

Not all roads are barriers: Large mammals use logging roads in a timber concession of south-eastern Cameroon

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ABSTRACT

In the literature, roads are often considered to be barriers for large vertebrates. In central Africa, the creation of roads and skid trails by logging operations leads to changes in the structure of forest landscapes that could influence wildlife movements. To assess the use of logging roads by six emblematic species of the central African forests, we conducted a camera trap (CT) survey on three types of tracks (secondary roads, skid trails, and elephant paths as control) in a logging concession of south-eastern Cameroon. The relative abundance indices (RAI) of each species derived from the CT data were used in a mixed linear model to test the effects of four factors (type of track; time: day vs. night; gregariousness: alone vs. group; and time after logging: less than one year vs. between one and two years). The results showed no preference for any type of track for gorillas (*Gorilla gorilla*) and chimpanzees (*Pan troglodytes*). In contrast, significantly higher RAI on secondary roads were

observed for buffalos (*Syncerus caffer*), forest elephants (*Loxodonta cyclotis*), and bongos (*Tragelaphus eurycerus*). For the last two, the difference was only significant if they were detected in the most recently logged areas, at night (for elephants), or alone (for bongos). We could not test for leopard (*Panthera pardus*) as we captured only two events. Although none of the species appear to avoid roads and skid trails, nor do they perceive them as a barrier, further studies should be conducted to increase sampling efforts over time and space to consider seasonality, vegetation growth after logging, geographical variability, and other anthropogenic influence. However, these first results reveal the importance of closing roads after logging to limit encounters between wildlife and humans and highlight the relevance of characterizing roads (type of road, width, surfacing, and canopy structure over the road) when studying their impact on wildlife.

1. Introduction

Of the 1070 million hectares of tropical forest, an estimated 400 million are currently used for timber production (Blaser et al., 2011), of which 54 million are located in central Africa (Eba'a Atyi et al., 2022). In the context of continuing biodiversity loss (Ceballos et al., 2017; Roy et al., 2022), this area represents a major issue for conservation. Although they are disturbed environments, some forest concessions host many mammal species, especially when they are sustainably managed (Clark et al., 2009). Species diversity and abundance are sometimes close to those found in protected areas (Clark et al., 2009; Haurez et al., 2014), and even higher in some cases (Brodie et al., 2015; Matthews and Matthews, 2006).

Logging has many impacts on wildlife, both through the timber extraction itself and through the construction of associated infrastructures. Logging results in changes in forest structure, landscape fragmentation, noise disturbance, increased hunting pressure, human presence, and encourage the arrival of farmers or illegal miners. The impact of these disturbances on the presence and abundance of large mammals, the most vulnerable to human-induced changes (Dirzo et al., 2014) has been extensively studied (Kleinschroth and Healey, 2017; Laurance et al., 2006). However, less is known about the impacts of logging on wildlife behaviour, such as the effect on their movements.

Mainly influenced by the location of feeding and watering areas (Beirne et al., 2020; Blake and Inkamba-Nkulu, 2004), movement patterns have implications for major ecological processes (e.g. seed dispersal, gene flow; Carvalho et al., 2018; Côrtes and Uriarte, 2013) or health issues (e.g.

disease transmission; Tracey et al., 2014). Game trails are widely used by mammals to move around (Fonteyn et al., 2021). The largest are the tracks of forest elephants (*Loxodonta cyclotis*), created by the repeated movements of these giants. They form a network of intertwined tracks within the forest, the most used ones being up to three meters wide (Vanleeuwe and Gautier-Hion, 1998).

