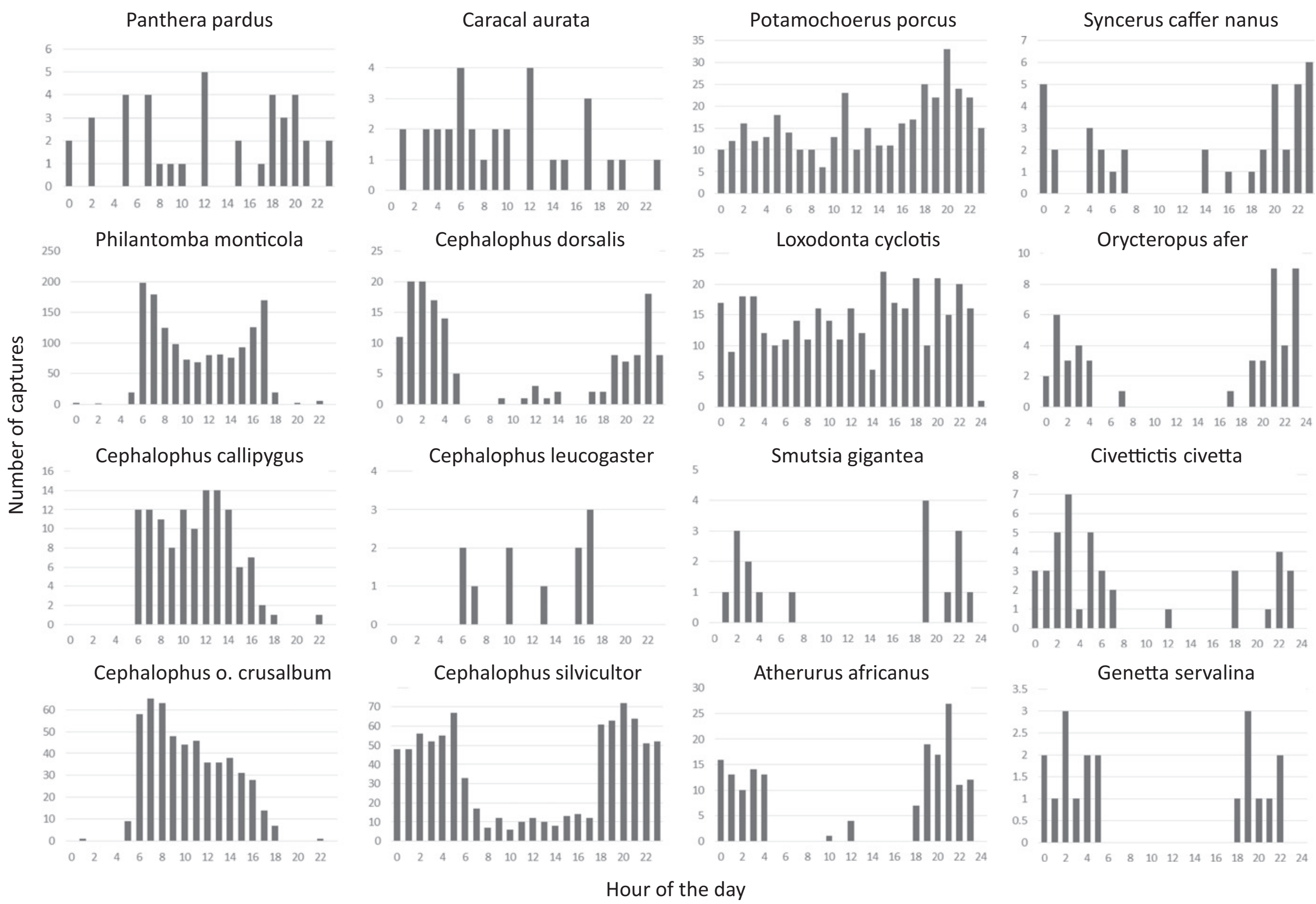

FIGURE 4 Number of camera events per time of day for species with more than 10 camera trap events

of Congo. Alternatively, it is possible that the original population was extinct, and that this individual crossed the Congo River and travelled a considerable distance through the Congolian savannah. If so, the chances for the species' natural recolonization of the Batéké area from neighbouring populations are small, and re-introduction programmes and intensive conservation efforts would be necessary to guarantee the establishment and survival of a lion population (Henschel, 2009).

