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Population Status, Distribution, and Habitat Use Drivers of the Hooded Vulture *Necrosyrtes monachus* and the White Backed Vulture *Gyps africanus* in Northern Cameroon

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Abstract

Despite providing essential ecosystem services, African vulture populations are declining rapidly. To address the severe data deficit in Cameroon, this study assessed vulture richness, abundance, distribution, and habitat conditions in the North region. We conducted feeding, roost point, and road transect surveys across 48 non-linear transects during the dry seasons of 2021, 2023, and 2024, focusing on major slaughterhouses and the peripheries of Bénoué and Bouba Ndjida National Parks. Vultures were absent from most surveyed sites, resulting in a low Kilometric Abundance Index (KAI) that signals severe range contractions and imminent local extirpation. Of six historically recorded species, only two residents were confirmed: the White-backed vulture (*Gyps africanus*, n = 67) and the Hooded vulture (*Necrosyrtes monachus*, n = 51). A single Endangered Egyptian vulture (*Neophron percnopterus*) was recorded as a migrant, while Rüppell's, Lappet-faced, and White-headed vultures were completely undetected. Abundance varies sharply by administrative division based on land-use patterns. The Mayo-Rey division held the highest overall abundance, while Mayo-Louti recorded the highest mean group size (6.6 individuals) and KAI (0.21 birds/km). Vulture distribution is dictated by a trifecta of habitat structure, resource availability, and human disturbance. Heterogeneous, woody landscapes and water availability significantly increase counts; a 1% increase in shrub cover correlates with an 11% increase in vulture numbers. White-backed vulture hotspots and nesting sites were heavily restricted to riparian corridors featuring shrub mosaics and mature African Fan Palms (*Borassus aethiopum*). Conversely, the presence of human huts reduced expected vulture abundance by roughly 73%. While proximity to river systems is a primary positive predictor, these areas double as high-risk poisoning hotspots. Long-term vulture conservation must prioritize protecting mature tree canopies, safeguarding riparian habitats, and mitigating human disturbance around key abattoirs and National Park peripheries.

Keywords

Vulture Population, Distribution Pattern, Habitat Use, Conservation Status, Cameroon

1. Introduction

African vulture populations have experienced catastrophic declines in recent decades [1]-[7] with many species plummeting by over 90% [8]. Once-abundant species including the Hooded vulture (*Necrosyrtes monachus*), White-backed vulture (*Gyps africanus*), white-headed vulture (*Trigonoceps occipitalis*), Rüppell's vulture (*Gyps rueppelli*), and lappet-faced vulture (*Torgos tracheliotos*) have faced significant reductions [9] and are now classified as Endangered or Critically Endangered on the IUCN Red List [1] [2] [4] [10]-[14]. This multi-species collapse is primarily driven by anthropogenic pressures [15]-[20]. In West and Central Africa, intentional killing is heavily driven by the illegal trade of vulture body parts for magico-traditional medicine and belief-based practices, often utilizing lethal poisoned baits [8] [21]. Vultures also fall victim to accidental, indiscriminate poisoning from agricultural pesticides or to targeted poisoning of apex predators [3] [9]. These threats are compounded by collisions with energy infrastructure, habitat loss from savanna conversion for agriculture, and subsequent food shortages linked to declines in wild ungulates [5] [9] [21]. Vulture distribution is shaped by both biogeographical zones and human influence. Across the Sahelian, Sudanian, and Guinea savanna zones, raptor diversity varies; notably, seasonal inundation zones provide critical foraging areas that support high raptor richness [22]. While protected areas remain core strongholds, partly cultivated peripheral zones also serve as vital foraging grounds [22]. This is particularly true for the hooded vulture, a human commensal frequently found near settlements, slaughterhouses, and waste sites where food resources are predictable [3] [22]. In Cameroon where few studies are available [22]-[24], vulture populations are likely experiencing unquantified declines, threatening the critical ecosystem services they provide as natural scavengers. Despite their ecological value, there remains a critical shortage of baseline data on local vulture populations and distributions, presenting a major obstacle to effective conservation planning.

This study assessed the current population status and distribution patterns of vulture species in northern Cameroon using direct counts conducted in the vicinity of National Parks and major regional slaughterhouses. The study therefore provides a systematic baseline for conservation policy by assessing the current population status and distribution patterns of Hooded vulture and White-backed vulture in northern Cameroon using direct counts conducted near National Parks and major regional slaughterhouses, identifying and quantifying the key environmental and human induced drivers of vulture richness and abundance, and developing spatial models of habitat suitability and distribution to inform targeted conservation planning and management.

Key components of the study are:

-Population assessment: direct counts across designated study sites.

-Driver identification: evaluation and quantification of ecological and anthropogenic predictors of richness and abundance.

-Spatial modelling: habitat suitability and distribution models to guide local conservation policy.

2. Methods

2.1. Study Area

The study was carried out in the North region of Cameroon (8.3468˚N, 13.8744˚E), including Mayo Rey, Bénoué, Mayo Louti, and Faro administrative divisions (**Figure 1**, **Table 1**). All slaughterhouses located in the main towns of the region were included in the study, along with additional ones include rural areas (bush) in the vicinities of Benoue and Bouba Ndjida National Parks. This region is part of the North Cameroon Conservation Complex, an expansive, contiguous network of protected areas covering approximately 730,000 hectares that includes Faro, Bénoué, and Bouba-Ndjida National Parks. The area is integral to the Biodiversity Conservation and Management Project in Cameroon and features 34 surrounding hunting zones. The landscape is characterized by a mosaic of Sudano-Sahelian savanna woodlands, gallery forests, and seasonal floodplains, with an extensive hydrographic network primarily drained by the Bénoué River, which serves as the only permanent water course [25]. The region supports exceptional biodiversity, hosting the last remaining populations of the Critically Endangered Kordofan Giraffe (*Giraffa camelopardalis antiquorum*) and the African Savanna Elephant (*Loxodonta africana*). It also sustains significant populations of Derby Eland (*Taurotragus derbianus*), Lion (*Panthera leo*), Leopard (*Panthera pardus*), and one of the largest concentrations of Hippopotamus (*Hippopotamus amphibius*) in Central Africa [26] [27]. Recognized as an Important Bird Area (IBA). The climate is tropical, characterized by a distinct wet season from May to October and a dry season from November to April. Annual rainfall ranges from 900 to 1500 mm, with ambient temperatures typically fluctuating between 21˚C and 36˚C, though extreme heat events reaching 45˚C have been recorded in recent years. Access to sites was approved by the administrative authorities, the Divisional Officer and the Governor of the North region. For each subdivision surveyed we notified the Subdivisional Officer and the chiefs of different villages. Sites with minimal security conditions were not covered.