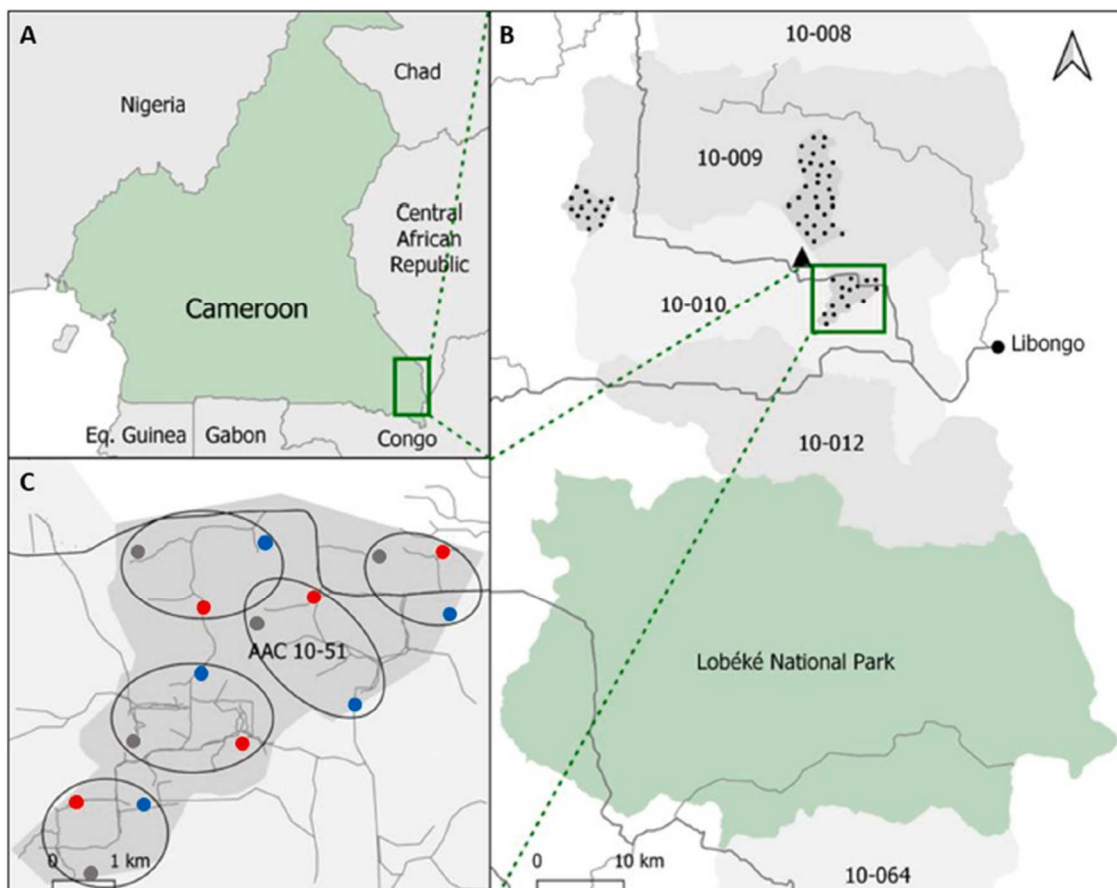
Human disturbances can alter animal movement, with effects varying according to the nature of the disturbance and the species impacted (Doherty et al., 2021). As one of the major human impacts on landscape structure, the road network could affect mammal movements. Roads present both inconveniences and opportunities for mammals. On the one hand, they present a high risk of collision with vehicles and facilitate poaching in previously inaccessible areas, in which case they would generally be avoided. On the other hand, they could be used for communication, foraging, movement, refuge, and thermoregulation (Hill et al., 2021).

Four types of roads are found in timber concessions (Estève and Killmann, 2005; Kleinschroth and Healey, 2017). They have different characteristics in terms of width, duration and intensity of use, human frequentation, connectivity, or alongside vegetation that could influence the way animals use them (Chen and Koprowski, 2019; van der Hoeven et al., 2010). Access roads connect the concession with the public transport network. A few main roads are permanent and are intended to access the whole concession. Many secondary roads are created for a limited period (generally-one year) and are used by trucks for log transport. They branch off from the main roads, are dead-end and abandoned when logging off the Annual Allowable Cut (AAC) is completed. Finally, the logs are dragged from the felling site to the log yard lying along the roads using skid trails. These are only used for the extraction of a few logs by skidders and bulldozers, so there is no side clearance or ground levelling as with the main and secondary roads.

In central Africa, the few studies that have looked at the influence of logging roads on large mammals show contrasting results. Some have found that the abundance of forest elephants, gorillas and chimpanzees increases with distance from the road (Clark et al., 2009; Laurance et al.,

