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Gorilla Abundance Estimations within North-East Moukalaba-Doudou National Park, Gabon

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Keywords
Census · Density · Western lowland gorilla · Nest distribution

Abstract
Accurate measures of animal population densities are essential to evaluate conservation status and implement action plans to ensure species survival. Gorilla numbers were assessed using the recce survey method within Moukalaba-Doudou National Park (MDNP) in Gabon using fresh nest counts of up to 1 week old. We walked 3,592 km within a 23.01-km^2 study site totalling a sampling effort of 297 days. Encounter rate was 0.12 fresh nests per kilometre, and gorilla density estimates generated by home range sizes (by minimal convex polygon) ranged between 1.14 and 1.48 gorillas/km^2. Gorillas preferred mixed forest for nesting over other habitats (Cheason index value 1.31). Results showed that gorilla density values within the study area concurred with previous studies that used line transect methodologies. We conclude that the choice of sampling design is dependent on environmental conditions characterised by each habitat type and target species.

Introduction

The population of great apes in rain forests continues to decline despite conservation efforts by non-governmental organisations and research teams. Anthropogenic activities such as bushmeat hunting and habitat loss caused by the expansion of logging concessions, mining companies and agricultural plantations continue to threaten species numbers [Brooks et al., 2002; Estrada et al., 2018; Strindberg et al., 2018]. Additionally, populations are affected by disease epidemics such as anthrax, corona virus and Ebola [Bermejo et al., 2006; Leendertz et al., 2006; Melin et al., 2020]. In 2018, the *IUCN Red List of Threatened Species* uploaded a new version in which it classified the western gorilla (*Gorilla gorilla*) as Critically Endangered [Maisels et al., 2018]. It is imperative to monitor population sizes of great apes to better understand the threats to them and formulate appropriate conservation action plans as a lack of preservation could lead to species extinction [Tranquilli et al., 2012].

Indicators for the presence of great apes include faeces, footprints, hairs, food remains and nests. These signs are fixed and can remain for several days or even months, making them extremely useful when surveying popula-

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tion densities [Tutin and Fernandez, 1984; Plumptre and Reynolds, 1996; Furuichi et al., 2001; Morgan et al., 2006; Takenoshita and Yamagiwa, 2008; Maloueki et al., 2013; Maloueki, 2019]. Current methods for estimating the distribution and abundance of mammals include line transects, camera traps and DNA sampling [Buckland et al., 1993; Mills et al., 2000; Nakashima et al., 2013b], but simpler recce methods (reconnaissance surveys) are also used [Silveira et al., 2003; Todd et al., 2008]. Recce surveys can be the most efficient and rapid method for detecting species richness and relative abundance more so than camera traps and transect surveys depending on species targeted and environmental conditions [Silveira et al., 2003]. Although recce surveys have limitations, they are relatively low cost and cause less environmental disturbances. They also cover a large area and are easily accessible even in remote areas. Studies at several sites have established that there are good correlations between data collected during recce surveys and line transects in the same area, at least for gorilla nests [White and Edwards, 2000; Plumptre and Cox, 2006]. Additionally, data show a good correlation between direct observations of tracked groups and nest counts along line transects in great apes such as chimpanzee and gorilla groups [Tutin, 1996; Bermejo, 2004; Morgan et al., 2006; Ando et al., 2008].

We used recce surveys to compare density estimate values obtained from gorilla censuses at the Douguetsi site around Moukalaba-Doudou National Park (MDNP). In order to compare the effectiveness of different survey methods used in previous studies, we collected data from nest and faeces counts along transect surveys combined with direct observations of a tracked gorilla group. Only few studies have compared previous methodologies at the same study site [Ando et al., 2008; Takenoshita and Yamagiwa, 2008; Nakashima et al., 2013b]. We hypothesised that nest count data from recce surveys and direct observations would directly correlate with data from faecal counts along transect surveys.

