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Seasonal and habitat-dependent variation in the survival time of antelope, buffalo, and gorilla dung in the Congo Basin Rainforest of South-East Cameroon.

Neba Ngwa Akongnwi[1,2], Djieto Lordon Champlain[1], Massussi Jacques Anselme[3], Hongo Shun[4], Towa Olivier William Kamgaing[4], Akoutou Mvondo Etienne[2]

[1]Department of Animal Biology, Faculty of Science – University of Yaounde 1, Cameroon
[2]Institute of Agricultural Research for Development (IRAD) Cameroon
[3]African Wildlife Foundation (AWF)
[4]Center for African Area Studies Kyoto University Japan.

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Corresponding Author

Neba Ngwa Akongnwi

E-mail: *akongnwi2005@gmail.com*

Tel: *+237671365720*

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ABBREVIATIONS

FMU : Forest Management Units
UFA : Unité Forestière d'Aménagement

ABSTRACT

Dung-based surveys are widely used to estimate the abundance and population density of elusive forest mammals. The accuracy of these survey depends on reliable estimates of dung density, defaecation rate, and dung survival (decay) time, which may vary with season and habitat. This study evaluated the survival time of dung from antelopes, buffaloes, and gorillas in the Congo basin rainforest of South-East Cameroon, comparing less disturbed forests represented by the Nki and Boumba Bek national parks with more disturbed forests represented by Forest Management Unit (FMU) 10018. A total of 336 dung piles were monitored during the long rainy season (2022), short rainy season (2023), and long dry season (2024) until complete decomposition. Dung survival time differed significantly among mammal species, seasons, and habitats ($P<0.05$). For all three mammal species, dung persisted longest during the long dry season, and shortest during the short rainy season. In the short rainy season, mean dung survival time was 2.44 and 2.34 days for antelopes in the park and FMU, respectively, 1.35 and 1.17 days for gorillas, and 22.07 days for buffaloes in the park. Across habitats and seasons, gorilla dung exhibited the shortest overall mean survival time (2.01 days), whereas buffalo dung persisted for the longest period. Field observations indicates that dung removal by dung beetles was the principal driver of dung disappearance, although rainfall and other environmental factors also contributed to decomposition. The findings demonstrated that dung survival time varies substantially among mammal species, habitats and seasons. Consequently, habitat and season specific estimates of dung-based survival time are essential for improving the accuracy of dung-based estimates of mammal abundance and population density in the Congo basin rainforest of Central Africa.

INTRODUCTION

Dung is an important component of terrestrial ecosystems because it returns undigested nutrients to the soil, thereby contributing to nutrient cycling and ecosystem productivity (Haynes and Williams, 1993; Wu and Sun, 2010; Jacob and Jonathan, 2018). In addition to enriching the soil with essential nutrients such as nitrogen, phosphorus, and potassium, dung provides food and breeding resources for a wide range of invertebrates, particularly dung beetles. It also serves as a valuable ecological indicator for monitoring wildlife population, especially in tropical rainforest where direct observations of mammals are often difficult (Towa et al., 2022).

Large and medium-sized forest mammals are commonly surveyed using indirect methods based on dung, nests, tracks or other field signs. Such approaches have been widely applied to estimate the abundance and distribution of numerous wildlife species including deer (Marques *et al*. 2001), wild boars (Acevedo et al., 2006), kangaroos (Vernes, 1999) wallabies (Johnson and Jarman, 1987), cassowaries (Westcott ,1999), elephants (Barnes and Jensen, 1987), antelopes and other elusive mammals inhabiting tropical forests. Indirect survey methods are particularly valuable in dense rainforests where poor visibility and secretive behaviours of wildlife limits the effectiveness of direct observations. Consequently, dung counts have become one of the most widely used techniques for estimating abundance and population density in tropical African forest (Koster and Hart, 1988; Nummelin, 1990; White, 1994; Fitzgibbon et al., 1995; McCoy, 1995; Muchaal and Ngandjui, 1999; Ngandjui and Blanc, 2000; Rovero and Marshall, 2004; Nielsen, 2006; Nathalie van Vliet et al., 2008; Elenga et al., 2020; and Towa et al., 2022).

Reliable estimation of animal density from dung counts requires accurate information on three key parameters: dung density, defaecation rate, and dung survival (decay) time (White and Edwards, 2000; Marques et al., 2001; Thomas et al., 2010; and Towa et al., 2022). Among these parameters, dung survival time is particularly important because it determines the length of time dung remains detectable in the field. Failure to count for variation in dung decay rates can lead to bias estimates of animal abundance and density. However, dung survival time is influenced by several environmental factors including: seasons, habitat characteristics, rainfall, temperature and activities of decomposer organisms such as dung beetles (Laing et al., 2003).

