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Assessment of species richness and relative abundance of medium and large mammals within and outside of Moukalaba-Doudou National Park, Gabon

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ABSTRACT: Animal populations monitoring within and outside the park is important for identifying mammal communities but also for designing conservation plans. We assessed the diversity and the relative of medium and large mammals in and outside of Moukalaba-Doudou National Park, Gabon, using camera traps. The cumulative time for all functional camera traps was 3060.42 camera-days in the park and 2880.68 in the buffer area. Overall, of 30 medium and large mammal species and 3 rodent species were detected in the park, whereas 25 species and 3 rodent species were detected in the buffer area. Moreover, the forest dwelling species were more abundant in the park than in the buffer area ($p = 0.018$) and most of savanna dwelling species were more abundant in the buffer area ($p < 0.001$). In both areas, duiker species were more abundant than other detected species. However, the ratio red/blue duikers revealed a high hunting pressure in the buffer area. We succeed to identify at least 5 groups of western gorillas with more than 7 individuals within the park and 3 in the buffer area. Implementing a habituation process in the buffer area will require prior consultation with the local populations to ensure they refrain from hunting. Gorilla habituation could be used as a stool of protecting biodiversity but also of enhancing the benefits to the communities through community-based ecotourism.

KEYWORDS: Moukalaba-Doudou, Buffer area, camera trap survey, species richness, western gorilla habituation.

1 INTRODUCTION

Global biodiversity is experiencing a crisis described as the sixth mass extinction, caused primarily by human activities [1]. In order to reduce this decline in biodiversity, several countries have created National Parks which are the refuges for many animal communities [2]. Gabon, a Congo Basin country, established thirteen terrestrial national parks in 2002, covering approximately 11% of its territory, and 20 marine protected areas in 2017, representing approximately 26% of its exclusive economic zone [3]. Each National Park is surrounded by a buffer zone which can be used for customary purposes by local populations but also for mining and logging. However, most of the investigations on mammalian diversity and abundance are targeted within the National Parks of the country [4], but outside of the protected areas records and conservation status of the different species of mammals are poorly known. Information on local fauna composition is essential for future conservation strategies and can provide basic knowledge for more complex ecological and biogeographical studies [5].

Moukalaba-Doudou National Park (hereafter, Moukalaba) is the third largest terrestrial park in Gabon, with an area of 4,496 km^2 and is comprised of several types of vegetation including savannah. This park inhabits at least 40 species including 11 Primates, 13 Carnivora, 10 Ungulates, and seven other taxa [4], [6], [7], [8], [9]. The largest populations of great apes and blue duikers in central African forests occur in Moukalaba [10], [11]. In contrast, we have very little or no information on its faunal richness in most of the buffer zones of the park. In order to maintain the role assigned to this protected area, it is crucial not only to know the diversity of the species present within the park but also in their buffer zones for understanding the influence of human practices on these animal communities [12].

On the other hand, in Moukalaba, a long-term socioecological study of great apes through wild western gorilla habituation began in 2001, and a group of gorillas has been habituated [13], [14]. This group, despite being mainly focused on research, is the subject of selective ecotourism [15]. Based on this experience, the park authorities want to establish sustainable ecotourism through gorilla viewing. It is therefore essential, for sustainable ecotourism and according to IUCN standards, to habituate at least two groups of gorillas

within or outside the park [16]. Surveying medium and large mammals can provide information on the potential western lowland gorilla groups inhabiting those target areas.

Thus, in order to preserve and increase biodiversity conservation actions and to evaluate western lowland gorilla groups potential within Moukalaba and its buffer area, it appears crucial to complete and update data on the diversity, abundance, and distribution of mammals. The main objective of this study was to determine the species richness, relative abundance and spatial distribution of medium-sized and large mammals in the park and the buffer area.

2 MATERIALS AND METHODS

2.1 STUDY AREA

The study was conducted in the northeastern part of the Moukalaba-Doudou National Park which is located in the southwest of the Republic of Gabon, and in the village of Doussala, on the opposite bank of the Moukalaba River, which forms the boundary of the MDNP (Figure 1). The Moukalaba River's width varies from 20 to 40 m splits the park and the buffer zone. The vegetation type in the Moukalaba area is savanna mosaic forest with a mixture of primary forest, secondary forest, riverine forest, mountain forest, and savanna [17]. The buffer area of the park is also a savanna mosaic forest with savannas larger than in the park (Figure 1). The annual rainfall around the study area ranges from 1.176 to 2.043 mm and the dry season is mainly from May to September, and the rainy season is from October to April [10]. The surrounding population within the buffer area is estimated to around 30 people and uses this area for fishing, shifting cultivation and hunting [15], [18].