Methods

Study Site

Our survey site was located at Douguetsi (02°22′11.42″ S, 10°33′44.53″ E; Fig. 1) which covers 23.01 km^2 and is situated in the north-east part of the MDNP in Gabon [for further details of the study site see Iwata and Ando, 2007; Ando et al., 2008; Takenoshita et al., 2008]. The main habitat types are mixed forest (MXF) with mixed species of primary forest that has been selectively logged (open understorey), old secondary forest (OSF) that is *Musanga cecropioides* dominated (less dense understorey), savannah with open grassy vegetation and swamp forest (SWF) that is seasonally inundated with riparian forest along the watercourses. The mean temperature is 26 °C, and annual rainfall is 1,300–1,800 mm. There are two distinct seasons per year: rainy (October to April) and dry (May to September). It seldom rains during the three months in the middle of the dry season (June to August). The forests in this area were selectively logged from the 1960s until the 1980s.

Study Animals and Census Methods

Detailed information about the tracked group "Mussiru" (MUG) can be found in Maloueki et al. [2020]. Due to the lack of detailed observations, the group size from nest counts is 11 individuals excluding infants. The group contained one silverback male whose behaviour alternated between "naivety/curiosity" and "aggressive" and other members who still appeared to be wary of human presence. During our surveys in search of MUG, we recorded all individual fresh nests opportunistically. Surveys found nests were also present from other neighbouring gorilla groups along with those of solitary males. Nesting sites were only assigned to the focus group when traces were confirmed with an observational encounter. In addition, we recorded encounters with untracked groups or solitary males. We followed only fresh traces and gorilla vocalisations or chest beating sounds as directions towards possible nesting sites. We also visited fruiting trees, previous nesting sites and followed other characteristic signs until we encountered gorillas [Tutin and Fernandez, 1984; Ando et al., 2008].

The study was conducted from March 2019 to March 2020, with a sampling effort of 297 days of census (track surveys) and a total of 3,592 km walked. We followed pre-existing elephant trails and when necessary cut a path of least resistance through forest vegetation. We visited each trail at least once and used random selection to perform surveys. The research team was made up of 2–3 lesser teams that included 2 trackers and 1 researcher within each. Data are collected between 07:00 and 15:00 (partial day trails) to avoid losing visual signs or direct contact with group members.

Previous research has documented that great apes reuse nesting sites and individual nests [bonobos: Maloueki et al., 2013; chimpanzees: Plumptre and Reynolds, 1996; gorillas: Iwata and Ando, 2007; orang-utans: Ancrenaz et al., 2004], we therefore only recorded individual fresh nests up to 1 week old upon their building [Tutin and Fernandez, 1984]. Reused nests were only counted as new if additional construction materials were found within the structure. We assigned nest sites to gorillas when either more than one ground nest was present or nests exhibited other characteristic signs to discriminate gorilla nests from those of chimpanzees (e.g., footprints, food remains, faeces, hair or urine smell) [Tutin and Fernandez, 1984; Furuichi et al., 1997; Sanz et al., 2007]. This meant that old nests were not recorded to avoid misidentification from nest-builder species. When a nest was located, we searched intensively for other nests around a ≥30-m area [Maloueki, 2019]. We used a Global Positioning System (GPS) to locate each nesting site sampled to evaluate nesting habitat selection.

Data Analysis

Fisher tests were used to compare data sets from nests and considered $p < 0.05$ significant. We analysed the following parameters: (1) the number of fresh nests sampled in each habitat types, (2) nesting behaviours according to seasonal change, (3) if seasonal change affected nest group size. We used Paleontological Statistics (PAST) [Hammer et al., 2001] Software Version 3.23 for