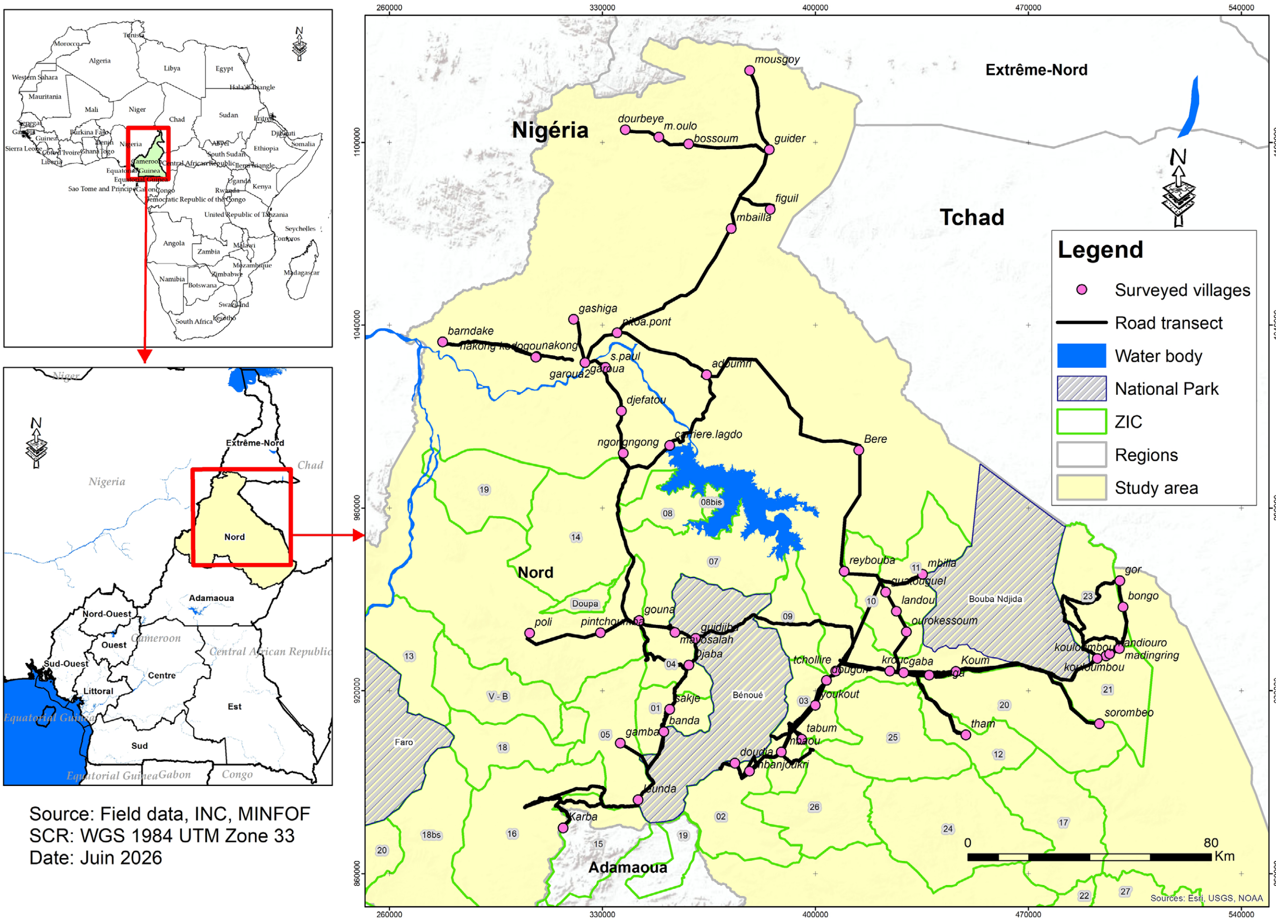

Figure 1. Map showing the location of study area in North Cameroon: Surveyed sites near and far from National Parks and road routes covered.

Table 1. Description of main categories of study sites.

Type of study sites	Sites Description	Specificity of study area
Benoue National Park (BNP) vicinity	The PNB and 9 peripheral hunting zones (HZ or ZIC) and covers an area of 800,000 ha. There are approximately 100 villages surrounding the BNP, 12 of which are located within Conservation Areas 1 and 4. For the BNP, we cover the hunting zones 03, 25, 26, 05, 15 and 16 (mainly in Mayo Rey Division).	Bushland (rural area)
Bouba Ndjida National Park (BNNP) vicinity	The PNBN extends over an area of 220,000 ha, and is surrounded by five HZ (10, 11, 12, 20, and 23) which constitute the study site (exclusively in Mayo Rey Division).	Bushland (rural area)
Slaughterhouses	Covered mainly 03 divisions, Benoue with Garoua as the main town, Mayo Louti with Guider as head of department, and Faro with Poli as head of department. We surveyed slaughterhouse sites in the following 12 subdivisions: Garoua 1, Garoua 2, Garoua 3, Pitoa, Tcheboa, Demsa, Bibemi, Barndaké, Guider, Figuil, Lagdo, and Poli.	Urban or semi-urban area and rural area

2.2. Data Collection: Vulture Surveys

Data were collected during the dry season in January-March 2021, April 2023 and March-April 2024. We adopted a combination of point counts (roost and feeding points) and road transect surveys associated with habitat characterization. Since vultures in North Cameroon are often human commensals, surveys should be conducted at probable "hotspots" such as slaughterhouses (abattoirs), hills, and dumpsites. The survey consisted of roost and feeding count points and a road transect survey to maximize encounters with critically endangered species.