Previous studies conducted in central African rainforests have demonstrated substantial seasonal variation in dung survival time. Nathalie van Vliet et al. (2008) reported that dung beetle was the principal factor driving dung decomposition in north-eastern Gabon, where dung survival time was shortest during the short

rainy season. Similarly, Koster and Hart (1988) estimated mean dung survival times of approximately 18 and 21 days for blue and red duikers, respectively, in the Democratic Republic of Congo. More recently, Towa et al. (2022) estimated seasonal dung survival times for blue and red duikers in Nki National Park, Cameroon, and demonstrated that dung persisted considerably longer during the dry season than during the long rainy seasons.

Despite these important contributions, previous studies have focused primarily on duiker species, with little information available for other ecological important forest mammals such as gorillas and buffaloes. Furthermore, the influence of habitat disturbance on dung survival time has received limited attention. Understanding how dung persistence varies among mammal species, seasons and habitat types is essential for improving the accuracy of dung-based wildlife surveys and population estimates.

The present studies therefore investigated the survival time of dung produced by antelopes, gorillas, and buffaloes under contrasting environmental conditions in the Congo basin rainforest of south-east Cameroon. Specifically, the study compared dung survival time between less disturbed forests represented by the Nki and Boumba Bek National parks and more disturbed forests represented by the Forest Management unit (FMU) 10018 across three seasons. We hypothesized that dung survival time differs significantly among mammal species, seasons, and habitat types because of variation in environmental conditions and decomposer activity. The findings provide habitat- and season- specific estimates of dung survival time that improve the accuracy of dung-based assessments of mammal abundance and contributes to more effective wildlife monitoring and conservation in the Congo basin rainforest of Central Africa.

MATERIALS AND METHOD

Study site

This study was conducted in the Congo basin rainforest of south-eastern region of Cameroon, within two contrasting forest habitat types to evaluate the influence of habitat disturbance on dung survival time. The first habitats type comprises a less disturbed tropical rainforest represented by the Nki and Boumba Bek national parks, while the second comprised a more disturbed forest represented by the forest management unit (FMU) 10018.

The Nki National Park

Located in the East Region of Cameroon, the Nki national park lies between 2^{o} 25' N and 14^{o} 25' E, with a surface area of about 309,362 ha. The climate is equatorial with four seasons a major dry season that runs from December to February, a minor rainy season from March to June, a minor dry season from July to August, and a major rainy season from September to November (Ekobo, 1998; Towa et al., 2022). The mean annual rainfall is 1660mm and the mean temperature is 23^{o}C (Towa et al., 2022). The vegetation is a mixture of evergreen and semi-deciduous forest (Letouzey, 1985). The biodiversity of the park is very rich; there are approximately 180 species of mammals with about 34 of them being large mammals (Fig 1).