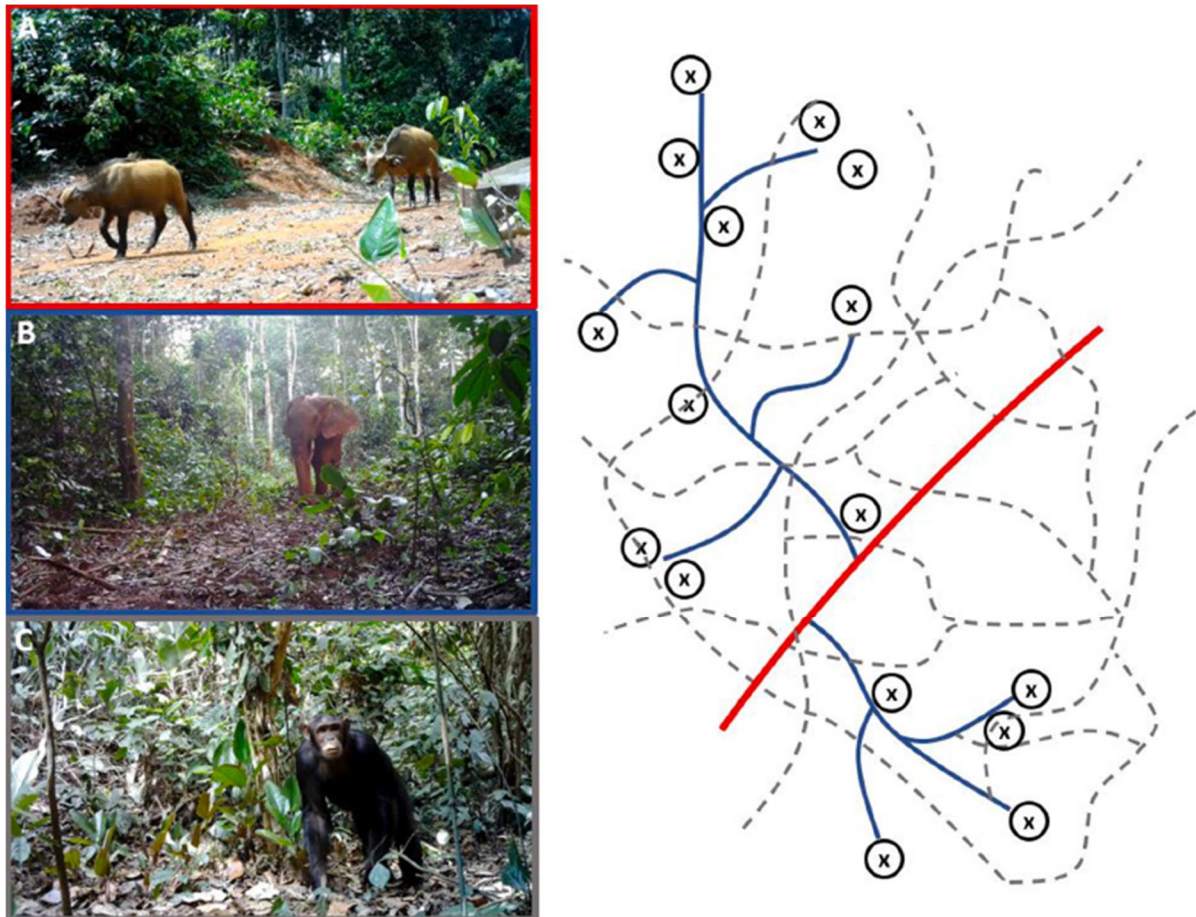
2006; Stokes et al., 2010), while Tchakoudeu Kehou et al. (2021) showed the opposite for gorillas and chimpanzees. The response of duikers also varies between studies (Clark et al., 2009; Laurance et al., 2006). Vanthomme et al. (2013) reported that the effect of roads can vary depending on the type of road. Although some studies have investigated road crossing (Blake et al., 2008; van der Hoeven et al., 2010), little is known about the use of logging roads by large mammals. In a concession where anti-poaching is a priority, and where old roads are less risky than elsewhere, we expect them to be used more than animal tracks as they would allow the animals to move and feed more easily.

Figure 1. (A) Location of the SEFAC logging concession (green frame) in Cameroon. (B) Location of the study area (black dots represent camera traps) in the SEFAC logging concession. The black triangle symbolizes Faro Safaris' anti-poaching base. (C) The experimental scheme in AAC 10-51. Dots represent camera traps (red = secondary roads, blue = skid trails, and grey = elephant paths). Black ellipses indicate the plots. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



In this study, we used camera traps (CT) to compare the use of secondary logging roads, skid trails, and elephant paths by six large mammal species emblematic of tropical rainforest: forest elephant, Western gorilla (*Gorilla gorilla*), chimpanzee (*Pan troglodytes*), leopard (*Panthera pardus*), bongo (*Tragelaphus eurycerus*) and forest buffalo (*Syncerus caffer*). In addition to comparing the use of these three types of tracks, we also investigated whether specific circumstances regarding time since last logging (less than one year vs between one and two years), temporality (day vs night), and gregariousness (alone vs in a group) could lead a species to prefer using one type of track over another.

Figure. 2. Illustration of the three types of track and theoretical representation of their arrangement in the landscape. Secondary roads are shown in red, skid trails in blue, and elephant paths in grey dotted lines. The crosses represent felled trees and the circles represent logging gaps. The photos show two buffalos on a secondary road (A), an elephant on a skid trail (B), and a chimpanzee on an elephant path (C). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



2. Material and methods

2.1. STUDY AREA

The study area falls in the logging concession granted to the SEFAC company which is certified for legality. The concession covers an area of 4060 km² and is located in south-east Cameroon (between 2°64' N and 2°86' N; 15°60' E and 15°95' E), in the Boumba-Et-Ngoko department (Fig. 1A). Annual rainfall is about 1350 mm with two distinct rainy seasons (September-November and March-May) and the mean annual temperature is 24.3 °C. Soils derived from the old African Precambrian basement are of Ferralsols type (Faure, 1989; Jones et al., 2013) with an elevation varying between 400 and 600 m and a well-developed hydrographic network. The forest massif is part of the Congo-Guinean floristic region (Faure, 1989; White, 1983) and belongs to the “semi- deciduous” type whose dominant tree families are Fabaceae, Malvaceae, and Annonaceae (Letouzey, 1985; Réjou-méchain et al., 2021). A recent camera trap survey in the Forest Management Unit (FMU) 10–012 captured 36 mammal species, reflecting the high diversity of wildlife present in the concession. Forest elephants, leopards, gorillas, chimpanzees, buffalos, bongos, and many species of duikers were detected, most of them in both recently and formerly logged areas (Tossens, 2021). Trophy hunting is practiced in some parts of the concession, called “zones d'intérêt cynégetique” (ZIC = game area). The ZICs cover 2500 km² and are managed by the Faro Safaris organization (Fig. 1B), which also contributes to law enforcement through daily control patrols. This study was conducted within the ZICs, in two FMUs north of the Lobéké National Park: FMUs 10-009 and 10-010 (Fig. 1B). In each FMU, two AACs were selected, one logged less than one year ago (AACs 09-53 and 10-51) and the other logged between one and two years ago (AACs 09-52 and 10-45). The area of AACs ranges from 20.9 to 31.0 km².