2.2.1. Vulture's Data Collection: Roost (Rivers) and Feeding Count (Slaughter Areas)

Data was collected from feeding site (abattoirs or slaughter areas and dumpsites) and roost site by direct counting method [28] using binoculars and/ or naked eyes. The survey was done in towns and rural areas spread over the North region of Cameroon. Vulture's survey was conducted in all time of the day. The feeding counts were mainly from 7 am to 12 am and roost counts from 3 pm to 6 pm. Feeding locations include slaughterhouses in the main subdivision of North Cameroon. Roost sites were mainly near rivers or mountain/hill. At each survey site, the distance to the observed bird and the number of vulture individuals identified were recorded around. In addition, information on habitat characteristics/threats to the species was recorded. Each point count was equal to circular a100 meter radius plot, so we covered a radius of 100 m around our position. One hundred and twenty-four plots (probable feeding and roost points) were surveyed, equivalent to 3,893,600 m^2 or 3.8936 km^2. Circular plots are suitable for surveying rare or hard-to-identify species. Their advantages include [28]: increased focus on species and their habitats, more time for species identification and species occurrence easily associated with habitat characteristics. The materials used were a pair of binoculars, a telescope, a stopwatch, a handheld GPS device, recording sheet, a field guide to birds of Western Africa by Borrow and Demey (2014) and a Camera. The data collected were:

- location of sampling station (longitude, latitude, elevation, proximity to national Park);
- richness (number of species) and abundance (count per species) of birds;
- main habitat characteristic;
- percent area coverage by height class (grass and herbs: <1 m; shrubs: 1 - 5 m; trees: >5 m) also percent area of bare soil, human settlements, and water surface;
- presence of streams, vultures' nest, burnt surface and hill;
- indices presence of human activity (person, huts, gold extraction, crop farms and herding).

Also all the indirect indices of the presence of vulture species (fecal remains) were recorded. To maintain strict consistency across all predictor data and eliminate inter-observer variance, habitat characterization at every survey location (both point counts and roadside stops) was visually estimated solely by the principal researcher. The same protocol was used for point counts and roadside stops to estimate habitat variables.

2.2.2. Road Transect Survey

To be efficient we combined point counts with road-survey transects. We used motorcycle and traveled at speeds of 20 - 40 km·h^{-1}, and made counts at times of the day [29] between 7 am and 5 pm. We used a non-observer driver and 2 observers. We identified and recorded all vulture's species detected visually. At each probable vulture sighting, we stopped the vehicle to make the observation. A 10-minute, 360˚ scan of the survey point focused on visual cues of all vulture's species present on ground and on trees or in sky (flying). We conducted road transect surveys along primary and secondary roads linking subdivisions and villages, near slaughter areas, and at the edge of the National Parks (Benoue and Bouba Ndjida). We make a total of 48 non-linear transects. In addition, information on habitat characteristics and potential conflict between existing human activities and vultures was recorded at each point of vultures identified (see above, like explained in the roost and feeding point count section). We have a look at least 100 m (radius) on each side of the road, like a study area was a savanna.

2.3. Statistical Modeling

The population status of vultures was assessed based on three important variables: The number of vultures directly sighted (counts), occurrence of indirect indices of presence (faecal remains) and the kilometric abundance indices (KAI). We statistically modeled vulture counts per sighting (dependent variable) using a Poisson generalized linear mixed model (GLMM), since this dependent variable was scaled as integers. The Bernoulli distribution of whether (1) or not (0) the observer sighted an indirect sign of vulture presence was modeled using a logit GLMM. In models, we included the observer's identity and the surveyed village as random intercepts to account for differences in detection probability and non-independence among repeated surveys within villages. We further justified the multilevel model (both fixed and random effects) by evaluating the difference between the marginal and conditional R^2 for each model, along with the additional variance accounted for by the random effect. Transect length was also included as an offset to control for unequal sampling effort (in Km). Seventeen independent variables were initially subjected to statistical selection in the model as predictors of the above dependent variables: altitudinal gradient, Julian day, time of the day, administrative division, site (around abattoirs, Benoue National Park and the Bouba Ndjida National Park), presence/absence of burnt surfaces, presence/absence of rivers, presence/absence of marked pasture, presence/absence of hunting huts, presence/absence of crops, presence/absence of human during the survey, estimated % of bare soil, estimated % of grass cover, estimated % of shrubs cover, estimated % of tree cover, estimated % of water surface, estimated % of human settlements. To ensure there was no multicollinearity among the 17 independent variables, we calculated the variance inflation factor (VIF) for these variables and retained variables that were sufficiently orthogonal (VIF ≤ 5). When an important categorical predictor was associated with very high VIF or unstable variance, we used univariate analysis, such as the Chi-squared, to model it. By progressive elimination or addition of single terms we checked for their importance in the model based on whether their removal or addition significantly changed the Akaike's Information Criterion (AIC) value and the likelihood ratio (LR) statistics, respectively. An independent variable was considered important in the model if the AIC value increased by at least 2 units upon elimination, otherwise it was omitted in the final model. Similarly, the variable was important if the LR test for adding the variable resulted to in a significantly small p-value (<0.05). Both selection metrics helped to control overfitting of the model, and reduce irrelevant random noise captured by the model. We also checked if the residuals were autocorrelated using the Durbin-Watson test, which assumes independence of residuals when $p > 0.05$. Additionally, for the logit GLMM, McFadden pseudo-R^2 was calculated as a likelihood-based measure of goodness of fit, alongside the area under the ROC curve (AUC) to assess discriminatory performance of the two factor levels (presence/absence of indirect vulture's indices). Similarly, the performance of the Poisson GLMM, was evaluated through the DHARMa (Diagnostics for Hierarchical Regression Models) residual simulations of predicted residuals and comparing with observed values. The variance was considered consistent (no overdispersion) if the dispersion test non-significant ($p > 0.05$). The DHARMa zero-inflation test, comparing expected zeros with observed zeros, was conducted, and the dependent variable was not zero-inflated if the ratio observed/expected zero-inflated zeros was closer to 1 ($p > 0.05$). While the conditions for distance sampling were not fulfilled due to the vast and risky nature of the landscape, vulture density was compared across space using the Kilometric Abundance Indices (KAI). This approach is widely applied in avian surveys, particularly for broad-scale monitoring programmes based on line transects. It allows rapid evaluation of bird populations and is especially valuable during preliminary assessments aimed at identifying population patterns and trends in wide-ranging species such as raptors [30]. In addition, the method is well-suited to open landscapes like those surveyed in this study, where roadside counts tend to favour open habitats and grasslands, which can potentially biase abundance estimates [31] [32]. Kilometric index was defined as:

Formula: KAI = (Number of sightings)/(Total transect length (km))

This index was used as a proxy for population density estimation.

The KAI expresses the ratio of the total number of individuals (or signs of presence) observed to the total length of the survey path. Aligning with the survey's objectives and addressing low encounter rates, Hooded and White-backed vulture abundance data were pooled into a single critically endangered category for abundance modeling. All statistical analyses were performed using the software R, version 4.1.0 [33] and results were considered significant at 5% threshold.