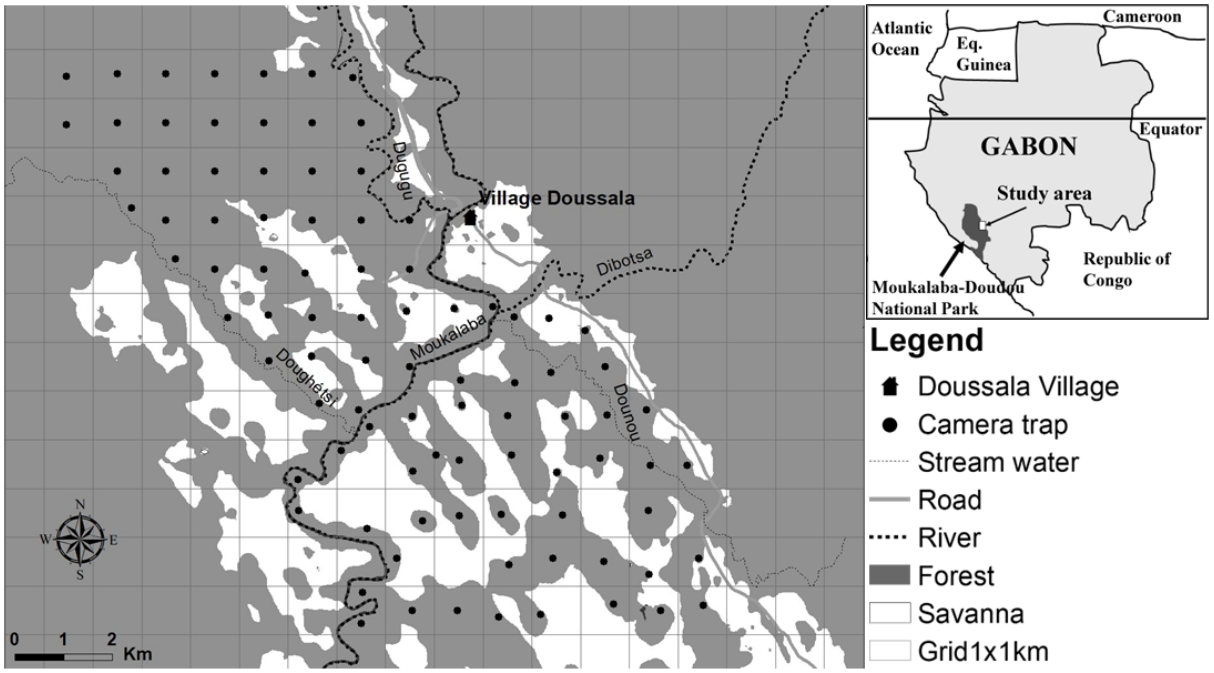

Fig. 1. Study area and camera trap locations within and outside Moukalaba-Doudou National Park

2.2 MEDIUM AND LARGE MAMMAL SURVEY

We conducted a camera trap survey within and outside of Moukalaba during the dry season from mid-June to mid-September in 2022 and 2023 respectively. We used motion-triggered camera traps DIGITNOW BR693 Surveillance Camera with 8MP CMOS Sensor. Before deploying cameras, each study area was previously stratified in 1km x 1km grid covering around 60 Km^2 (Figure 1). The camera traps were therefore placed 100 m around the center of each grid. However, to avoid sunlight, we placed the cameras at the forest edge or in small fragments of forest within the savannah. The precise positioning of the cameras was determined by the presence of trees suitable for placing cameras and the presence of animal tracks.

We placed 46 camera traps within the park and the buffer area. Each camera was mounted around 50 centimeters above the ground on a tree without baits. The cameras were angled parallel to the animal trail facing north or south. We programmed each camera to "video mode," which enables the capture of a short 30-second video clip with the capture interval being five seconds. Because gorillas

can sometimes stay for several hours in front of the same camera, the data were filtered to exclude videos of the same species at the same station within a period of 1 hour to ensure that the events were independent [12], [19].