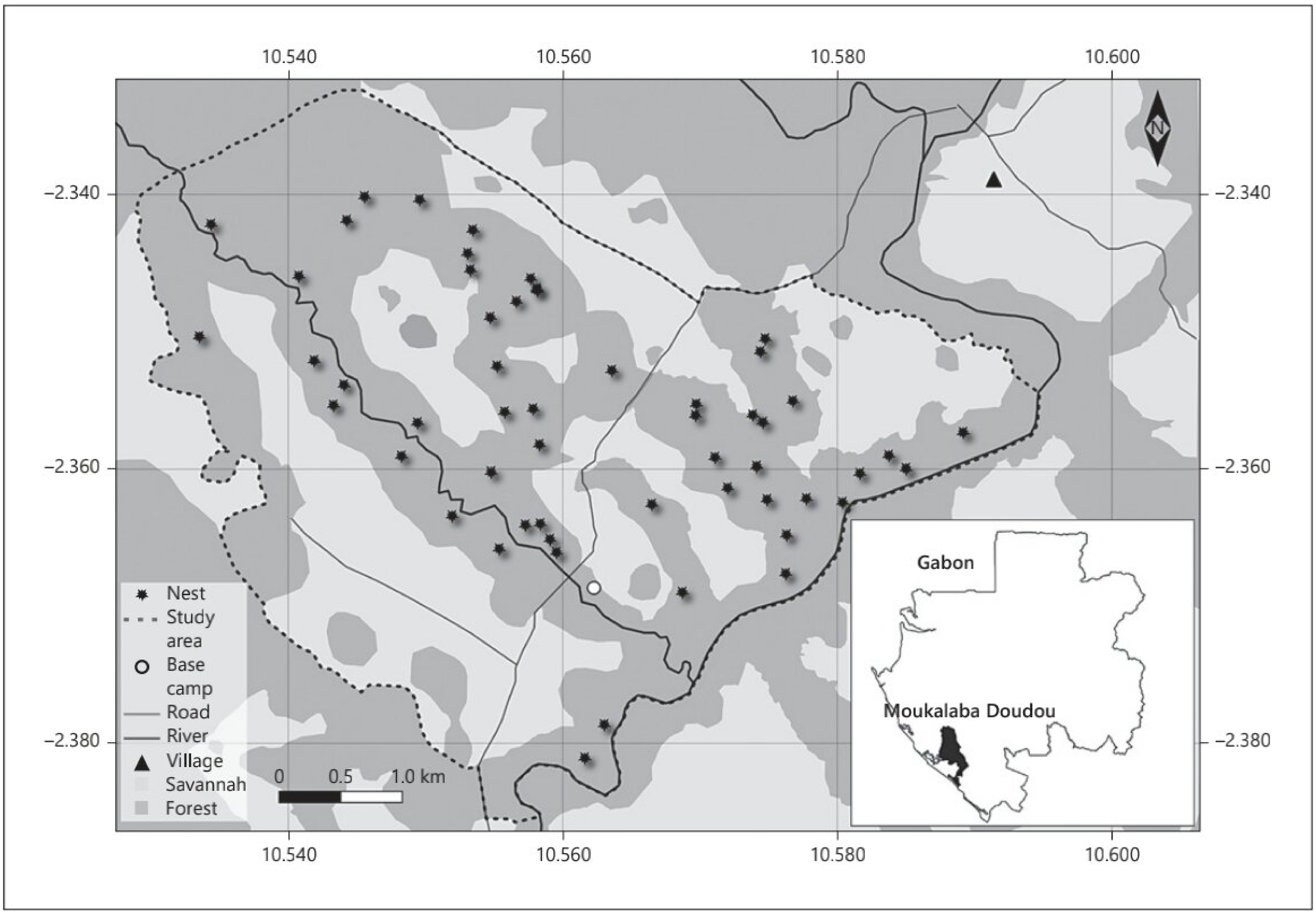

Fig. 1. Location of study site and spatial distribution of nests.

analysis and the Cheason Index to evaluate habitat selection for nesting [Manly et al., 2002] given by the formula below:

$$\alpha_i = \frac{\frac{r_i}{p_i}}{\sum_{i=1}^{m} \frac{r_i}{p_i}}$$

and

$$\alpha_i' = m\alpha_i,$$

where r_i is the proportion of nests in habitat, i is overall nests and p_i is the proportion of availability of habitat i in the environment and m is the total number of habitat types. The values of α range from 0 (complete avoidance) to 1 (complete preference). We calculated a second value α' from α. When $\alpha_i' > 1$, the habitat is considered preferred by the animal as a function of its availability, whereas for $\alpha_i' < 1$, the habitat is avoided as a function of its availability, and for $\alpha_i' = 1$, the habitat is used randomly as a function of its availability.