3. Results

3.1. Vulture Status: Survey Effort and Univariate Analysis of Vulture Sightings in Relation to Species, Site, Division and Time of the Day

Field surveys were conducted over 43 days in the dry season (January- March 2021; April 2023, and March-April 2024) mainly across three administrative divisions of northern Cameroon (Bénoué, Mayo-Louti, and Mayo-Rey). Surveys covered 51 villages located around abattoirs, the Bénoué National Park (BNP) and the Bouba Ndjida National Park (BNNP). A total of 124 counting points and 48 non-linear transects (total averaging 948 km) of unequal length were walked, ranging from 1 to 60 km (mean = 22.5 km). The greatest effort was made in 2021 within the Mayo-Rey division, on the periphery of the Bénoué and Bouba Ndjida National Parks, consisting of 76 counting points and road stops covering a total distance of 559 km. This was followed by surveys in the Faro, Mayo-Louti, and Bénoué divisions in 2023 and 2024, which included 48 counting points and road stops covering 389 km around the main slaughterhouses of the North region. Notably, the Faro division recorded the lowest sampling effort due to security constraints.

This survey resulting in 38 sightings and a total of 119 vulture individuals recorded. We did not record any vultures at the vast majority of the surveyed sites in the North region, highlighting the rarity of these species in Cameroon. Of the six vulture species historically reported in the study area, three (richness) were detected during the surveys: Hooded vulture (*Necrosyrtes monachus*) (n = 51), White-backed vulture (*Gyps africanus*) (n = 67), and Egyptian vulture (*Neophron percnopterus*) (n = 1). There was no significant difference in the total number of Hooded and White-backed vultures recorded during the study ($\chi^2 = 2.17$, df = 1, p = 0.141). Only a single Egyptian vulture *Neophron percnopterus* individual (paleartic visitor/migrant) was detected and was therefore excluded from further analysis. The hooded vultures were recorded at slaughter areas and their vicinities; the White-backed vultures were recorded only around Benoué and Bouba Ndjida National Parks. No evidence of other critically endangered or endangered vultures, including the white-headed vulture *Trigonoceps occipitalis*, Rüppell's vulture *Gyps rueppellii* and lappet-faced vulture *Torgos tracheliotos*, was found in the study area.

Mean group size per sighting was similar for both species, with White-backed vultures showing a slightly higher average number of individuals per sighting (3.53 ± 4.41) than Hooded Vultures (3.19 ± 4.37). When both species were lumped together, the overall mean group size was 3.37 ± 4.33 individuals per sighting, with counts ranging from one to 20 individuals (**Table 2**). Spatial variation in vulture sightings was evident among survey sites. Pairwise comparisons of total vulture counts among sites (with Holm-adjusted p-values) revealed significantly more vultures recorded at abattoirs than at BNNP (p = 0.028). Mean numbers of vultures per sighting were highest at BNNP (4.43 ± 7.11), followed by abattoirs (3.19

± 4.37) and BNP (3.00 ± 1.86).

Table 2. Univariate analysis of vulture sightings in relation to species, site, division and time of the day.

	Factor Levels	N	$\bar{x} \pm s$	min	max	Effort (km)	KAI (birds/km)
Vulture Species	Hooded vulture	51	3.19 ± 4.37	1	19	...	...
	White-backed vulture	67	3.53 ± 4.41	1	20	...	...
	Both species	118	3.37 ± 4.33	1	20	...	...
Site	BNP	36	3.00 ± 1.86	1	7	225	0.16
	BNNP	31	4.43 ± 7.11	1	20	318	0.10
	Abattoir	51	3.19 ± 4.37	1	19	410	0.12
Division	Benoue	18	1.64 ± 0.81	1	3	254	0.07
	MayoLouti	33	6.60 ± 6.99	3	19	156	0.21
	MayoRey	67	3.53 ± 4.41	1	20	542	0.12
Time of the day	Morning	88	4.19 ± 5.30	1	20	...	...
	Mid-day	22	2.44 ± 2.13	1	7	...	...
	Afternoon	3	1 ± 0	1	1	...	...

N = Total number sighted during the study; $\bar{x}$ = mean bird per sighting, s = standard deviation, min = minimum number per sighting, max = maximum number per sighting KAI = kilometric Abundance Indices.

When survey effort was accounted for, kilometric abundance indices (KAI) ranged from 0.07 birds/km in Bénoué to 0.16 birds/km in BNP, with intermediate values at abattoirs (0.12 birds/km) and BNNP (0.10 birds/km) (Table 2). Administrative divisions differed significantly in total vulture counts. Pairwise comparisons indicated significant differences among all three divisions ($p < 0.05$), with Mayo-Rey recording the highest total number of vultures, followed by Mayo-Louti, while Bénoué had the least overall vulture counts. Consistently, Mayo-Louti showed the highest mean number of vultures per sighting (6.60 ± 6.99) and the highest KAI (0.21 birds/km), whereas Mayo-Rey, despite the greatest survey effort (542 km), had a lower KAI (0.12 birds/km) and a mean group size of 3.53 ± 4.41 individuals per sighting (Table 2). Benoue had the least mean group size of 1.64 ± 0.81 individuals per sighting and also the lowest KAI (0.07 birds/km). Temporal variation in vulture sightings was apparent across the day. Most individuals were recorded in the morning (N = 88), followed by midday (N = 22), and afternoon (N = 3). Morning detections were significantly higher than detections at other times of the day lumped ($\chi^2 = 35.12$, df = 1, $p < 0.001$). Mean group size was also highest in the morning (4.19 ± 5.30 individuals per sighting) compared to midday (2.44 ± 2.13), while all afternoon sightings involved single individuals (Table

2). During the survey, four inactive white-backed vulture nests were recorded, all located in Mayo-Rey Division, in close proximity to rivers and on Palms fan *Borassus aethiopum* (ronier).