2.3 DATA ANALYSIS

We identified the animal species in the videos following the nomenclature of Kingdon et al. (2013) [20] and Nakashima (2015) [6]. We were unable to discriminate *Cephalophus ogilbyi* and *C. callipugus*; and *Genetta cristata* and *G.servalina*. In the present study, we treated the two red duikers and the two genets as single species. All statistical analyses were performed using R version 1.3.1093 (R Core Team 2024). P values less than 0.05 were considered statistically significant (**P<0.05*; ***P<0.01*; ****P<0.001*). To examine whether the number of recorded species reached an asymptote, we plotted a species accumulation curve, using Kindt's exact method in the R package "vegan" [21]. We drew separate accumulation curves for each study site. 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 1000, indicating the number of captures per 1000 days of camera trapping [11]. The species richness and diversity of medium and large mammal species in each area type were computed using the Shannon–Weaver Diversity Index [22].

Additionally, 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. We did not consider an unidentified species for analysis to avoid unnecessary bias in species level estimation of RAI and naïve occupancy. A one-way analysis of variance with Tukey HSD multiple comparisons was utilized to test the differences between the relative abundance of each species across study sites. Finally, to identify the number of potential western lowland gorilla groups suitable for habituation within the study area, we selected the event including at least 7 individuals [23] and we assumed that a group is different from another if the distance between the camera traps that detected them is at least 3 km.

3 RESULTS

3.1 SAMPLING COVERAGE

We carried out a camera trap survey at 92 locations within and outside Moukalaba and 38 and 35 were functional respectively. Among the 19 non-functional cameras in this study, African forest elephant (*Loxodonta africana cyclotis*) broke 11 (Park 4; buffer area 7) and chimpanzee (*Pan troglodytes troglodytes*) 5 (Park 4; buffer 1). The cumulative time for all functional camera traps was 3060.42 camera-days in the park and 2880.68 in the buffer area. The species accumulation curve is saturated for each sampling area (Figure 2). This suggested that the camera traps captured the majority of terrestrial species inhabiting each area during the sampling period.

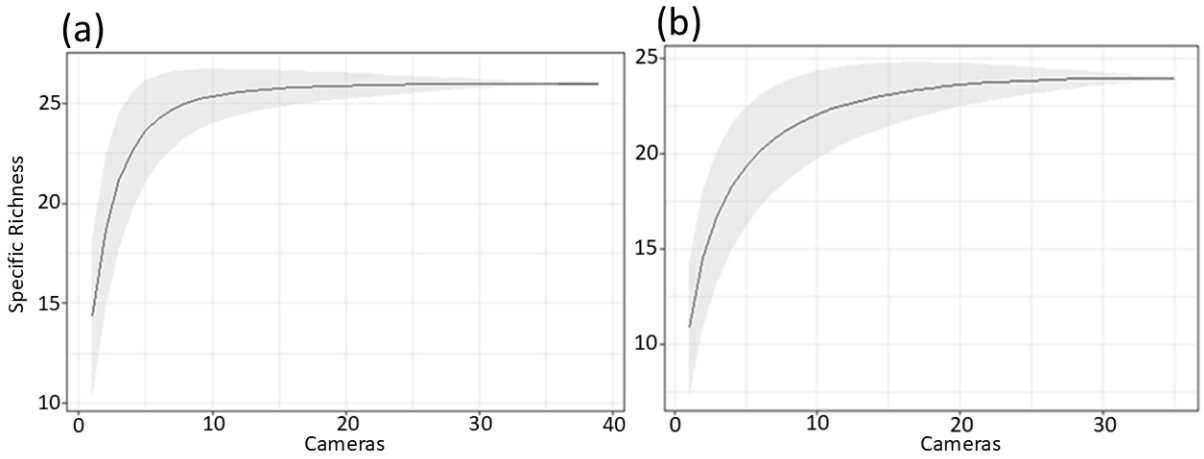

Fig. 2. Species accumulation curves for the two survey areas. (a) In the park and (b) in the buffer area. The black line represents the mean accumulation curve of species while the lighter shading shows on standard deviation around this mean using Kindt's exact method [21]