To estimate gorilla abundance, we calculated home range size with the minimal convex polygon method under the software QGIS Version 2.18. from GPS points at each night's nest site sampled or at the first contact and every 1 h to separate points when we tracked gorillas. We then divided group size by group range to generate a home range density estimate. For calculating the density of gorillas from nest counts using recce surveys, we also used the nest range following this formula:

D (gorillas/km^2) = number of nests built in the nest range (km^2)/days census.

We assumed the nest production rate in gorillas is 1 per day as previously reported at the Lopé Reserve in Gabon [Tutin et al., 1995].

Results

During routine surveys, we recorded gorilla group sizes as soon as contact started (mean = 2.93 gorillas/group, SD = 2.79, range = 1–20) including MUG. We counted all individuals seen in the group when the observation con-

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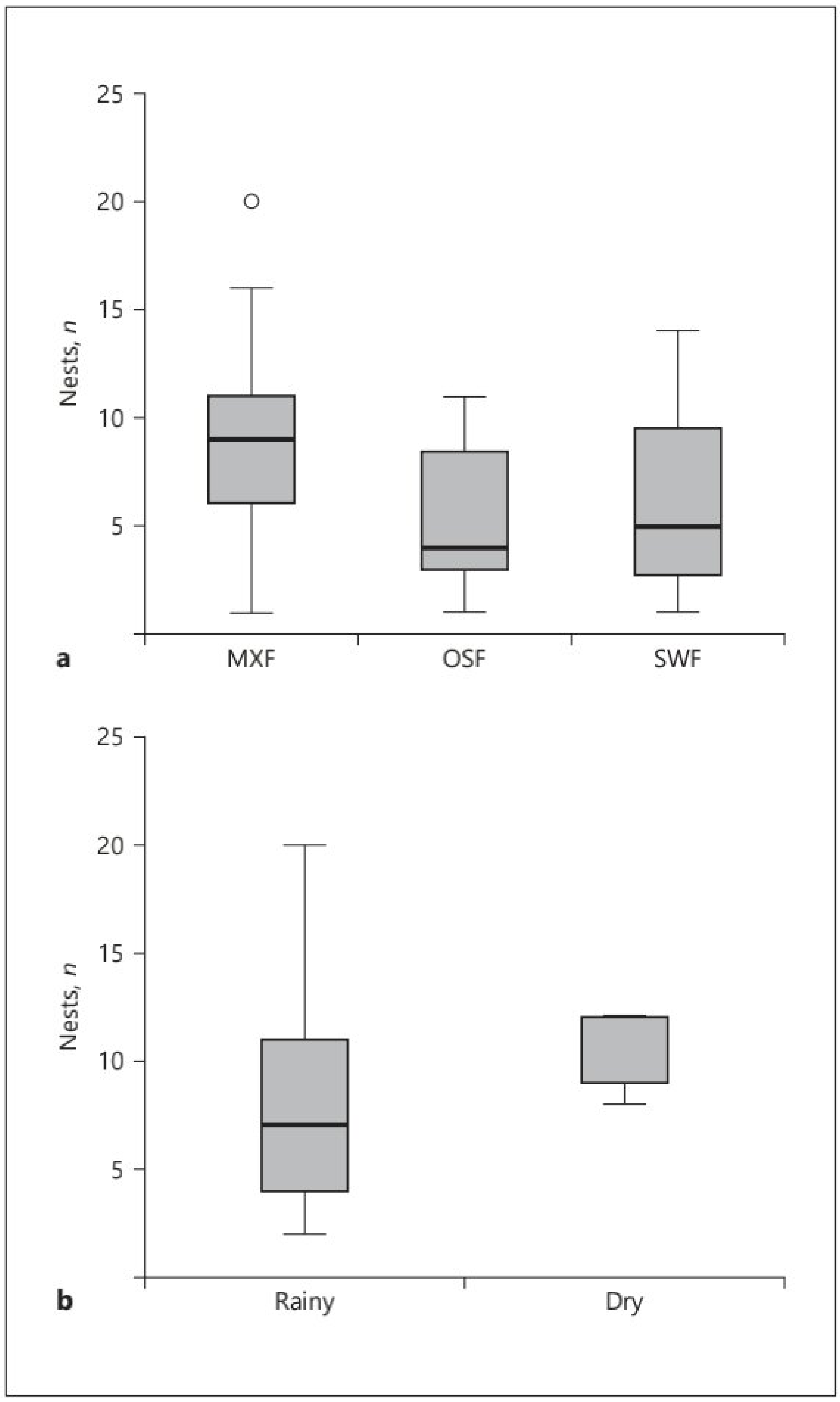