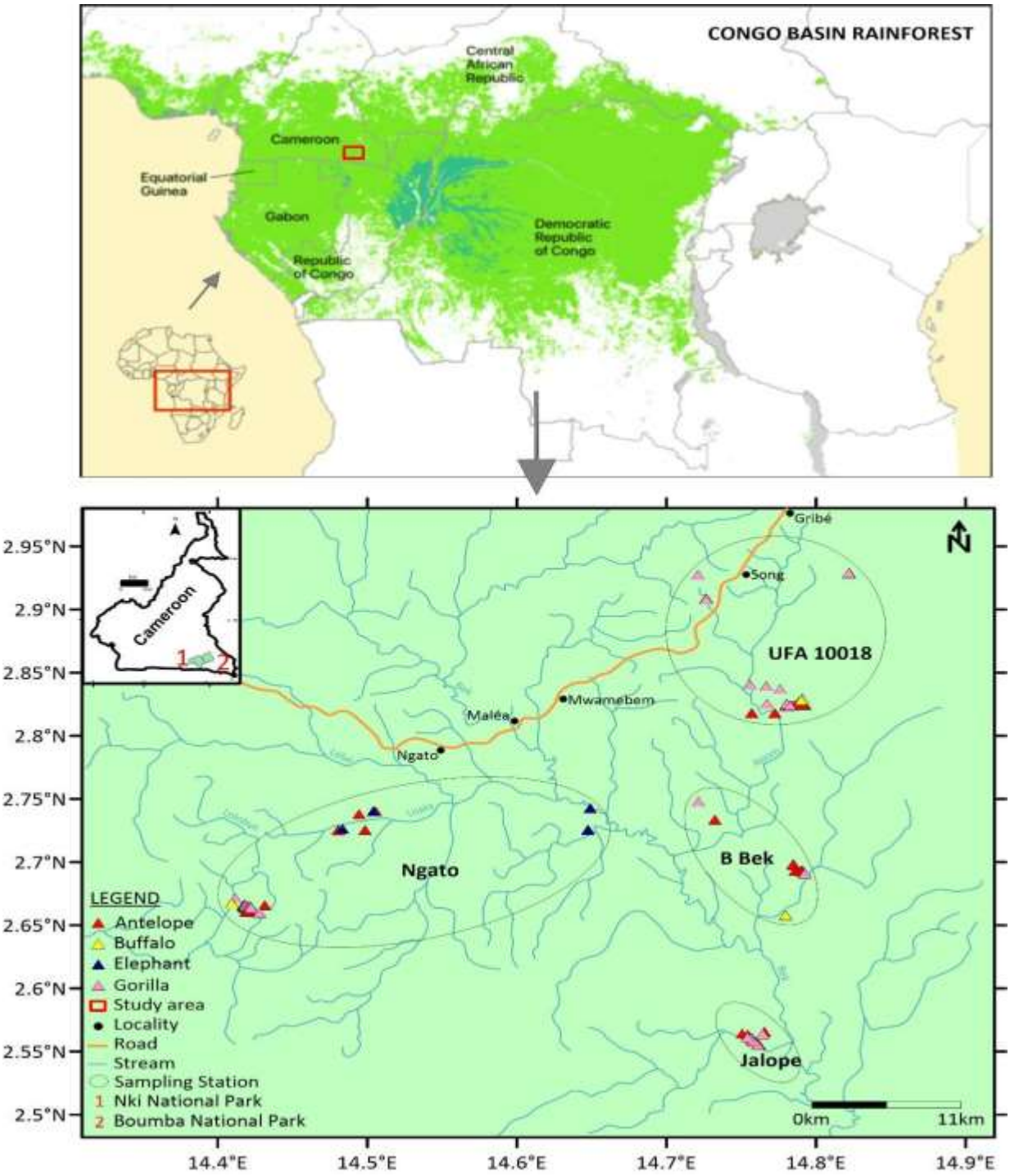

Figure 1. Study area and spatial distribution of dung sampling stations across localities in the south-eastern Cameroon sector of the Congo Basin rainforest. Sampling stations are classified according to dung producer (antelope, buffalo, and gorilla).

The Boumba National Park

Located in the East region of Cameroon, the Boumba Bek national park lies between 02º13'N and 15º42'E, with a surface area of 238,255ha (MINFOF, 2011). Like in the Nki National Park the climate of this region is equatorial with four seasons: a major dry season that runs from December to February, a minor rainy season from March to June, a minor dry season from July to August, and a major rainy season from September to November. The mean annual rainfall is 1550mm and the mean temperature is 24ºC. The vegetation is a mixture of evergreen and semi-deciduous forest interspersed by maranthacae forest type, large swamps, and forest clearing which attracts several mammalian species notably gorillas, buffaloes, elephants and medium sized

antelopes. The Boumba Bek national park is known for its rich biodiversity especially forest mammals with about 34 identified species (MINFOF, 2010; Nzooh et al., 2016) **(Fig 1).**

The Forest Management Unit (FMU or UFA) 10018

FMU 10018 is located in the East Region of Cameroon adjacent to the Boumba Bek National park. The area consists of selective logged and regenerating secondary forest and represents a more disturbed habitat than the protected national parks. Commercial logging has modified the forest structure, making the FMU suitable for evaluating the effects of habitat disturbance on dung survival and decomposition dynamics (Fig 1).

METHODOLOGY

Data collection

Field surveys were made along permanent trails within the forest of the different localities to identify dung (faecal matter) from buffaloes, gorillas and antelopes. Dung that were identified were ad libitum fresh and intact faeces of not more than one-day old. Although it was not possible to know the exact time of defaecation, experienced trackers and researchers could reasonably estimate the age (Viquerat et al.,2013; Elenga et al., 2020; and Towa et al., 2022).

At the point of identification of the dung, the date was noted, the GPS coordinates taken; and the position marked. Moreover, each identified dung was assigned an identified code. For antelopes, the acronym ANT used (e.g. ANT 1, ANT 2, and ANT 3 etc.), indicated the first, second and third antelope dung respectively identified for a particular season. For gorillas, the acronym GO was used, and for buffaloes, the acronym BUF was used.

All identified and marked dung pats were allow exposed to observe the degradation (decay) process, and the morphological evolution of the dung pat, in order to estimate the dung survival time (decay time). Dung piles were visited every day to check whether they had disappeared or still remained.

For each identified dung, photographs were taken using the Nikon camera from the day of identification to the day of disappearance of each dung pat. The photographs were used to classify each identified dung pile into the different stages of dung decay process. The dung piles were classified into different stages of decay according to Barnes and Jensen (1987). The dung piles were considered fully decayed when they reach stage E **(Table 1)**.

This experiment was repeated three times during the long rainy season of 2022 (September 2022 to November 2022), the short rainy season of 2023 (April 2023 to July 2023), and the long dry season of 2024 (December 2023 to February 2024); and within two forest sub – habitats i.e. the park and the Forest Management Unit or FMU.