3.2 SPECIES RICHNESS, RAI AND NAÏVE OCCUPANCY

We succeed to identify 33 mammal species belonging to six taxonomic groups (5 Primates, 11 Carnivora, 10 Ungulates, 3 Pholidota, 3 Rodentia and 1 Proboscidea) across the entire study area. The number of detected species differed between the two areas, with 33 species detected within the park and 28 species within the buffer area (Table 1). We recorded Egyptian mongoose (*Herpestes ichneumon*), African golden cat (*Profelis aurata*), sitatunga (*Tragelaphus spekii*), tree pangolin (*Uromanis tetradactyla*) and African palm civet (*Nandinia binotata*) in the park only. The highest species diversity of the medium and large mammals was recorded in the park (H'

= 1.96) than in the buffer area (H' = 1.18). Moreover, among detected species in both target areas, two have been categorized as endangered, nine as vulnerable, two as near threatened, and 20 as least concern by the IUCN Red List of threatened species (Table 1).

Table 1. Overview of species identified within and outside Moukalaba-Doudou Park based on a total of 3060.42 and 2880.68 camera days respectively. Indicated is the number of captures of a given species per1000 camera days (relative abundance index; RAI) and the proportion of locations at which a species was recorded (naïve occupancy) as well as in the park and the buffer area

Species		RAI		Naïve occupancy		Animal per event
		Moukalaba	Buffer area	Moukalaba	Buffer area	
Primates						
Central chimpanzee [EN]	*Pan troglodytes troglodytes*	21.23	11.80	0.63	0.60	1–8
Western gorilla [CR]	*Gorilla gorilla gorilla*	17.64	8.33	0.58	0.48	1–16
Mandrill [VU]	*Mandrillus sphinx*	2.94	1.04	0.24	< 0.1	1-20
Red-capped mangabey [VU]	*Cercocebus torquatus*	10.45	5.90	0.58	0.48	1-14
Moustached monkey [VU]	*Cercopithecus cephus*	7.19	5.20	0.47	0.31	1-12
Carnivora						
Black-legged mongoose	*Bdeogale nigripes*	10.45	8.33	0.47	0.48	1
Long-snouted mongoose	*Herpestes naso*	18.95	12.49	0.63	0.60	1–2
Egyptian mongoose	*Herpestes ichneumon*	< 1	–	< 0.1	–	1
Marsh mongoose	*Atilax paludinosus*	2.94	1.73	0.24	0.14	1
Unidentified mongoose		5.55	3.47	0.24	0.14	1
African palm civet	*Nandinia binotata*	<1	–	< 0.1	–	1
African civet	*Civettictis civetta*	8.17	5.90	0.58	0.37	1
Servaline genet	*Genetta servalina*	26.14	20.83	0.81	0.83	1–2
Rusty-spotted Genet	*Genetta maculata*	4.24	3.47	0.28	0.14	1
African linsang	*Poiana richardsonii*	< 1	< 1	< 0.1	< 0.1	1
Unidentified genet		3.92	2.08	0.24	0.14	1
Leopard [VU]	*Panthera pardus*	7.19	5.90	0.52	0.42	1
African golden cat [VU]	*Profelis aurata*	1.31	–	< 0.1	–	1
Cetartiodactyla						
Red river hog	*Potamochoerus porcus*	98.23	43.32	0.75	0.68	1–23
Water chevrotain	*Hyemoschus aquaticus*	18.95	29.50	0.40	0.48	1–2
African buffalo	*Syncerus caffer nanus*	16.66	24.30	0.45	0.77	1–10
Sitatunga	*Tragelaphus spekii*	<1	–	< 0.1	–	1
Bush buck	*Tragelaphus scriptus*	7.14	11.80	0.45	0.77	1
Blue duiker	*Philantomba monticola*	325.51	274.56	1	1	1–3
Bay duiker [NT]	*Cephalophus dorsalis*	37.20	18.55	0.45	0.48	1
Peters's/Ogilby's duiker	*Cephalophus callipygus/ogilbyi*	248.16	95.82	0.75	0.77	1–2
Yellow-backed duiker [NT]	*Cephalophus silvicultor*	76.73	48.95	0.75	0.64	1
Waterbuck	*Kobus ellipsiprymnus*	18.45	28.93	0.45	0.77	1–6
Pholidota						
Giant pangolin [VU]	*Smutsia gigantea*	3.92	2.43	0.34	0.23	1
Tree pangolin [VU]	*Phataginus tricuspis*	< 1	–	< 0.1	–	1
Long-tailed pangolin [VU]	*Uromanis tetradactyla*	1.96	< 1	0.15	< 0.1	1
Proboscidea						
African forest elephant [VU]	*Loxodonta africana ciclotis*	148.76	178.98	1	1	1–18
Rodentia						
Brush-tailed porcupine	*Atherurus africanus*	15.35	24.99	0.56	0.64	1–2
Giant pouched rat	*Cricetomys spp*	5.90	10.75	0.34	0.42	1
Cane rat	*Thryonomys spp.*	2.29	4.57	0.15	0.23	1–4