2.2. TYPES OF TRACKS AND HUMAN PRESENCE

The camera trap survey was carried out on three types of tracks: secondary logging roads and skid trails, which are artificial linear features, and elephant paths, which exist naturally in the forest and are used by many mammal species to move around whether the environment is disturbed or not (Fig. 2). In this study, elephant paths were considered as the control modality, as this is where the animals move before roads and forest tracks are opened. No logging vehicles travel through the sampled AACs, except for 10-51 which is crossed by the main road of the concession. As logging is

complete in the sampled areas, access to the secondary roads is prevented by barriers or earth mounds. Only the anti-poaching team can unlock the barriers to patrol these areas.

The distance between the sampling points and the nearest village varies between 15 and 25 km. Since there is an anti-poaching activity in the area, and several studies have shown that hunting decreases from a distance of 10 km (Abernethy et al., 2013; Foerster et al., 2011), we assumed that poaching is limited in the area and that an anthropogenic effect on the results of this study is negligible and consistent. We also considered the effect of trophy hunting to be nil, as its intensity is very low (from May to July with only eight to ten clients per season) and distributed over a much larger area than the study area. To ensure this, we conducted a preliminary analysis by modeling a linear model with three anthropogenic factors: distance to the nearest main road, distance to the nearest village, and distance to the anti-poaching base. The result confirmed our assumption since none of these three factors showed a significant effect on the detection rates of the six species studied (minimum p-value = 0.0803).

Table 1 - Factors used in the mixed linear model.

Factor	Type	n	Values	Description
Track	Fixed	3	R, S, E	Type of the track: secondary road, skid trail, elephant path
Year	Fixed	2	1, 2	Time since the last logging operation (years): 1 = less than one year, 2 = between 1 and 2 years
Time	Fixed	2	Day, Night	Time of day: day = between 6 am and 6 pm
Gregariousness	Fixed	2	Alone, Group	Gregariousness: group = more than one individual
Plot	Random	20	From 1 to 20	Plot ID

2.3. CAMERA TRAP SURVEY

Sixty CTs (Bolyguard SG 2060X, Boly, Victoriaville, QC, Canada) were deployed between February and April 2022 on the three types of tracks across the study area. Within each selected AAC, a grid of points spaced by 1 km was randomly generated using QGIS 3.22.9 software. To allocate the 60 CTs equally among the four AACs, 15 points were selected in each one (Fig. 1C). To account for habitat heterogeneity and data independence, cluster sampling was carried out and the 15 survey points were defined according to the following successive steps. First, each AAC was divided into 5 sub-

areas (plot). Then, in each plot, the road sample point was assigned by crossing the grid of random points with the known road layout. The point closest to the road was selected.

Similarly, the sample point for the skid trails was allocated using the theoretical skid trail layout. Finally, from the unattributed points of the random grid, the one furthest away from the road and track layouts was designated as the elephant path sample point. This resulted in five plots of three CTs (one per type of track) in each AAC. The position of some points was slightly modified to fit the road network, but a minimum distance of 1 km was ensured between each CT. In the field, the CTs were set up on the assigned track type closest to the theoretical point. Ten- second videos were recorded whenever movement was detected by the CT, which remained on site for approximately- six weeks.

2.4.DATA ANALYSES

All videos from the camera traps were processed using Timelapse 2.2.4.0 software. Videos with one of the six species studied were selected and the number of individuals was recorded. Two successive videos were considered independent detection events if the videos were recorded at an interval of at least 30 min (Fonteyn et al., 2021). As an event may consist of several videos, and individuals are sometimes difficult to recognize from one video to another, the number of individuals attributed to an event corresponds to the maximum number of individuals observed on a single video. Two CTs that only worked one day due to a malfunction were removed from the dataset. The relative abundance index (RAI) of every studied species was calculated for each CT as follows:

$$RAI = \frac{\text{Number of independent events}}{\text{Number of camera.days}} \times 100$$

We adjusted the RAI when testing for differences between diurnal and nocturnal activity by dividing the number of camera days by two, assuming an equal length of day and night in our study area. This index was then related to the five factors described in Table 1. As one of those factors had a random effect, we fitted a mixed linear model to test the effect of these five factors on the RAI of each species. Analyses were performed using R software (R-Development-Core-Team), version 4.2.2, with the “lme4” (version 1.1–31), “car” (version 3.1–1), “ggplot2” (version 3.4.0), and “emmeans” (version 1.8.2) packages.