Fig. 2. Distribution of nests. **a** In different habitat types. MXF, mixed forest; OSF, old secondary forest; SWF, swamp forest. There is no significant difference between nests built in different habitat types ($F = 3.06$, df = 22.32, $p = 0.06$). **b** Within nest group sizes with seasonal changes. Boxplot showing median (thick line), lower and upper quartile (box), sample minimum and maximum (whisker) and outlier (dot).

ditions were optimal as well as any solitary males. Mean gorilla group sizes for untracked groups or solitary males were 2.21 gorillas/group (SD = 2.60, range = 1–20) and MUG mean 4.56 gorillas/group (SD = 2.55, range = 1–13), respectively. Most encounters with gorillas were due to naivety. Upon locating groups at fruiting trees or resting on the ground, we would approach silently so as not to be noticed by them.

In total we recorded 441 fresh nests in 62 nest sites (mean = 7.11 nest/site, SD = 4.42, range = 1–20; see Table 1 and Fig. 2a). Fresh nest encounter rate was 0.12/km. Nests were mostly arboreal, with 377 (85.5%) nests in the trees and 64 (14.5%) nests on the ground. We recorded $n = 8$ reused nests (1.8%) which were mainly built above ground within 3 nest sites and found there were more reused nest sites during the rainy season ($n = 10$; 83.3%) than in the dry season ($n = 2$; 16.7%). Seasonal changes did not affect whether gorillas constructed ground or arboreal nests. We found a significant difference following the nest group size ($F = 11.97$, df = 12.68, $p = 0.004$, Fig. 2b) between the rainy season (mean = 7.53, SD = 4.14, range = 2–20, $n = 49$) and the dry season (mean = 10.83, SD = 1.83, range = 8–12, n = 6).

Most nests were located in MXF (49%), SWF (31%) and OSF (20%). The Cheason Index values show that gorillas preferred MXF and used other habitat types (OSF and SWF) randomly (Table 1).

The group studied ranged over an area of 9.66 km^2, therefore night nests were sampled around Douguesti site within a largest range of 11.73 km^2 using the minimal convex polygon method. We estimated a density of 1.14 gorillas/km^2 from direct observations of the tracked group and 1.48 gorillas/km^2 from nest counts by recce surveys, respectively, around the focus site (Table 2). Density values found were relatively similar to findings by Ando et al. [2008] and Nakashima et al. [2013b] (Tables 2, 3).

Discussion

Gorilla Abundance

Our research correlates with peer findings that gorilla population numbers within the study area remain stable [Ando et al., 2008; Nakashima et al., 2013b]. Possible reasons for this are the lack of human pressures within the park [Nakashima et al., 2013a] and previous outbreaks of Ebola within Gabon not impacting MDNP [Georges et al., 1999; Huijbregts et al., 2003; Walsh et al., 2003; WHO, 2003].

Our study shows a positive correlation between density estimate values using recce surveys and those from nest counts using line transects. Equally, White [1992] and Tutin [1996] at the Lopé found similar density values ranging from 0.3 to 1.0 gorillas/km^2. Blom et al. [2001] and Todd et al. [2008] reported homogenous findings around Dzanga Sangha with gorilla densities ranging from 0.98 to 2.14 gorillas/km^2. In contrast, however, Tak-

Table 1. Nesting habitat selection (Cheason index, α_i') overall for gorillas at Douguetsi site

Habitat type[1]	Overall (all habitat types, $n = 3$)						
	nests	habitat available	r_i	p_i	r_i/p_i	α_i	α_i'
MXF	233	27	0.6005	0.4909	1.2233	0.4380	1.3139
OSF	61	11	0.1572	0.2000	0.7861	0.2814	0.8443
SWF	94	17	0.2423	0.3091	0.7838	0.2806	0.8419
Total	388	55			2.7932		

MXF, mixed forest; OSF, old secondary forest; SWF, swamp forest. [1] Here we considered the nest sites (N = 55) for which the habitats were characterised.