In both areas, ungulates were the most frequently observed taxonomic group, followed by forest elephant and rodents. The blue duiker (*Philantomba monticola*) was the most frequently captured species, followed by the Peters's/Ogilby's duiker (*Cephalophus callipygus/ogilbyi*), the forest elephant and the red river hog (*Potamochoerus porcus*). However, among the 21 most frequently observed species (RAI ≥ 0.5 for 100 camera days and RAI ≥ 5 for 1000 camera days [24]) in both areas, 14 species showed higher RAIs in the park as compared to the buffer area (Wilcoxon test; N = 14 species, *p = 0.018*). These included four primate species, as well as two mongoose

species, four forest duikers, the red river hog, the leopard (*Panthera pardus*), African civet (*Civettictis civetta*) and the servaline genet (*Genetta servalina*). In contrast, only 7 species showed higher RAIs in the buffer area compared to the park (Wilcoxon test; N = 7 species, $p < 0.001$). These included the water chevrotain (*Hyemoschus aquaticus*), the bushbuck (*Tragelaphus scriptus*), the waterbuck (*Kobus ellipsiprymnus*), the African buffalo (*Syncerus caffer nanus*), the elephant and three rodent species.

A maximum score of naïve occupancy was 1 in both areas, which corresponds to detection on all functional locations. Only the blue duiker and the elephant achieve this score. However, we found some species on more locations in the buffer area than within the park. Bushbuck, waterbuck, brush-tailed porcupine (*Atherurus africanus*), giant pouched rat (*Cricetomys spp*) as well as cane rat (*Thryonomys spp.*) were detected at more locations in the buffer area as compared to the park (Table 1).

3.3 ANIMAL GROUP SIZES

We counted the largest number of individuals per camera event for the red river hog (26 animals), followed by the mandrill (*Mandillus sphinx*) (20), forest elephant (18), western lowland gorilla (16), red-capped mangabey (*Cercocebus torquatus*), Moustached monkey (*Cercopithecus Cephus*) (12), forest buffalo (10), chimpanzee (8), waterbuck (6), cane rat (4) and blue duiker (3) (Table1). In the specific case of great apes, although the relative abundance of chimpanzee was significantly higher with that of western lowland gorilla in both sides ($p < 0.001$), the western lowland gorilla showed a higher number of group size (Table 1). We succeed to identify at least 5 groups with more than 7 individuals within the park and 3 in the buffer area (Figure 3).