Only the fixed factors and all their interactions, plus the random plot factor, were used to fit the model. Factors and interactions with a significant effect were subjected to a comparison of means test using a Tukey-adjusted P value (function “emmeans”). The tests were considered statistically significant if the p-value < 0.05. As the leopard was only detected twice, analyses were not conducted for this species.

Figure 3. Boxplots of the Relative Abundance Index (RAI) by type of track for each species. R = secondary roads, S = skid trails, E = elephant paths. Species to the right of the dotted line were observed <50 times, so the results should be interpreted with caution.

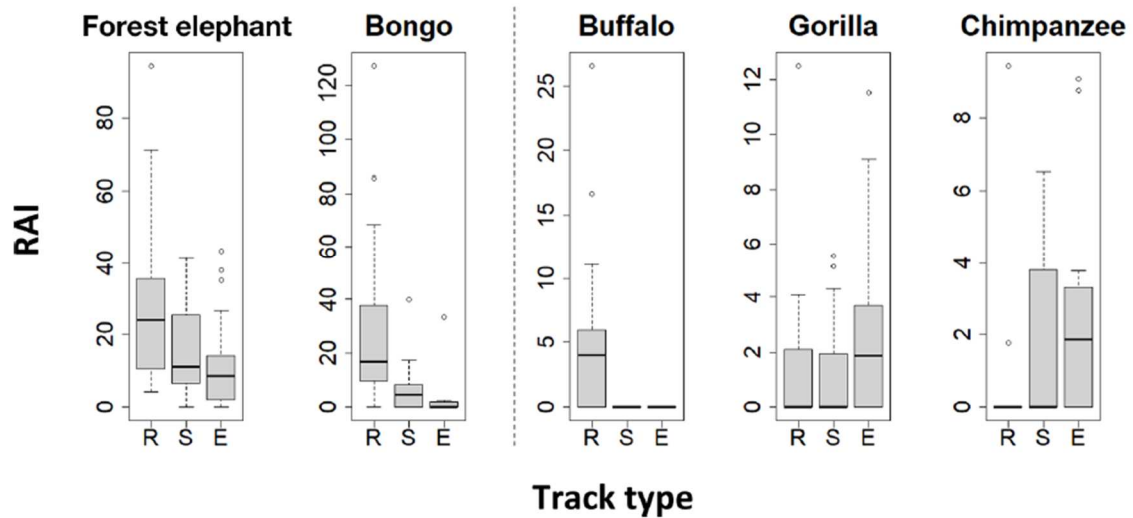
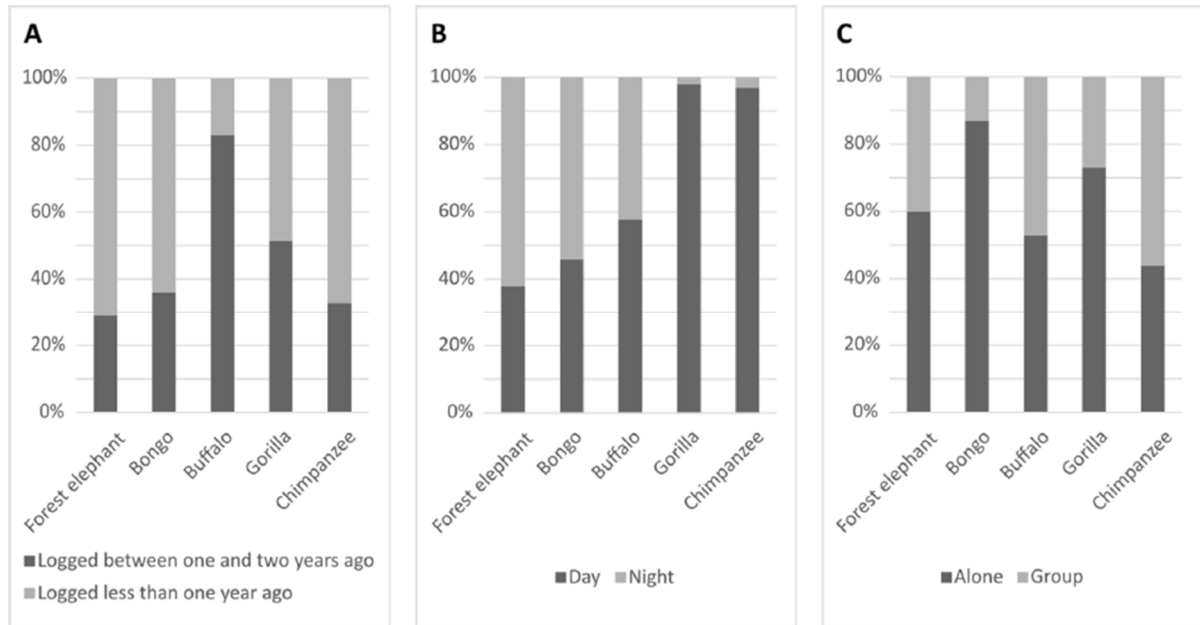


Figure 4. Percentage of independent events observed for each modality of the fixed factors year (A), time (B), and gregariousness (C).