Table 1. Stages of dung decay as per Barnes and Jensen (1987)

Stage	Condition of dung pile
A	Pile intact, very fresh, moist, with odour
B	Pile intact, fresh but dry, no odour
C1	More than 50% of the pile distinguishable, some has disintegrated
C2	Less than 50% of the pile distinguishable, the rest has disintegrated
D	Pile completely disintegrated and forms a flat mass.
E	Decay to the stage where it would be impossible to detect at 2m range in the undergrowth, and would not be seen unless directly underfoot.

Data analysis

Dung survival time was calculated as the number of days between the initial identification of fresh dung pile and its complete disappearance (decay stage E). Mean survival time, standard deviation(SD), minimum and maximum survival time were computed for each mammal species, season, and habitat.

The effect of season, habitat, and mammal species on dung survival time were evaluated using analyses of variance (ANOVA). Where significant differences were detected ($P<0.05$), pairwise comparisons among means were performed using Turkey Honest Significant Difference (HSD) test.

All statistical analyses were conducted using R version 4.5.1. and statistical significance was assessed at the 5% probability level.

RESULTS

Number of dung piles monitored

A total of 336 fresh dung piles were identified and monitored throughout the study. Of these 120 were recorded during the long rainy season, 106 during the short rainy season, and 110 during the long dry season. Across habitats, 230 dung piles were monitored in the park (less disturbed forest), whereas 106 were monitored in forest management unit (FMU) (more disturbed forest). In the park the monitored dung comprised 116 dung of antelope, 62 gorilla dung, and 52 buffalo dung while the FMU contained 40 dung of antelope, 60 gorilla dung, and 6 buffalo dung piles (Table 2).

Table 2: number of dung per mammal per habitat per season

Mammals	Habitat	Seasons		
		LDS	LRS	SRS
Antelope	**Park**	28	41	47
Buffalo	**Park**	15	26	11
Gorilla	**Park**	27	22	13
Antelope	**FMU**	22	05	13
Buffalo	**FMU**	0	06	0
gorilla	**FMU**	18	20	22
Total		**110**	**120**	**106**
Grand total		**336**		

Effect of season on dung survival time

Season significantly (P<0.05) influenced the survival time of dung produced by antelopes, buffaloes, and gorillas (sum sq = 134.6; Df = 2; F = 32.741; Pr (>F) = 1.123e – 4). Across all mammal species, dung persisted longest during the long dry season and shortest during the short rainy season. For antelopes, the mean dung survival time during the short rainy season was 2.44 days in the park and 2.34 days in the FMU. During the long dry season, most antelope dung remained undecomposed throughout the monitoring period; consequently, complete survival time could not be estimated. During the long rainy season, mean survival time was 3.50days in the park and 4.44 days in the FMU.

Gorilla dung exhibited the shortest survival times among the three mammal species. During the short rainy season, mean survival time was 1.35 days in the park and 1.76 days in the FMU. Survival time increased during the long rainy season to 2.50 days and 1.76 days, respectively, and was longest during the long dry season – 2.56 and2.53 days respectively.

Buffalo dung persisted substantially longer than the dung of antelopes and gorillas. In the park, mean survival time was 24.71 days during the long rainy season and 22.07 days during the short rainy season. As antelope dung, buffalo dung, did not completely decompose during the monitoring period in the long dry season, preventing estimation of complete survival time (Tables 3 and 4; Figures 2-4).

Table 3. Mean ± SD survival time, minimum and maximum values of antelopes, gorillas and buffaloes in the primary or less disturbed forest (Park), of south-east Cameroon.

Mammal/Season	Survival time (days)			Sample size
	Mean ± SD	Min	Max	
Antelope				
Long dry season	*	*	*	50
Long rainy season	3.50 **±** 1.30	1	6	41
Short rainy season	2.44 **±** 1.15	1	5	47
Gorilla				
Long dry season	2.56 **±** 1.06	1	4	27
Long rainy season	2.50 **±** 0.58	1	3	22
Short rainy season	1.35 **±** 0.48	1	2	13
Buffalo				
Long dry season	*	*	*	15
Long rainy season	24.71 **±** 1.98	17	28	26
Short rainy season	22.O7 **±** 2.54	18	-	11

The asterisk (*) means dung was identified but did not disappear completely during the period set for data collection.

Table 4. Mean ± SD survival time, minimum and maximum values of antelopes, gorillas and buffaloes in the secondary or more disturbed forest (FMU), of south-east Cameroon.