3.2. Effects of Habitat Conditions on Vulture Abundance

The Poisson generalized linear mixed model (GLMM) used to explain the variation of vulture abundance, showed good performance. The DHARMa residual simulations indicated a satisfactory model fit: the nonparametric dispersion test showed no evidence of overdispersion (dispersion = 2.33×10^{-9}, p = 0.064), and the zero-inflation test revealed no significant deviation between observed and expected zeros (ratio = 0.90, p = 0.232). Model fixed effects explained 27% of the variance in vulture abundance (marginal $R^2 = 0.27$), while the full model including both fixed and random intercepts, explained 82.8% of the variance (conditional $R^2 = 0.83$), supporting the use of a multilevel model to account for vulture abundance in this study. Results from the fitted model revealed that habitat structure, human disturbance, and resource availability significantly influenced vulture abundance. The presence of hunter or farmer huts was associated with a significant reduction in vulture abundance (Table 3). Sites where huts were present recorded fewer vultures per sighting compared to sites without huts (IRR = 0.27, SE = 0.18, 95% CI = 0.07 - 0.99, p = 0.049, also Figure 2) with a significant decrease of approximately 73% in expected vulture counts. Vegetation structure had a strong positive influence on vulture abundance (Table 3). Shrub cover was positively associated with the number of vultures observed (IRR = 1.11, SE = 0.04, 95% CI = 1.03 - 1.20, p = 0.005, also Figure 2). Each unit increase in % of shrub

Table 3. Poisson GLMM to explain vulture abundance (from direct sighting).

Fixed effects	Direct sighting (N = 115)				
	IRR	*SE*	*95%CI*	*Z value*	*p value*
Baseline	0.10	0.28	0.00 - 23.45	−0.82	0.410
Hunting huts [Present]	0.27	0.18	0.07 - 0.99	−1.97	**0.049**
Shrub cover (%)	1.11	0.04	1.03 - 1.20	2.78	**0.005**
Tree cover (%)	1.12	0.04	1.04 - 1.21	2.84	**0.005**
Water presence (%)	1.12	0.05	1.03 - 1.22	2.71	**0.007**
Altitudinal gradient (m)	0.98	0.01	0.96 - 1.00	−2.42	**0.015**
Random Effects					
σ^2	5.58				
$\tau_{00\ \mathrm{village}}$	15.59				
$\tau_{00\ \mathrm{observers}}$	2.71				
ICC	0.77				
Marginal R^2/Conditional R^2	0.27/0.83				

cover was estimated to lead to a 11% increase in expected vulture counts. Similarly, tree cover significantly increased vulture abundance (IRR = 1.12, SE = 0.04, 95% CI = 1.04 - 1.21, p = 0.005, also Figure 2). Water availability was also a significant predictor of vulture abundance. The number of vultures encountered increased with increasing water presence (IRR = 1.12, SE = 0.05, 95% CI = 1.03 - 1.22, p = 0.007, also Figure 2). In contrast, the altitudinal gradient had a small but significant negative effect on vulture abundance (IRR = 0.98, SE = 0.01, 95% CI = 0.96 - 1.00, p = 0.015, also Figure 2), suggesting a decline in vulture abundance with increasing elevation. The two random-effects (village and observer identity) indicated substantial variability associated with the village-level (τ_{00} = 15.59) and to a lesser extent with observer identity (τ_{00} = 2.71), with a high intraclass correlation coefficient (ICC = 0.77).

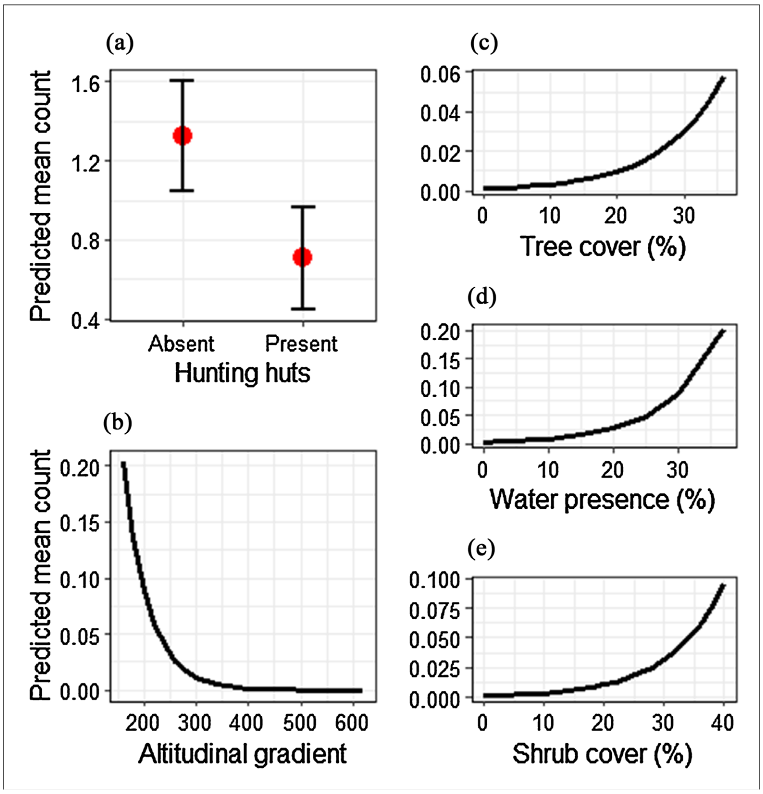

Figure 2. Predicted number of vultures per sighting shaped by (a) the presence or absence of huts; (b) altitudinal gradient; (c) tree cover; (d) the amount of water available; and (e) the shrub cover.

3.3. Effects of Habitat Conditions on the Indirect Sighting Pattern of Vultures

A total of 40 signs of faecal remains were detected and recorded as indirect indices of presence (IIP). Water presence was positively associated with the occurrence of this IIP of vulture (Table 4). Sites with higher water cover had significantly higher odds of faecal remains detection compared to sites with lower water (odds ratio = 1.45, SE = 0.24, 95% CI = 1.04 - 2.00, p = 0.026, Table 4 and Figure 3(a)). Tree cover also had a significant positive effect on the probability of detecting indirect signs of presence. The odds of sighting faecal remains increased with increasing tree cover (OR = 1.18, SE = 0.08, 95% CI = 1.03 - 1.35, p = 0.021, Table 4 and Figure 3(b)). The intensity of bare soil cover, the presence or absence of humans, and the administrative division where the survey was conducted were not significantly associated with IIP. The above fixed effects explained 59% of the proportion

Table 4. logit GLMM to explain vulture occurrence from indirect indices of presence (faecal remains).