3. Results

3.1. CAMERA TRAP SURVEY

The total sampling effort was 2457 camera.days (mean = 42.4 per CT). Of the 10,199 animal detections, 3522 concerned the six species studied resulting in 904 independent events. Forest elephants and bongos accounted for 53 % and 33 % of independent events, respectively. Other species were less represented (about 5 % each, except leopard = 0.2 %). The findings for these species should therefore be considered with caution.

Forest elephants, bongos, and buffalos were mostly (exclusively for the latter) observed on the secondary roads, while no preference was found for gorillas and chimpanzees (Fig. 3). Only two captures of leopard were recorded, on a secondary road, at night, and showing a solitary individual. Gorillas and chimpanzees were almost exclusively diurnal while forest elephants were rather nocturnal (Fig. 4B). Bongos and buffalos were active both at night and during the day (Fig. 4B). Bongos and forest elephants were mostly seen alone, while other species were seen in groups as well as solitary (Fig. 4C). The maximum number of individuals seen together is six for bongos; five for forest elephants, gorillas, and buffalos; and three for chimpanzees. While buffalos were mainly observed in the AACs logged more than one year ago, forest elephants were more detected in the areas logged more recently and no trend was apparent for the other species (Fig. 4A). Most of the videos showed animals walking or foraging.

3.2.MIXED LINEAR MODEL

The results of the mixed linear model used to test the effects of the factors time, group, year, and plot on the use of the three track types are summarized in Table 2.

As the standard deviation of the factor plot is lower than the residual standard deviation for each species, it can be assumed that there is no effect of the random factor. In any situation, gorillas and chimpanzees did not use one type of track significantly more than another. The preference of forest elephants, bongos, and buffalos for secondary logging roads cannot be generalized to the entire study area. Indeed, forest elephants were mainly detected on the roads only at night, in the AACs logged less than one year ago. In other cases, they have been observed as often on roads as on skid trails and elephant paths (Fig. 5A). For bongos, it is also in the most recently logged AACs that they seemed to show a preference for roads (Fig. 5C). They were mainly used by solitary individuals, while groups were equally observed on all three types of tracks (Fig. 5D). Although buffalos were only observed on the roads, in the areas logged less than one year ago the difference is not significant with the skid trails and the elephant paths, probably due to an insufficient number of observations (Fig. 5B).

Table 2 Significance of the effect of the factors track, year, time, gregariousness, and their interactions on the RAI of the 5 species studied. ***p-value < 0.001; **p-value < 0.01; *p-value < 0.05; °p-value < 0.1; NS = Not significant. Only factors and interactions with a p-value < 0.1 for at least one species are mentioned. The standard deviation is given for the factor plot and the residuals. As indicated by “cfr Fig. 5”, significant interactions are illustrated in Fig. 5. The tests were considered statistically significant if the p-value < 0.05. Buffalo, gorilla and chimpanzee were observed less than 50 times, so the results should be interpreted with caution for these species.

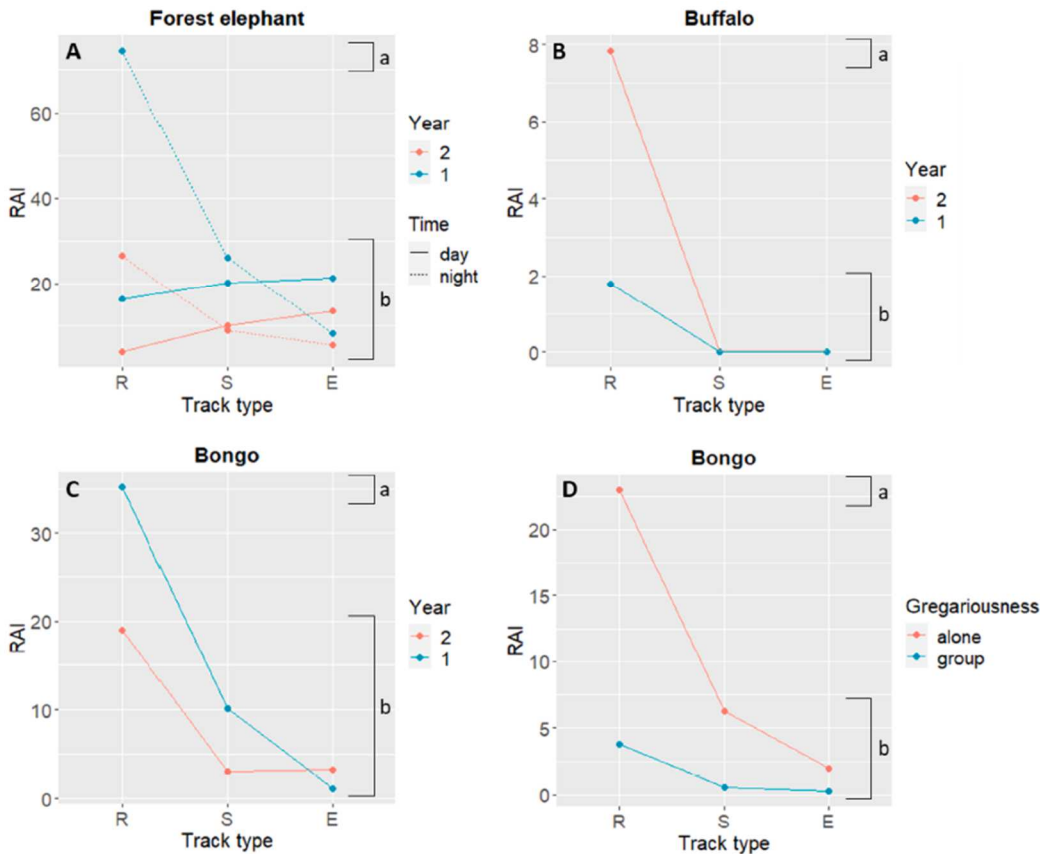
Factors	Species				
	Forest elephant	Bongo	Buffalo	Gorilla	Chimpanzee
Track	***	***	***	NS	NS
Year	***	°	°	NS	NS
Time	**	NS	NS	Day > Night***	Day > Night***
Gregariousness	Alone > Group**	***	NS	NS	NS
Track*Year	***	* cfr Fig. 5C	** cfr Fig. 5B	NS	NS
Track*Time	***	NS	NS	NS	NS
Year*Time	*	NS	NS	NS	NS
Track*Gregariousness	NS	*** cfr Fig. 5D	NS	NS	NS
Time*Gregariousness	NS	NS	NS	NS	NS
Track*Year*Time	* cfr Fig. 5A	NS	NS	NS	NS
Track*Year*Gregariousness	NS	NS	NS	NS	°
Plot	0.6674	0.8107	0.1570	0.0000	0.03482
Residual	2.8540	3.8917	0.7881	0.7151	0.59591