Mammal/Season	Sample size	Survival time (days)			Probability
		Mean ± SD	Min	Max	
Antelope					
Long dry season	22	*	*	*	P<0.05
Long rainy season	05	4.44 ± 1.84	1	6	
Short rainy season	13	2.34 ± 2.26	1	2	
Gorilla					
Long dry season	18	2.53 ± 0.80	1	4	P<0.05
Long rainy season	20	1.76 ± 0.43	1	2	
Short rainy season	22	1.17 ± 0.49	1	3	
Buffalo					
Long dry season	-	-	-	-	P<0.05
Long rainy season	6	21.03 ± 0.67	20	22	
Short rainy season		-	-	-	

The dash (-) indicates that, dung was not seen during that season while the asterisk (*) means dung was identified but did not disappear completely during the period set for data collection

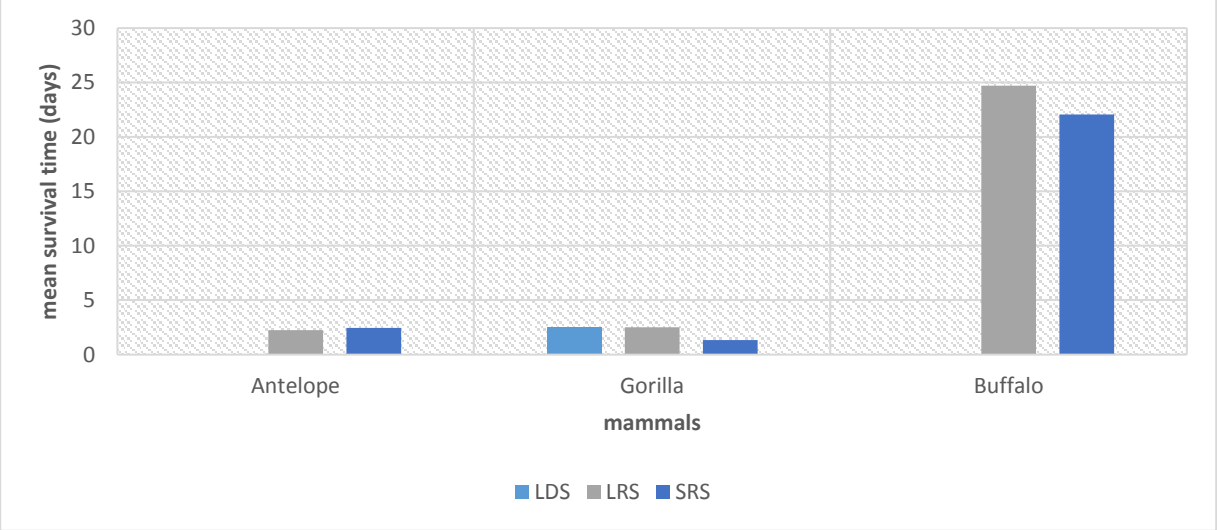

Figure 2. Mean survival time as influenced by seasons in the less disturbed forest or park.

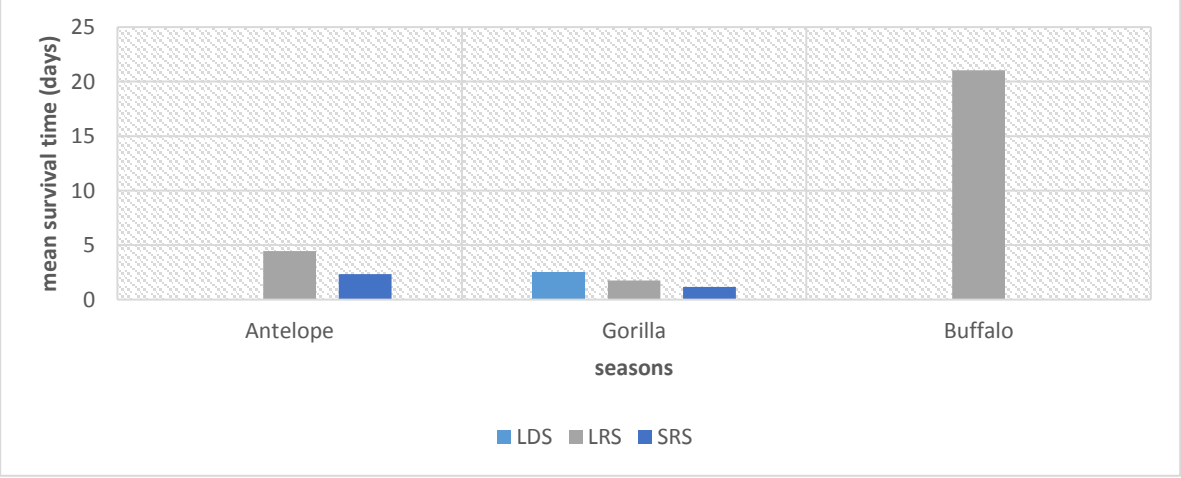

Figure 3. mean survival time as influenced by seasons in the more disturbed forest or FMU. Buffalo dung were not found during the short rainy and long dry, seasons in the FMU.