Fixed Effects	**Indirect indices of presence (N = 115)**				
	Odds Ratios	*SE*	*95% CI*	*Z value*	*P value*
Baseline	0.03	0.09	0.00 - 15.71	−1.11	0.267
Bare of soil (%)	1.05	0.03	0.99 - 1.11	1.55	0.122
Water presence (%)	1.45	0.24	1.04 - 2.00	2.22	**0.026**
Human presence [Yes]	5.41	4.83	0.94 - 31.15	1.89	0.059
Tree cover (%)	1.18	0.08	1.03 - 1.35	2.31	**0.021**
Division [Mayolouti]	1.60	1.36	0.31 - 8.40	0.56	0.576
Division [Mayorey]	0.00	0.00	0.00 - 2.43	−1.74	0.082
Random Effects					
$\sigma 2$	3.29				
τ_{00} observers	8.06				
τ_{00} village	0.07				
ICC	0.71				
Marginal R^2/Conditional R^2			0.59/0.88		

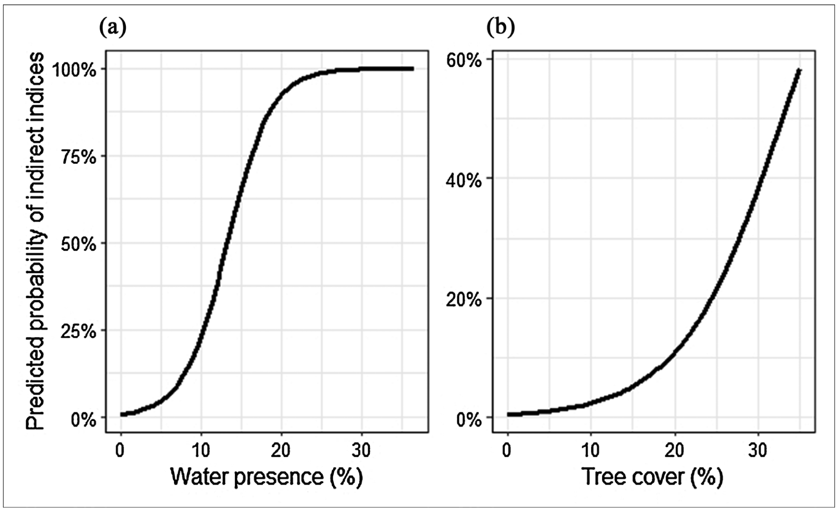

Figure 3. Predicted probability of indirect indices of occurrence of vultures (faecal remains) being shaped by sighting shaped by (a) the amount of water available and (b) tree cover.

of variation in the occurrence of IIP (marginal $R^2 = 0.59$), and this was increased to 88% when the random effects were included in the model (conditional $R^2 = 0.88$). Model explanatory power was further supported by a high McFadden pseudo-R^2 (0.43) and an excellent discriminatory performance (AUC = 0.95).

4. Discussion

4.1. Vulture Status in North Cameroon: Richness and Abundance According to Site

This survey revealed a low abundance of vultures in Cameroon. Indeed, the KAI was between 0.07 to 0.21 bird/km according to administrative Divisions and distance from protected areas. We mainly recorded Hooded vulture and White-backed vulture in urban and rural areas surveyed, all classified as Critically Endangered on the IUCN Red List. The only Egyptian Vulture (*Neophron percnopterus)* classified like Endangered [34] and recorded near a river in Mayo Rey division is a Palearctic visitor/migrant species in Cameroon [35]. While we detected a total of 119 vultures during the survey, we later excluded this individual in the statistical analyses. No evidence of other critically endangered or endangered vultures, including the White-headed vulture (*Trigonoceps occipitalis)*, Rüppell's vulture (*Gyps rueppellii)* and Lappet-faced vulture (*Torgos tracheliotos)*, was found in the study area. The absence of the majority of vulture species resident known to occur in the region [35] could indicated a current severe range contraction of the vulture species. Our results suggest that environmental stressors may be driving these populations toward critical ecological thresholds, beyond which local recovery becomes increasingly difficult to sustain without targeted intervention. This highlights the urgent need for transboundary conservation strategies that address the socio-economic drivers of the illegal wildlife trade [36]. While a lack of recording of these species at these high-probability sites strongly signals a severe population decline, it should not be misconstrued as proof of regional extinction, as unsurveyed habitats outside these hotspots may still harbor undetected individuals. The hotspots based survey used in this study optimized resources to track remaining rare populations, but it limits broader ecological conclusions. Indeed, our findings indicate a significant collapse in the vulture community diversity and abundance, reflecting the broader African vulture crisis [4]. The observation that only two (Hooded vulture and White backed vulture) of the six historically reported vulture resident species were observed in Cameroon is a stark indicator of the "African vulture crisis", a phenomenon characterized by rapid, continent-wide population collapses [4]. This result aligns with broader regional trends in West Africa, where anthropogenic pressures have decimated scavenger communities [15]-[20]. The absence of detection of these three vulture species is not necessarily a sudden event but likely the result of long-term, compounding pressures. In Cameroon the decline in vultures' population may comes from intentional poisoning of vultures mainly for fetishism (pers. obs). This results in Cameroon reflecting the general trend of vulture decline in Central Africa.

However, extensive research and monitoring inside the Cameroon National Parks and their environs are necessary to conclude an absence. There is a persistent and illegal demand for vulture parts for use in fetishism in Cameroon (pers obs). This has led to targeting and killing vultures, which is particularly devastating for already fragmented populations. While primary drivers such as poisoning and trade for traditional medicine account for the vast majority of documented African vulture deaths, habitat degradation [5] [37] and food unavailability are increasingly recognized as a significant secondary driver that undermines population resilience and hampers recovery efforts [9] [38].

Hooded vultures were recorded only in the slaughter areas and their vicinities, and no observations were made near the National Parks. This species is the most likely to be found near human settlements, markets, and abattoirs [39]. While this proximity allows them to exploit human-produced waste, it also keeps them in constant, high-risk contact with poison and infrastructure hazards [39]. On the contrary, White-backed vulture was recorded only in hunting zones near Benoue and Bouba Ndjida National Parks, and no observations were made around slaughter areas. White-backed vulture prefers bushland or rural areas far from human settlements. It is a highly social species, they are particularly vulnerable to mass mortality events, as a single poisoned carcass can kill dozens of individuals simultaneously [4] or a hundred. Egyptian vulture was historically present in Far North Cameroon (e.g., near Rumsiki) as a migrant species; this species faces significant threats from habitat degradation and the loss of nesting cliffs [23]. His sporadic observation in only one site in the North region near a river in the vicinity of Benoue National Park indicates that it continuously occurs in Cameroon as a migrant, even if its almost absence indicates that the North region is not its home range [35].