According to the IUCN, the distribution of mandrills in Gabon is restricted to the east by the Ivindo and *Ogoue* Rivers (Oates & Butynski, 2008; Telfer et al., 2003). Interviews and recce surveys conducted in the surroundings of the BPNP suggest that mandrills have been present in the Mopia area north of the Mpassa River, but were assumed extirpated due to poaching (N. Bout, pers. comm.). Despite mandrills living in large and acoustically conspicuous groups, their presence has never previously been recorded in the BPNP. It is possible that the recorded young males are transient emigrating males that traversed the *Ogoue* River or bypassed it south of the BPNP. Our observations suggest the need for a redefinition of current distribution maps by extending the southern range of mandrills to the east traversing the *Ogoue* River.

The white-legged duiker is restricted to southern Gabon and north-western Congo and has recently been upgraded on the IUCN Red List to Near Threatened, close to meeting the criteria for Vulnerable, due to an estimated population decline of 10% within only 14 years (IUCN SSC Antelope Specialist Group, 2016). In our study, the white-legged duiker was the third most frequently captured species after the blue duiker and the yellow-backed duiker. This indicates the Batéké area as a potential stronghold of this subspecies. The white-legged duiker is sympatric in parts of Gabon with the phenotypically similar Peters' duiker, which was also one of the most frequently observed species in our study. The prominent distinction between the two species is the characteristic white legs of the white-legged duiker in contrast to the Peters' duiker's dark brown-black legs. In addition, the dorsal strip expands over the rump in the Peters' duiker but not in the white-legged duiker. While we were generally able to distinguish between the two species based on the legs, this was not always the case. In many capture events, we could not determine the species even though the legs were visible. In addition, in many events in which we were able to identify the white-legged duikers based on the legs, the dorsal strip appeared to be expanding over the rump (Figure 5). These observations highlight the possibility of hybridization between white-legged duiker and the Peters' duiker in the area, as suggested by Kingdon (2015). However, descriptions of the male and female phenotype, as well as ontogenetic changes in phenotype, are not available for both species.

FIGURE 5 Examples of the phenotypic variation between white-legged duiker and Peters' duiker. Typically, the white-legged duiker has characteristic bright white legs (a) and a dorsal strip that does not extend over the rump (b). The Peters' duiker is highly similar to the white-legged duiker but has dark brown-black legs (c) and a dorsal strip that extends over the rump (d). In 36% of capture events in which we were able to identify the white-legged duiker based on the legs, the dorsal strip appeared to be expanding over the rump (e, f). In approximately 10% of capture events in which legs were clearly visible, a distinction between white-legged and Peters' duiker was not possible based on their coloration. For instance, a thin dorsal strip may indicate a white-legged duiker, but the legs are not distinctively white nor dark (g) [Colour figure can be viewed at wileyonlinelibrary.com]

Therefore, sex and age differences cannot be ruled out to be accountable for the observed phenotypical variation. Future studies on specimens, for instance collected in local markets, can help to explain this phenotypical variation in combination with genetic analysis.

The relative abundance measure RAI as well as naïve occupancy are imperfect indicators for species abundance and occupancy (Jennelle, Runge, & MacKenzie, 2002; Sollmann et al., 2013; Tobler et al., 2008) as they do not take into account variation in detection probabilities associated with sampling design and a species' behaviour. Despite their limitations, our initial results may point to differences in the abundance of some species to the east and west of the Mpassa River. Ten species had higher RAI values in the western as compared to the eastern section, including four of the seven forest duiker species, as well as the red river hog, forest buffalo, and elephants. Additionally, the chimpanzee (a key seed disperser) and the leopard (a key predator) were found in more locations in the west compared to the east. It is possible that with increasing distance from the continuous rainforest and potentially decreasing productivity, the forest habitat becomes less suitable for some forest species. Alternatively, decreased levels of abundance in the east may reflect incipient effects of the increased levels of illegal hunting to the southeast of our study area (Fay, 2016). Future analysis can revisit these preliminary results using occupancy models (MacKenzie, 2006) or approaches estimating density from camera trap data without the need for individual identification (Howe et al., 2017) based on detailed data on hunting pressure and ecological context.