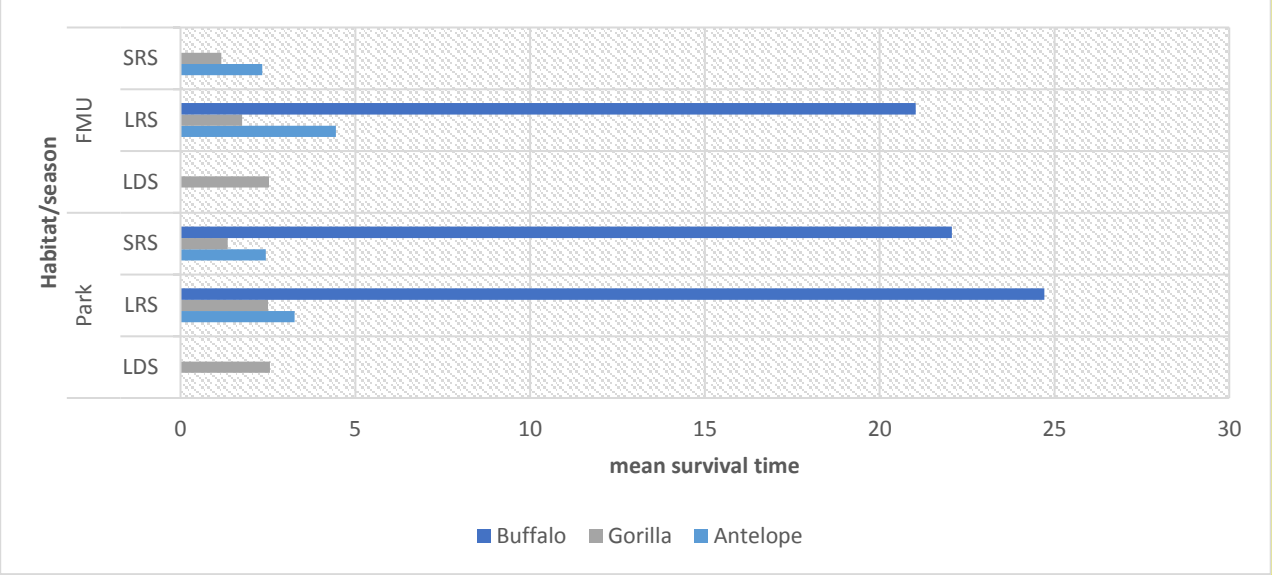

Figure 4. Mean survival time as influenced by habitats (less disturbed forest or park, and more disturbed forest or FMU).

Effect of habitat on the dung survival time

Habitat had a significant (P<0.05) effect on dung survival time for all three mammal species (sum sq = 347.2; Df = 1; F = 33.789; Pr(<F) = <2.2e – 16).

For antelopes, dung survival time was shorter in the park (3.50 days) than in the FMU (4.44 days) during the long rainy season, conversely, during the short rainy season, survival time was slightly shorter in the FMU (2.34 days) than in the park (2.44 days)**.**

Gorilla dung consistently decomposed more rapidly in FMU than in the park across all seasons. mean survival time in FMU was 2.53 days during the long dry season, 1.76 days during the long rainy season, and 1.76 days during the short rainy season.

For buffaloes, dung survival time was shorter during the long rainy season in the FMU (21.03 days) than in the park (24.71 days). Buffalo dung was not encountered in the FMU during the long dry and short dry seasons (Tables 3 and 4; Figures 2-4).

General pattern of dung survival

Comparison among mammal species revealed marked differences in dung persistence. Gorilla dung consistently exhibited the shortest survival time, whereas buffalo dung persisted for the longest duration. When data from all seasons and habitat were combined, the overall mean survival time were 2.01 **±** 0.94 days for gorillas, 3.13 **±** 1.68 days for antelopes, and 23.43 **±** 2.42 days for buffaloes **(**Table 5 and Fig 5).

Pairwise comparison showed that buffalo dung survived significantly longer than both antelope and gorilla dung (SE = 0.11; t = 58; Pr(>t) = <2e - 16), while gorilla dung decomposed significantly faster than antelope dung (SE = 0.10; t = -73.57; Pr(>t) = <2e - 16).

Field observations indicates that dung removal by dung beetles was the principal cause of dung disappearance, although rainfall and other environmental factors also contributed to decomposition. During the long dry season, only gorilla dung decomposed completely within the monitoring period, whereas antelope and buffalo dung remained undecomposed by the end of data collection.

Table 5. Generalized Mean ± SD survival time, minimum and maximum values of antelopes, gorillas and buffaloes not taken into consideration seasons and habitats.

Mammals	Sample size	Mean ± SD	Min	Max	Probability
Antelopes	156	3.13 **±** 1.68	1	6	P<0.05
Gorillas	112	2.01 **±** 0.94	1	4	
Buffaloes	58	23.43 **±** 2.42	17	28	