Four inactive White-backed vulture nests were recorded in the Mayo-Rey Division, all located on African Fan Palms in close proximity to a river. This habitat profile appears highly suitable for supporting White-backed vulture (*Gyps africanus*) hotspots in the region. Indeed, personal observations during this study confirm that this specific habitat harbors a community of White-backed vultures. This suggests that the primary habitat characteristic for the species in this region consists of African Fan Palms (*Borassus aethiopum*) distributed along riverbanks.

4.2. Two Sympatric Vulture Species Present in Northern Cameroon: The Hooded and White-Backed Vultures

Our result indicated that White-backed vultures typically exhibit a higher average number of individuals per sighting than Hooded vultures (even though it was significant at the 10% level) is grounded in the distinct ecological niches and foraging strategies of these two species. White-backed vultures primarily inhabit scrublands within protected areas, where they are shielded from human pressure and, consequently, observed in larger groups [40] [41]. In contrast, hooded vultures often reside in human-dominated landscapes; this proximity increases their exposure to anthropogenic threats, which likely accounts for their smaller, more dispersed group sightings. In addition, the differences in sighting group sizes are largely driven by how these species interact with their environment and food sources. White-backed Vultures are highly social, obligate scavengers that rely on locating large, ephemeral food sources such as animal carcasses, across expansive landscapes. Their social structure is adapted for efficient "social foraging"; by flying in groups or monitoring the movements of other vultures, they increase the probability of locating food [42]. Consequently, when a carcass is located, they frequently aggregate in large numbers to exploit the resource quickly, leading to higher counts during sightings. In contrast, the Hooded Vulture is often characterized as a more solitary or small-group-oriented species. While they are known to congregate at predictable food sources like slaughterhouses, markets, and waste sites in urban or peri-urban environments [39], their day-to-day ranging behavior often involves smaller groups. Their association with human-dominated landscapes means they may be observed singly or in pairs more frequently than the large, gregarious groups typical of Gyps vultures at wild carcass sites.

4.3. Factors Affecting the Distribution Pattern of Vultures

Vultures were observed across all divisions of the North Region, with the exception of the Faro division, where no vultures were detected during the survey (which only covered the Poli and Pintchoumba slaughterhouses). Though the overall survey effort included Faro, this Division was not included in the statistical test.

Our results show disparities between the administrative Divisions survey (Mayo-Rey, Mayo-Louti, and Bénoué) in total vulture counts. Such disparities reflect a complex interplay of land-use patterns, human population density, and the availability of primary habitats for scavenging birds [39] [43] [44]. Mayo Rey recording higher counts exclusively the White backed vulture. This area provide both the necessary nesting sites (large trees and hills) and a consistent supply of carcasses from wildlife, which are essential for supporting larger vulture populations [42]. In contrast, the Bénoué Division showed the lowest counts, exclusively the Hooded Vulture. The high human pressure in urban areas, particularly in the Benoue, could explain this very low vulture of count. The higher levels of human encroachment and habitat fragmentation in this Division explain the lowest count vultures. Urbanization and agricultural expansion often correlate with a decline in vulture sightings, not just due to direct persecution, but also due to the loss of suitable foraging grounds and the potential for secondary poisoning [39]. So, the Mayo Rey division, which acts as a buffer zone for the National Parks, naturally shows higher "total counts" of vultures than the Benoue division, primarily dedicated to high-intensity agriculture or dense human settlement. The larger group sizes recorded in Mayo Louti (6.60 individuals) suggest a landscape capable of supporting communal foraging, whereas the very small group size in Bénoué division (1.64) suggests a population that is increasingly fragmented or "solitary", often a sign of high environmental stress [42]. The least overall vulture counts (KAI 0.07; Group size 1.64) recorded in Benoue division is due to human-dominated landscape effect, where anthropogenic pressure (e.g., poisoning, habitat degradation) forces individuals (hooded vultures) to forage as solitary scavengers rather than the naturally occurring communal groups [4] [45]. While 67 individuals of White-backed vulture (*Gyps africanus*) were recorded during this study, the total population is likely much higher. For instance, management staff from one hunting zone reported an estimated population of approximately 400 individuals within their area. This specific zone appeared to be one of the most effectively managed hunting areas surrounding Bouba Ndjida and Bénoué National Parks. However, because the majority of hunting zones in the region appear to be poorly managed, this higher population estimate cannot be extrapolated across other zones. Consequently, well-managed hunting zones may represent some of the final refuges for White-backed vultures in Cameroon.

In North Cameroon, slaughterhouses serve as vital feeding sites for vultures, especially the Hooded vulture. These sites are predominantly located in high-density urban areas, which intensifies anthropogenic pressure on habitats that are otherwise critical to vulture conservation. The study indicated that the vast majority of slaughter areas in North Cameroon currently host no vultures, despite records from several decades ago indicating they were once abundant. The absence of birds from most of these historically saturated feeding sites in the Bénoué Division reflects a drastic decline of the Hooded Vulture in Cameroon, driven by intense anthropogenic pressures such as poaching, poisoning, and habitat alteration [15]-[20]. This study suggest that the Mayo-Louti Division may serve as a vital anchor for the regional vulture population. Conversely, the Bénoué area could potentially function as an ecological sink, a landscape where cumulative external pressures appear to constrain the social and foraging behaviors necessary for long-term population stability.

4.4. Habitat Structure, Human Disturbance and Resource Availability as Drivers of Vulture Abundance

Findings revealed that vulture abundance is driven by the trifecta of habitat structure, human disturbance, and resource availability, aligning with ecological theory regarding the conservation of obligate scavengers [39] [46] [47]. These factors do not operate in isolation; rather, they form an interconnected framework that determines whether a landscape can sustain a stable vulture population. Vultures are wide-ranging species that require vast, open landscapes to soar and locate carcasses through thermal gliding [42]. Complex habitats, such as scrublands or savannas, offer essential nesting and roosting sites (e.g., large, mature trees). When habitat structure becomes fragmented, often due to agricultural conversion, the energy cost of foraging for a vulture increases significantly, leading to a decline in overall abundance [39]. Human activity often functions as a limiting factor that outweighs the benefits of high-quality habitat. Anthropogenic pressure including direct persecution, the use of pesticides in agriculture, and retaliatory poisoning, remains the leading driver of mortality for African vultures. So the high human pressure is directly linked to a lower abundance of vultures. Vultures are highly wary of human infrastructure; high levels of traffic, noise, and settlement density may cause birds to abandon otherwise productive foraging grounds, contributing to the lower Kilometric Abundance Index (KAI) observed in developed regions [39]. Lack of resource availability could also explain the lowest abundance of vultures.