The confirmed presence of a species reveals some insights on the structure and composition of mammal communities, allowing some evaluation of ecosystem health. The presence of an intact herbivore community is crucial to the structure of the forest plant community as their foraging activity can lead to the suppression, but also to the enhancement of plant recruitment (Paige & Whitham, 1987; Snyder et al., 2006). Large-sized frugivorous species influence the structure of the tree species community as they play an important role in the dispersal of seeds of large tree species (e.g. Campos-Arceiz & Blake, 2011; Wright et al., 2000). In the long term, changes in plant community resulting from the reduction of frugivorous and herbivorous mammal species due to poaching may have consequences on the capability of tropical forests to store carbon, with detrimental effects on global climate (Brodie & Gibbs, 2009; Osuri et al., 2016). In line with other camera trap studies (Ahumada et al., 2011; Rovero et al., 2014), herbivorous ungulates were by far the most frequently captured species in our study. In addition, large frugivores, such as the forest elephants and two species of great apes, were regularly observed on our camera traps. A high diversity and abundance of primary consumers is intrinsically necessary to sustain carnivorous predator species. Our frequent observations of leopards across the study area confirm them as the key predator in the mosaic (Henschel, 2009). Our camera trap events appear to include multiple females with cubs, suggesting sufficiently high prey densities to maintain this population. As large felids may structure the community of primary consumers by reducing their numbers, their presence may in turn facilitate forest regeneration and influence the structure of the plant community indirectly (Snyder et al., 2006; Terborgh, 1988).

Our study marks the starting point for monitoring the mammal species in BPNP. We focused on forest-dwelling species, and continuing survey efforts could be expanded to cover more habitat types. The BPNP is unique within Gabon's network of protected areas due to its high proportion of savannah habitat and connectedness to a larger savannah landscape. Hence, future monitoring should include the savannah to monitor the side-striped jackal (*Canis adustus*, Sundevall), the serval (*Leptailurus serval*, Schreber) and bush duiker. In addition, swamp areas can be surveyed for otter species, camera traps can be installed in trees to identify galago and pangolin species (Bowler et al., 2016; Olson et al., 2012), and complementary trapping surveys can be conducted to investigate the presence of small mammal species, which remain little understood for the BPNP. Expanding the survey area towards the southeast in the national park, where poaching seems particularly severe (Fay, 2016) will be important for a comprehensive assessment of hunting pressure and its impact on the mammal species community.

Our results confirm the presence of twelve mammal species with special conservation status according to the IUCN (2017), highlighting the significant conservation value of the BPNP. Within the network of protected areas in Gabon, the BPNP appears to be the only site in which the savannah-dwelling serval, jackal and bush duiker occur sympatrically, and the only park with, currently, four felid species. Ten years ago, anthropogenic influences were considered to have pushed large mammals to the threshold of extinction (e.g. Bout, 2006). Notably, our camera traps have never captured poachers, neither have we come across any signs of recent poaching in our study area during the study period. Within our specific study area and on the level of species presence, our results may reflect the recuperation of mammal species, probably due to reduced poaching because of the activities of the gorilla reintroduction programme (King, 2008), similar to other sites at which research presence had a positive effect on wildlife protection (Campbell, Kuehl, Diarrassouba, N'Goran, & Boesch, 2011; N'Goran et al., 2012). In the light of the alarming resurgence of poaching in other parts of the national park (Fay, 2016), it is now of crucial importance that the Batéké Plateau National Park is rigorously protected to guarantee the survival of this fragile mammal species community.

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