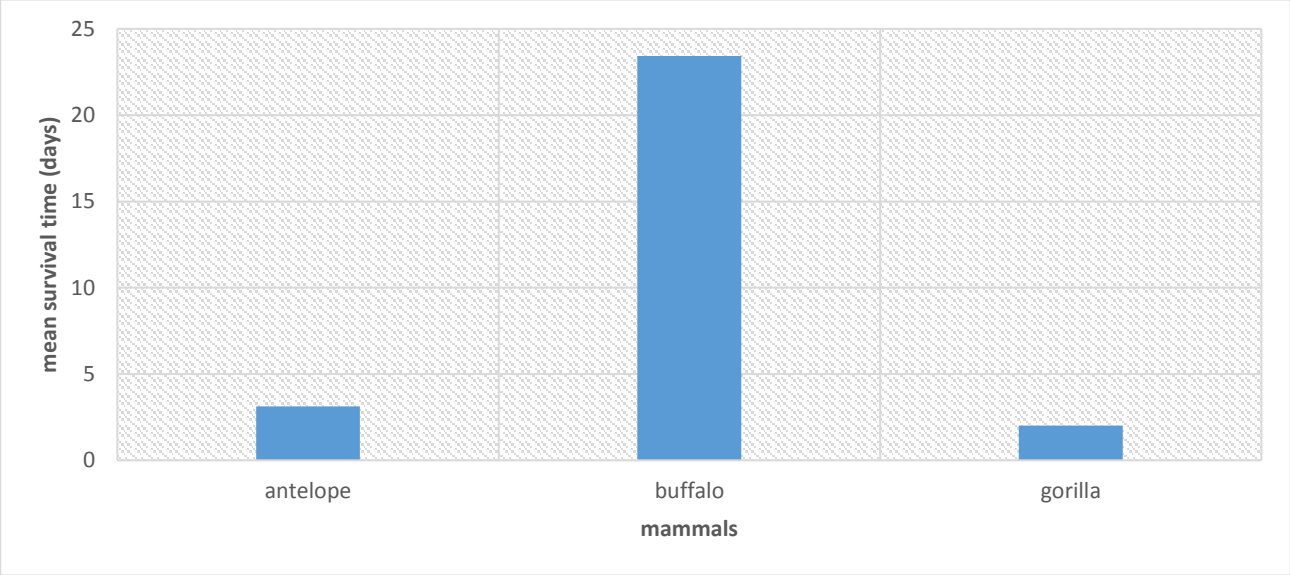

Figure 5. Generalized pattern of mean survival time for different mammals

DISCUSSION

For antelope dung, our findings show that, the survival time is extremely shorter in the Congo basin forest of south-east Cameroon especially during the rainy seasons (2.44 – 3.5 days and 2.34 – 4.44 days in the park and fmu respectively) when compared with survival time obtained from other regions in Central Africa. White (1994) estimated antelope (duiker) survival time to be about 2 months in the Lope National Park (Gabon). Koster and Hart (1998) estimated dung survival time for antelopes to be about 21 days. However, our results were in line with results obtained by Nathalie van Vliet *et al*., (2008) and Towa *et al*., (2022). Nathalie van Vliet *et al*., 2008 estimated the dung survival time of duiker to be about 3.4 days during the dry season in north east Gabon; Towa *et al*., (2022) estimated the mean dung survival time during the rainy season for the blue duiker to be 1.52 – 1.81days and for the red duiker to be 1.52 – 4.09 days in the Central African rainforest specifically in the Nki national park. Survival time was extremely longer during the long dry season (reasons why results are not shown in tables and figures because survival time was longer than period set to collect data) when compared to the long and short dry seasons. This corroborate results by Nathalie van Vliet et al. (2008) and Towa et al. (2021) who found out that dung survival time for antelopes (duikers) was up to seven times longer during the dry season when compared with the rainy seasons. They suggested that, these significant differences in antelope dung survival time among sites and seasons highlights the importance of site/season specific data to convert dung densities to antelope densities. In the equatorial rainforest of south-east Cameroon, decay of antelope dung is mainly because of an intense dung beetle activity. African tropical forests have a rich fauna of dung beetles (Cambefort and Walter, 1991; Nathalie van Vliet et al., 2008; Nathalie and Nasi, 2009; Towa et al., 2022). Many species of dung beetles are specialized to utilize either the large and rich in carbohydrates dung pats of large herbivores, or the smaller and rich in nitrogen droppings of medium sized herbivores like antelopes, which have a diverse diet which includes leaves and fruits (Dubost, 1984; Nathalie van Vliet et al., 2008; Nathalie and Nasi, 2009). Furthermore, Towa et al. (2022) highlighted that, beetle abundance and activity are likely to vary between regions, the use of dung survival time calculated in a given locality to estimate antelope (duiker) density in another locality may be inappropriate, even if a dung count survey is carried out in the same season as the estimation of dung survival time. This can be attributed to the main reason why in this present work there were differences in the survival time of dung of antelopes in the primary (less disturbed) forest or park (2.44 – 4.44days) and the secondary (more disturbed) forest or FMU. Dung survival time was longer in the long dry season, probably because the proportion of dung piles that beetles removed was significantly lower because of the rapid drying of dung pellets and the low abundance of beetles; but during the wet seasons, beetles were more abundant, dung moisture remained high for longer periods and therefore beetles removed more dung piles resulting in a shorter dung survival time than in dry seasons (Towa et al. 2022).