4. Discussion

Although several studies have assessed the impact of roads on wildlife by relating their abundance at different distances from the road (Clark et al., 2009; Laurance et al., 2006; Lhoest et al., 2020), few studies have addressed the use of logging tracks by large mammals in central Africa. By investigating the use of logging roads and skid trails by six large mammals, this CT survey conducted for six weeks in the SEFAC timber concession (south-eastern Cameroon) contributes to a better understanding of how the creation of logging roads affects the movements of large mammals.

Gorillas, chimpanzees, forest elephants, bongos, and buffalos do not seem to avoid secondary roads and skid trails as they were observed on them as much as on elephant paths. Secondary roads were even preferred by buffalos and, in specific conditions, by forest elephants (at night in the most recently logged areas), and bongos (when traveling alone and in the most recently logged areas). For buffalos, it is not surprising as they are known to prefer open areas and mainly stay near old roads or logging tracks (Bekhuis et al., 2008; Blake, 2002). However, our results contrast with studies that have found a positive correlation between distance to the road and the abundance of several species, including forest elephants, gorillas, and chimpanzees (Clark et al., 2009; Laurance et al., 2006). In addition to differences in experimental design, we suspect that differences in road type may explain these divergent results. Indeed, the roads that are usually studied in previous works are active, whereas in this study we sampled closed secondary roads.

Figure 5. Graphical representation of the interactions *Track*Year*Time* for the forest elephant (A), *Track*Year* for the buffalo (B) and the bongo (C), and *Track*Gregariousness* for the bongo (D). R = secondary roads, S = skid trails, E = elephant paths. Year-1 = logged less than one year ago, Year-2 = logged between one and two years ago. Points within the same group (a or b) do not have a significantly different RAI.



Therefore, our results underline not only the importance of closing roads after logging is finished, as many species use them, but also the relevance of characterizing roads (activity: active or closed; type: main, secondary or other type of road; width; surfacing: latherite, soil...; canopy structure over the road: open or closed canopy) when studying their impact on wildlife. The number of leopard records was too low to detect a preferential use of one type of track. Nevertheless, it is not surprising that the only two detections were on roads, as Felids are known to use them (Tobler et al., 2018).

Two major reasons may explain why large mammals use logging roads extensively. First, the development of pioneer vegetation along roadsides makes them attractive forage areas. Their use for feeding purposes has been observed for elephants (Barnes et al., 1997; Nummelin, 1990), gorillas (Matthews and Matthews, 2004; Morgan et al., 2018), chimpanzees (Bortolamiol et al., 2016), and buffalos (Bekhuis et al., 2008), even if the plant species sought differ from one animal species to another. This could also be the case for bongos as they are known to feed on herbaceous (Klaus-Hügi et al., 1999). The results of our CT survey are in line with this, as it was not rare to see forest elephants, buffalos, and bongos feeding on roadside vegetation in the videos. However, no such observation

was recorded for gorillas and chimpanzees, perhaps due to the elusiveness of their sightings. Actually, unlike the other species, gorillas and chimpanzees observed on a road were mostly just crossing it. It would therefore be worthwhile in the future to differentiate between the types of observations recorded (crossing, feeding, travelling). The second reason why large mammals may use roads is that they facilitate the movement of animals by providing a less obstructed path and thus allowing them to move faster and follow less tortuous trajectories (Roever et al., 2010) to reach points of interest to wildlife such as fruit trees, savannas, salt pans, and water. A third reason may be that the main paths used by elephants to travel long distances, called boulevards, are along mountain ridges (Vanleeuwe and Gautier-Hion, 1998), i.e. where roads are usually open. Roads may therefore have been built where there were already well-used elephant tracks. However, this reason does not apply to our study area, where the terrain is relatively flat and roads have been opened in a fairly systematic way.