Table 2. Density estimates calculated from direct observations of western lowland gorilla group sizes and home ranges

Study site, method	Range, km^2	Group size[a]	Density, gorillas/km^2	Source
Bai Hokou (1992)	22.9		0.57	Remis, 1997
Bai Hokou, 250 × 250 m grid	18.3		0.26	Cipolletta, 2004
Lopé	21.7		0.37	Tutin, 1996
Lossi, 100 × 100 grid (1996)	11	15	1.36	Bermejo, 2004
Mondika, 250 × 250 grid	15.4	7	0.45	Doran et al., 2004
MDNP, MCP	9.66	11	1.14	This study
MDNP, MCP[b]	11.73		1.48	This study
MDNP, unknown	12.4		3	Ando et al., 2008
MDNP, unknown	12.4	16	1.29	Ando et al., 2008

MDNP, Moukalaba-Doudou National Park; MCP, minimal convex polygon. [a] Excluding infants. [b] Density estimate from range nest.

enoshita and Yamagiwa [2008] reported density values of 6.99 gorillas/km^2 (Table 3) twice the amount of previous studies within the same area of MDNP. Population estimates from faeces counts along transect surveys can overestimate the actual number of individuals [Takenoshita and Yamagiwa, 2008]. Several possible reasons for this are: (i) defecation rate per individual and group size cannot be measured easily, thus increasing replication risk, and (ii) duration periods between two successive censuses as faeces may biodegrade due to environmental variables (such as species diet, coprophagous insects and seasonal changes). Even so, this methodology could be appropriate for monitoring fully habituated gorilla groups whose members and age class are well known [Todd et al., 2008].

To reduce stochastic variations (in relation to the demography of animal populations), we assume that densities reported in this study were underestimated. This could have been caused by several factors such as undetected nests high in the canopy and observational impairment by animal behaviours (gorilla members being fearful of human presence). Within the study area, we identified at least 9 gorilla groups (including our study group) and 7 solitary males whose home ranges overlapped [Maloueki et al., 2020]. Probable causes of population variations noted across the Congo Basin within study sites are difficult to explain without a greater knowledge of fruiting patterns and fruit abundance in each of the different habitats including the availability of terrestrial herbaceous vegetation across Central Africa.

Nest production rates and nest lifespan variables (nest disappearance/nest disintegration) can also influence population estimates and vary with each nest construction type, habitat type, seasonal change and tree species

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Table 3. Density values obtained across western lowland gorilla study sites in African rain forests from 2005 to date