For buffalo dung, our observations showed that in the primary forest or park, the mean survival time was longest during the long dry season (results not shown on the tables and figures because dung did not disappear during the period set for data collection) when compared to the rainy seasons (24.71 days for the long rainy season and 22.07 days for the short rainy season). This is in line with results obtained by Mosissa et al. (2019) and Lehmkuhl et al. (1994). Mosissa et al. (2019) observed that, the dung persistence time of the cape buffalo was higher during the dry season than in the wet season in the Jorgo – Wato Protected Forest (JWPF) in

Ethiopia. As described by Lehmkuhl et al. (1994), moisture promotes invertebrate diversity, activity and organic decomposition of dung. Seasonal variations in the dung decay rate in the equatorial forest of south east Cameroon could be attributed to variation in rainfall and abundance of decomposers between seasons. Dung beetles, flies and high rainfall were the main causes for the faster dung decay rate during the rainy seasons. During the dry season, dung dries up, dung decomposers were reduced, and termites act as key decomposers (Anderson and Coe, 1974; Mosissa et al., 2019). Furthermore, the production of loose or watery dung during the rainy season and condensed or thick dung during the dry season could have contributed to the seasonal variation in the mean dung survival time in the equatorial rainforest of south east Cameroon.

Furthermore, our findings showed that, for gorilla dung, the mean survival time in the equatorial rainforest of south-east Cameroon was 2.56 days during the long dry season and 1.35 – 1.76 days during the rainy seasons within the primary forest or park; while it was 2.53 days during the long dry season and 1.17 – 1.76 days during the rainy seasons in the secondary forest or forest management unit (FMU). These results are in line with findings by Yuji and Juichi (2008) in the northern part of Moukalaba – Doudou national park Gabon. In their finding, they observed that more than 50% of dung disappeared before 2 days. Like with the antelopes, there exist significant differences in the mean survival time of gorilla dung amongst habitats and seasons. This also highlights the importance of habitat/season specific data to convert dung density to gorilla population. For survival time for dung of antelopes, gorillas, and buffaloes when not taking the effects of seasons and habitats, the dung of gorilla had the shortest survival time i.e. 2.01 days while those of antelopes and buffaloes were 3.13 days and 23.43 days respectively. We observed that in the field, a very high odour emanated from the dung of gorilla when compared to those emanating from the dung of antelopes and buffaloes. Therefore, it can be hypothesized that this very high odour attracted more dung beetles to gorilla dung which accelerated the dung decay process. A large number of dung beetle species are associated with the dung of gorillas in the equatorial rainforest of south – east Cameroon. Dung odour attracts insects particularly dung beetles, through a complex mixture of volatile organic compounds (VOCs) that differ among mammalian species allowing olfactory discrimination and resource selection. These VOCs are typically carboxylic acids (e.g., butanoic acid) and nitrogen-rich (e.g., skatole, indole) and sulphur rich (e.g., dimethyl disulfide, dimethyl trisulfide (DMTS)) volatiles that play an important role in the attraction of coprophagous and necrophilous insects (Paczkowski et al., 2011; Dekeirsschhhieter et al., 2013; Davis et al., 2013; Von Hoermann et al., 2013; Von Hoermann et al., 2016; Pacual et al., 2017; Sandra et al., 2020).

CONCLUSION

This study demonstrated that dung survival time of antelopes, gorillas, and buffaloes in the Congo basin rainforest of south-east Cameroon varies significantly among mammal species, seasons and habitat types. Across all three species, dung persisted longest during the long dry season and shortest during the short rainy season. Gorilla dung exhibited the shortest overall survival time, whereas buffalo dung remained detectable for the longest period. Habitat also influenced dung persistence, with differences observed between the protected, less disturbed national parks and the more disturbed forest management unit (FMU 10018).

Field observations indicated that dung beetle activity was the principal driver of dung removal, although rainfall and other environmental factors also contributed to dung decomposition. These findings highlight the strong influence of environmental conditions on dung persistence and emphasize that dung survival time cannot be assumed to be constant across seasons, habitats, or mammal species.

The study provides the first comparative estimate of dung survival time for antelopes, buffaloes, and gorillas under contrasting environmental conditions in south east Cameroon. The results underscore the importance of using species, habitat-, and season-specific dung survival estimates when converting dung density into reliable estimate of mammal abundance and population density. Incorporating these locally derived estimates into dung-based wildlife survey will improve the accuracy of population assessments and support more effective conservation planning and management of tropical forest mammals in the Congo Basin.

COMPETING INTERESTS

No competing interest

AUTHORS CONTRIBUTION

Author 1: field work, manuscript conception, writing, visualization, and validation
Author 2: design the study, supervised field work, review, editing, visualization, and validation
Author 3: design the study, supervised field work, review, editing, visualization, and validation
Author 4: design the study, review, editing, visualization, and validation
Author 5: data analysis, review, editing, visualization, and validation

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