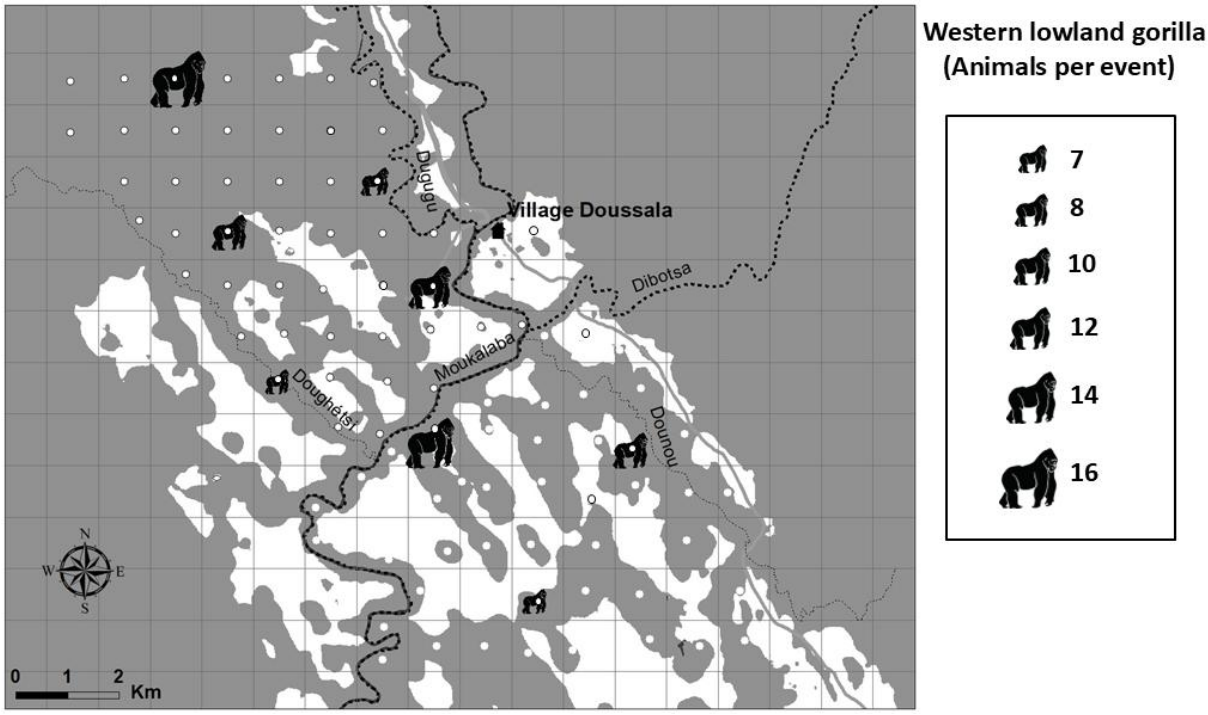

Fig. 3. Location of the western lowland gorilla groups with at least 7 members in and outside the national park

4 DISCUSSION

In this study, a total of 30 medium and large mammal species and 3 rodent species were detected in Moukalaba. Previously, using camera traps, 29 species of large to medium-sized mammal have been reported to occur in the park across the same target area [6]. Only one species, the sitatunga, was not detected in the previous study by camera trap but has been observed within the target area [6], [7]. Beyond species richness, the composition of the detected wildlife community suggests a low level of disturbance. The sitatunga is an antelope species adapted to the dense swamp and marshe forests [25]. Nakashima conducted mammal's inventory in 2015 during a total of 4165 camera-days and across several types of vegetation including savanna, young and old secondary forests and swamp forest [17]. The abundance of sitatunga may be naturally very low within the target area and could be detected occasionally, as might be the case in our study. Ecologically, the observed assemblage of mammals might be characteristic of the Moukalaba ecosystem.

Moreover, the number of detected species within the park was higher than in the buffer area. While related to the high species diversity of the medium and large mammals recorded in the park (H' = 1.96) than in the buffer area (H' = 1.18). In the park we recorded a total of 30 medium and large mammal species and 3 rodent species, whereas in the buffer area only 25 medium and large mammal species and 3 rodent species. The Egyptian mongoose, the African palm civet, the African golden cat, the sitatunga and the tree pangolin

were captured in the park but not in the buffer area (Table 1). However, the RAIs of those species were very low (RAI < 1), even in another national park [24]. Those species, which are difficult to detect within the national park, will be harder to detect within the area subject to human activities. The confirmed presence of the species inhabiting the buffer area reveals some insights on the structure and composition of mammal communities across this area.

In contrast, 7 species showed higher RAIs including naïve occupancy in the buffer area compared to the park ($p < 0.001$). These included the bush buck, the African buffalo, the waterbuck, the water chevrotain, the elephant and three rodent species. The bush buck, the African buffalo and water buck are savanna dwelling species [6], [20], and savannas are more extensive in the buffer zone than in the park (Figure 1). This might explain the higher number of detections of those species in the buffer area than in the park. Regarding the water chevrotain, it is a riverine forest species rarely found more than 500 m away from water [20], [26]. In this study, we deployed more camera traps near the waterways in the buffer zone than in the park, this could explain the higher number of detections obtained in the buffer zone compared to the park. For elephant, the density of elephant trails outside the national park has been suggested to be higher and the trails were wider than those in the national park, suggesting frequently used [27]. Probably due to the crop fields, elephant detection was higher in the buffer area than in the park. With regard to rodent species, they have been already suggested to be very abundant in forests heavily impacted by human activities including hunting [28], [29]. The availability of rodent foods is sufficient in heavily human-modified forests, thus facilitating their reproduction [30]. Future studies will also need to take into account factors, such as carrying capacity across both areas to better understand such local variation in species abundance.