Country and study site	Sampling design	Sampling method	Survey, km	Area, km^2	Density, gorillas/km^2	Source
Cameroon						
Boumba-Bek NP	Marked nest	Line transect	398	877 + 1,130	0.46 (0.29–0.74)	Bobo et al., 2014
Deng Deng NP	Marked nest	Line transect	136	523	0.67 (0.39–1.17)	Maisels et al., 2011
La Belgique research site	Marked nest	Line transect	30	32.4	0.15 (0.04–0.59)	Tagg and Willie, 2013
Wildlife management	Standing crop nest	Line transect	348.3	176	1.10–1.41[a]	Arnhem et al., 2008
Central African Republic						
Bai Hokou	Faeces counting	Track survey		1,240	0.98–1.7	Todd et al., 2008
Congo						
Bailly	Marked nest	Line transect	48	3,770	0.86 (0.43–1.74)	Stokes et al., 2010
Batanga swamps	Marked nest	Line transect	42	1,029	5.72 (2.9–11.0)	Stokes et al., 2008
CIB (Wildlife Management)	Marked nest	Line transect	3,450	11,970	1.92 (1.36–2.71)	Clark et al., 2009
Djeke Triangle	Marked nest	Line transect	34	102	1.47 (1.06–2.04)	Morgan et al., 2019
Goualougo Triangle	Marked nest	Line transect	222	310	2.34 (1.83–2.99)	Morgan et al., 2006
	Marked nest	Line transect	385	380	0.7–1.6	Sanz et al., 2007
	Marked nest	Line transect	385	380	1.1–2.4	Sanz et al., 2007
	Marked nest	Line transect	54	310	1.43 (1.03–1.98)	Morgan et al., 2019
	Marked nest	Line transect	55.8	380	1.70 (0.88–3.29)	Devos et al., 2008
	Standing crop nest	Line transect	55.8	380	2.63 (1.42–4.9)	Devos et al., 2008
Kabo (Wildlife Management)	Marked nest	Line transect	30	2,870	2.16 (1.02–4.56)	Stokes et al., 2010
Kabo East (Wildlife Management)	Marked nest	Line transect	107	415.38	1.05 (0.74–1.49)	Morgan et al., 2019
Kabo West (Wildlife Management)	Marked nest	Line transect	88	415.38	2.10 (1.52–2.91)	Morgan et al., 2019
Lac Télé	Marked nest	Line transect	42	1,029	5.25 (2.70–10.19)	Rainey et al., 2009
Lac Télé Community Reserve	Marked nest	Line transect	106	4,380	2.27 (1.66–3.11)	Stokes et al., 2010
Loundoungou (Wildlife Management)	Marked nest	Line transect	35.7	4,230	0.78 (0.34–1.77)	Stokes et al., 2010
Mokabi	Marked nest	Line transect	29	2,670	0.15 (0.05–0.45)	Stokes et al., 2010
Ndoki-Likouala Landscape	Marked nest	Line transect	329.7	27,970	1.65 (1.24–2.21)	Stokes et al., 2010
	Marked nest	Line transect	336	27,970	1.65 (1.24–2.21)	Stokes et al., 2008
Ngombe-Ntokou-Pikounda Landscape	Marked nest	Line transect	427.3	16,189.8	4.86 (3.80–6.23)	Maisels et al., 2014
Nouabalé-Ndoki NP	Marked nest	Line transect	40	4,190	1.02 (0.59–1.77)	Stokes et al., 2010
Ntokou-Ngombe-Pikounda	Marked nest	Line transect	148	18,445	4.10 (2.5–6.26)	Stokes et al., 2008
Odzala-Kokoua NP	Marked nest	Line transect	29.5	42	1.37 (0.35–5.59)	Devos et al., 2008
	Standing crop nest	Line transect	29.5	42	3.22 (1.61–6.44)	Devos et al., 2008
	Standing crop nest	Line transect	207.5	13,546	0.85 (0.58–1.25)	Bohm, 2018
Pokola (Wildlife Management)	Marked nest	Line transect	41	4,510	4.08 (2.27–7.36)	Stokes et al., 2010
Gabon						
Bambidie AAC 2012 (Wildlife Management)	Marked nest	Line transect	490	6,170	1–2.6	Haurez et al., 2016
MDNP	Faeces counting	Line transect	44.3	30	6.99	Takenoshita and Yamagiwa, 2008
	Standing crop nest	Line transect	53	500	0.04–3.30[a]	Nakashima et al., 2013b
Petit Loango NP	Marked nest	Line transect	16.65	20	0.08	Morgan, 2007

Included data are for the period after the known occurrence of Ebola haemorrhagic fever in gorillas. The parentheses indicate range of estimates. [a] If density (gorillas/km^2) = density of nests (km^2)/(nest lifespan [day] × nest production rate [day^{-1}]). With nest lifespan that is 78 days and the nest production rate of 1 per day in gorillas reported at the Lopé Reserve (Tutin et al., 1995).