Many other mammal species use roads, sometimes for additional reasons (Hill et al., 2021). For example, many species mark signals on roads to communicate as these are more visible in open areas (Mullu, 2015). Roads can serve as refuges for some species when their predators or competitors avoid them (Muhly et al., 2011). Loose soil on roadsides may attract some species as it makes burrowing easier (Brock and Kelt, 2004). In areas where elephant abundance has decreased, duikers move on logging roads when they usually moved on elephant paths (Naude et al., 2019).

Although forest roads were not avoided in our study area, in many other places they constitute a considerable barrier to wildlife (Blake et al., 2008; Laurance et al., 2009). Moreover, they provide new access for humans to remote areas, resulting in higher poaching pressure in their surroundings, which could explain, for example, why duikers and apes avoid crossing logging roads in some areas (van der Hoeven et al., 2010). In our case, anti-poaching measures and the fact that the study area is not close to villages could explain why secondary roads are less avoided (sometimes favored). Several studies have reported lower risk on roads within protected areas or private property where surveillance is adequate (Blake et al., 2008; Laurance et al., 2006). Our results support this and underline the importance of closing roads after logging and promoting law enforcement within timber concessions to reduce the risk of wildlife-human encounters.

A change in movement patterns could have important ecological consequences, notably for forest regeneration. Indeed, forest elephants and gorillas are known to play a crucial role in seed dispersal

(Campos- Arceiz and Blake, 2011; Haurez et al., 2018). A change in their travel habits would imply that they deposit their feces elsewhere, which could affect the distribution of many tree species whose seeds are dispersed by large frugivores. The high soil compaction on secondary roads could be an obstacle to the establishment of seedlings growing from seeds dispersed on these roads (Corria-Ainslie et al., 2015). On the other hand, dispersal to open areas could provide ideal conditions for the development of light-demanding species and thus contribute to the restoration of open tracks. Species that are mostly dispersed by forest elephants, bongos, or buffalos would probably be the most impacted as they seemed to travel a lot on roads. However, the use of secondary roads by gorillas was limited in our study, so the effects might be less significant for the species they dispersed.

The CT data also showed that forest elephants and bongos were observed more in areas logged less than one year ago, more specifically on secondary roads (and at night for forest elephants). Replicating this study in other parts of the concession would provide more data to examine whether this is a recurring pattern. As logging tracks change over time as they are colonized by vegetation (Kleinschroth and Healey, 2017), the time since the last logging operation likely has a significant effect on their use by large mammals. In this study, the sampled AACs have been logged at only one-year intervals. Sampling areas with a wider range of logging histories would allow for a better understanding of the evolution of wildlife behavior over time. Wrege et al. (2010) showed that forest elephants were more active at night in areas disturbed by human activities. Our results are consistent with this, as we found higher RAI of forest elephants at night in the most recently logged AACs.

Although this study provides new information on the use of logging roads by large mammals in south-eastern Cameroon, the number of observations limits the interpretation of the results. Increased sampling effort over time (longer periods and different seasons) and space (other concessions and areas with more contrasting logging histories) would provide a better understanding of how large mammals use space over time in logged forests.

5. Conclusions

This study aimed to investigate the influence of the creation of secondary roads and skid trails by logging operations on the movements of six large mammal species emblematic of the dense

rainforests of central Africa. Using camera traps, we showed that in a concession of south- eastern Cameroon, large mammals used secondary roads and skid trails as much as elephant paths. Buffalos even used roads more than the other types of tracks and this was also observed in specific areas for forest elephants (though only at night) and bongos. None of the species avoid roads and skid trails, nor do they perceive them as a barrier in the study area. Nonetheless, this finding cannot be generalized to all roads, as we only sampled secondary forest roads that are now closed to vehicles and far from human settlements (more than 15 km). However, our results indicate that the use of logging roads by large mammals should be a concern in wildlife management and protection measures. They also highlight the importance of closing access to roads once logging is complete, which is already a requirement in sustainable management- certified concessions.

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CRediT authorship contribution statement

Morgane Scalbert: Conceptualization, Methodology, Validation,

Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition. **Quentin Stiernon:** Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Sebastien Franceschini:** Validation, Formal analysis, Writing – review & editing, Visualization. **Cedric Vermeulen:** Conceptualization, Validation, Writing – review & editing, Supervision. **Yves Brostaux:** Methodology, Validation, Formal analysis, Writing – review & editing, Visualization. **Rene Ngwet:** Resources. **Jean-Louis Doucet:** Conceptualization, Methodology, Validation, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Rene Ngwet reports a relationship with SEFAC S.A. that includes: employment.

Data availability

Data will be made available on request.

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