Our study also pointed out that, in both areas, artiodactyls are the most detected order (Table 1). While related to the high RAIs of the blue and Peter's/Ogilby's duikers in both areas. The detection rate of blue and red duikers recorded in Moukalaba is higher so far compared to the Batéké Plateau National Park, Gabon [24], a certified logging area [31] and comparable with the results from the Afrotropical rainforest [32], [33], [34]. The red/blue duiker ratio, often considered as a good proxy for assessing the status of duiker populations and le level of hunting pressure within a target area [29], [35]. In Moukalaba this ratio (0.87) is almost similar to the one obtained in the Nouabalé-Ndoki National Park, which is characterized by a particularly low level of hunting pressure [33]; and is twice higher than in the buffer area (0.41). Hunting activity seems to be lower within the park due to a permanent presence of researchers. In contrast, although the surrounding population across the buffer area is very low [15], people depend heavily on natural resources for their livelihoods and wild meat including duikers is their main protein intake [18]. Hunting for wild meat is a major cause of wildlife decline in the tropics [28], [29]. It is therefore important to establish Optimal monitoring plans in the buffer area to ensure that some species will not be driven to local extinction.

On the other hand, among great apes and in both areas, western gorillas had the largest number of individuals per camera event compared to chimpanzees; whereas overall detection rate of chimpanzee was higher compared to gorilla. Our results were consistent with previous studies conducted in Moukalaba [11] and across several non-protected areas in Gabon [19]. The social structures and mating strategies of gorillas and chimpanzees differ in resource use despite their coexistence. Gorillas live in groups up to 11 individuals, dominated by a silverback male [36], [37]. While chimpanzees, which are higher territorial compared to gorillas, live in communities made up of many males and females and ranging from more than 20 individuals and group regularly breaks up into sub-groups of varying size [36], [38]. The cohesive social structure of gorillas against chimpanzees may lead more individuals to be captured in single event. And chimpanzees during boundary patrols and forage, they are ranging over greater distances than gorillas [37], therefore, the probability of camera traps to detect them might be higher.

A major contribution of our camera trap survey was the identification of 8 groups of western lowland gorillas with at least 7 members, 5 in the park and 3 in the buffer area (Figure 3). The presence of large groups of gorillas in both areas, could generate interest in conducting a habituation program to develop sustainable ecotourism. Habituation being the process by which animals become accustomed to human presence and eventually accept a human observer as a neutral element in their environment. It is not recommended in forests subject to hunting [39]. Within Moukalaba, hunting is almost non-existent and a long-term socioecological study of western lowland gorillas at this site started in 2001. As a result of this program a group of gorillas named Group Nidai (GN), which consisted currently of 12 members (Moukalaba Research Team, unpublished data). This group was captured during our campaign (group very close to the village) and four other groups. This group, which is subject of ecotourism, was captured during our survey (in Figure 3, the group very near to the village) and four other groups. The tourism demand for gorilla observation continues to increase in Moukalaba. Although habituation of western gorillas to human presence is generally an expensive, lengthy and difficult process [39], in order to avoid other tourism, at least two of the four remaining groups could be included in the process of habituation.

5 CONCLUSION

Our camera trap survey highlighted a good diversity of medium and large mammals in the north-eastern of Moukalaba and its buffer area. Most of the species previously known to inhabiting in the park were detected. The detections of leopards, giant pangolins, golden cats and tricuspid scaly pangolins, even if anecdotal, reinforce the park's appeal given the usually low abundance and elusive nature of those species. The diversity and abundance of species detected indicate a favorable outcome for estimating the biodiversity of the park and its buffer area, despite heavy hunting pressure in the buffer zone. Finally, we obtained relevant data of large and active populations

of western gorillas (8 groups of gorillas with at least 7 members), this confirmed the strong potential of the park and its buffer area for the preservation of this species through the development of gorilla-viewing ecotourism with local communities.

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CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

AUTHORS'CONTRIBUTIONS

AOEF designed the project. MNFL and NNQ collected camera trap data and conducted species identification from camera trap photos and videos. AOEF performed the data and wrote the manuscript.

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