[Tutin and Fernandez, 1984; Tutin et al., 1995; Plumptre and Reynolds, 1996; Morgan et al., 2006]. Further studies are needed to assess nest decay rates for each research site to limit apparent cross-site biases [Tutin et al., 1995; Plumptre and Reynolds, 1996; Morgan et al., 2006]. Moreover, great ape densities can be skewed using nests as population indicators. An earlier study in MDNP attributed all above-ground nests to chimpanzees and ground nests to gorillas [Nakashima et al., 2013b]. Our data show that this assumption may be unwarranted because gorillas build also nests above ground, leading to an underestimate of the abundance of gorillas in the area.

Increasing survey distances travelled may improve detection rates; however, recce surveys also influence encounter rate variance and therefore estimated precision of trail encounters [Keeping and Pelletier, 2014]. We increased our sampling efforts to minimise false absences caused by low visibility within the undergrowth or canopy [Keeping and Pelletier, 2014]. As all sampling methods have limitations [Plumptre et al., 2013], comparisons between studies and sites remain difficult. Therefore, there is no standardised methodology that can be transposed to all the study sites.

Nest Information and Management Implications

In accordance with Iwata and Ando [2007], our survey identified that gorillas from MDNP are mostly arboreal (building nests above ground) contrasting with what other studies have recorded across Central Africa [Remis, 1993; Tutin et al., 1995; Mehlman and Doran, 2002; Maloueki, pers commun.]. This may be due to the lack of appropriate construction material for ground nests in other areas, such as terrestrial herbaceous vegetation preferred by western gorillas (particularly the Marantaceae, Zingiberaceae and Commelinaceae families). The availability of terrestrial herbaceous vegetation across study sites in Central Africa is diverse and depends on the history of forest cover (ecological factors) and anthropogenic activities [Remis, 1993; Tutin et al., 1995; Furuichi et al., 1997; Mehlman and Doran, 2002; Willie et al., 2014]. Gorilla preferences for building nests above ground at our study site may have been influenced by factors such as the need for comfortable sleep, reducing the risk of bites from disease vectors like mosquitoes, thermoregulation conditions and avoiding predators/disturbance by large mammals [Tutin and Fernandez, 1984; Mehlman and Doran, 2002; Pruetz et al., 2007; Stewart, 2011; Samson and Hunt, 2012].

The fruiting peak of trees often correlates with the rainy season [Takenoshita et al., 2008] altering foraging behaviour which may impact the size of gorilla home ranges and distance travelled [Tutin, 1996; Goldsmith, 1999; Doran-Sheehy et al., 2004]. Several gorilla groups may share the same home range as our study group during the rainy season as ranges decrease to minimise the risk of interaction with other males [Bermejo, 2004]. However, the reverse may be observed during the dry season when scarcity of fruits may cause gorilla groups to travel further and become more territorial often competing with conspecific species as well as chimpanzees and elephants [Head et al., 2012].

We found no significant correlation between number of nests built and habitat types (Fig. 2a) suggesting that there was no group preference between habitats. Nonetheless, previous research has recorded that gorillas favour MXF and use other habitats such as OSV and SWF [Morgan et al., 2006; Arnhem et al., 2008]. This may be related to ecological factors such as food productivity within each habitat [Iwata and Ando, 2007; Tédonzong et al., 2018]. We did not find any nest sites in within savannah, suggesting that gorillas may avoid it. This is an important parameter when identifying high conservation value forests for an effective management plan within MDNP.

Conclusion

There is a need to improve methodologies used when collecting data of gorilla estimates within MDNP. We recommend future studies examine the effectiveness of different methods presented in previous research to limit biases and collate data from high conservation value forests. Despite differences in population estimates from other survey methods within the same area, MDNP continues to boast the highest gorilla density values in Gabon. It therefore should be considered one of the last reserves for the gorillas of Central Africa, surpassed only by the Congo (Table 3).

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Statement of Ethics

The research specified in this paper followed the protocols approved by the ethics committee from CENAREST on animal care, in accordance with the legal requirements established in the Gabonese Republic. The research complied with the World Medical Association Declaration of Helsinki.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

U.M.: designed the study plan and wrote the manuscript. All authors collected data in the field, analysed data, reviewed and adopted the final version of the paper.

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