4.5. Human Disturbance Is a Driver of Vulture Abundance Declining

Hunting and farming huts are associated with a 73% reduction in vulture abundance. This could be a critical indicator of how specific anthropogenic structures function as deterrence zones for scavenging birds. This decline is not merely a reflection of the hut's physical presence, but rather the associated human activities that directly impact vulture survival and behavior. The significant decrease in sightings near huts can be attributed to several overlapping ecological and behavioral factors, and it is an example of anthropogenic pressures. Vultures are highly intelligent and observant animals; they quickly learn to associate specific human structures with danger. The presence of hunters or farmers may poses a risk of direct shooting or intentional poisoning, as scavenging birds are often viewed as pests or as indicators of illegal poaching activity [42]. The 73% reduction could indicates a strong behavioral avoidance and psychological barrier that prevents vultures from entering or utilizing these areas [44]. In conservation terms this profound statistical signal, suggests that huts could effectively act as sinks or ecological traps. They remove high-quality habitat from the functional range of the vulture population.

4.6. Effect of Habitat Structure on Vultures Abundance

The positive correlation between vegetation structure (shrub and tree cover) and vulture abundance underscores the critical role that landscape complexity plays in supporting these raptors. For vultures, vegetation could be a functional component of their survival strategy, providing both shelter and the necessary conditions for foraging success. The finding that each 1% increase in shrub cover correlates with an 11% increase in vulture counts is particularly noteworthy. This strong association may suggest that shrublands offer significant ecological benefits. Shrub cover can help regulate local temperatures, potentially influencing the formation of thermals. Vultures are masters of soar-gliding, which relies on rising columns of warm air. An environment with a mosaic of shrub cover can influence surface heating and wind patterns, aiding in the energetic efficiency of their search flights [42]. Tree cover is arguably the most vital structural element for many Gyps species, it provides nesting and roosting sites for vultures and security. Large trees (African Fan Plam) provide the necessary height and platform stability for nesting. Vultures probably require high vantage points for roosting to remain safe from terrestrial predators and to facilitate efficient social take-offs in the morning, where they wait for thermals to develop before beginning their daily foraging range [42]. The results highlight that vultures thrive in heterogeneous landscapes rather than overly simplified or barren ones. Vegetation structure was a primary determinant of habitat suitability. The positive relationship between tree/shrub density and vulture counts validates the need for habitat restoration and the preservation of woody vegetation as a core component of vulture conservation strategies [44].

4.7. Water Availability Is a Significant Predictor of Vulture Abundance

This study confirms the well-documented positive relationship between water availability and vulture abundance in arid and semi-arid ecology. For White-backed and Hooded vultures, access to water acts as a vital environmental filter dictating daily movements and long-term distributions. Water bodies provide critical foraging, hydration, and thermoregulation sites, particularly along rivers where White-backed vultures rely on riparian corridors. Vultures frequently congregate at these sites to bathe, a behavior essential for maintaining feather condition, insulation, and the flight efficiency required for their soaring-based foraging strategies [42]. However, because river systems in North Cameroon draw high human activity for local livelihoods, they create dangerous intersection zones. These rivers have historically been primary sites for intentional and accidental vulture poisoning, significantly driving population declines. Local practices, such as using agricultural pesticides for illegal fishing, accidentally intoxicate visiting vultures (pers. obs.). Consequently, these essential aquatic habitats have transformed into high-risk poisoning zones. Effective vulture conservation therefore depends on protecting these « Blue hotspots » and preserving the surrounding trees and shrubs, which provide secure, vital roosting spaces for birds after drinking or bathing.

5. Conclusions

This study reveals a catastrophic collapse in avian scavenger species richness and abundance across Cameroon's Mayo-Rey, Mayo-Louti, and Bénoué divisions. Of six historically documented vulture species, only the Critically Endangered Hooded Vulture (*Necrosyrtes monachus*) and African White-backed Vulture (*Gyps africanus*) remain as resident populations. A single Egyptian Vulture (*Neophron percnopterus*) sighting represents a transient occurrence, while the complete undetection of White-headed, Rüppell's, and Lappet-faced vultures signals a severe regional range contraction driven by anthropogenic stressors crossing critical ecological thresholds. The absence of detections highlights the need to expand the study into Bénoué and Bouba Ndjida National Parks and intensify research to draw a definitive nationwide conclusion.

The remaining populations exhibit distinct eco-spatial dynamics dictated by habitat structure, human disturbance, and resource availability. White-backed Vulture is strictly restricted to hunting zones in the vicinities of National Parks within the Mayo-Rey division, showing a profound reliance on high tree density and African Fan Palms (*Borassus aethiopum*) along riparian corridors for nesting and roosting. Conversely, the Hooded Vulture exhibits a strong tendency toward urban commensalism, frequently aggregating around municipal abattoirs. However, this proximity to urban centers may function as a dangerous ecological trap. While the Mayo-Louti Division appears to act as a vital demographic anchor supporting communal foraging, the heavily urbanized and agricultural landscapes of the Bénoué Division seem to exhibit characteristics of an ecological sink. Under intense anthropogenic pressure in the Bénoué Division, Hooded Vultures appear to be experiencing a disruption in their social network structure. These birds have largely shifted away from their historically adaptive communal groups to forage more solitarily, with the mean group size depressed to just 1.64 individuals. Ultimately, these findings underscore the urgent need for targeted, landscape-level conservation strategies that address the dual realities of the vultures' reliance on protected areas and on the risky urban or semi urban environnments.

Authors' Contributions

Irène Blondelle Kenfack: writing—review and editing, writing—original draft, methodology, investigation, funding acquisition, data curation, conceptualisation. **Simon Awafor Tamungang**: writing—review and editing. **Mvo Denis Chuo:** writing—review and editing. **Taku Awa II**: writing—review and editing. **Jean Pascal Koh-Dimbot**: writing—review and editing, writing—original draft, data analysis. **Standly Nkemnyi Nkengbeza**: writing—review and editing. All the authors read and corrected the manuscript and agree with the current version.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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