



HABITAT UTILIZATION OF CHIMPANZEES IN MOUNT CAMEROON NATIONAL PARK, WEST COAST CLUSTER

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Abstract

This study assessed the habitat utilization of chimpanzees in Mount Cameroon National Park (West Coast Cluster), focusing on vegetation structure, nesting ecology, and ecological drivers across montane, sub-montane, and lowland forests. A cross-sectional field survey design was employed, integrating vegetation sampling, nest measurements, indirect signs, and spatial modelling. Results revealed significant variation in vegetation composition and diversity across habitats. The sub-montane forest exhibited the highest species diversity and evenness (Shannon index $H' = 2.68$; Evenness $E = 0.99$; Simpson index = 0.919), followed by the lowland forest ($H' = 2.35$; $E = 0.98$; Simpson = 0.888), while the montane forest showed lower diversity but higher abundance ($H' = 2.08$; $E = 0.90$; Simpson = 0.895). Nest distribution varied markedly across habitats, with the montane forest recording the highest nest abundance ($N = 135$), followed by the sub-montane ($N = 70$) and lowland forests ($N = 20$), indicating a clear altitudinal preference for nesting. Despite differences in vegetation structure, nest characteristics were relatively consistent across habitats, with mean nest heights ranging from 11.53 ± 2.10 m to 11.68 ± 1.85 m, canopy cover averaging 68.37–70.62%, and tree diameter (DBH) ranging from 65.77 ± 24.42 cm to 67.56 ± 28.28 cm. Indicators of habitat utilization showed contrasting patterns: montane forests had low activity signs (vocalizations: 4.4%; footprints: 11.9%), whereas sub-montane (vocalizations: 47.1%; footprints: 37.1%) and lowland forests (vocalizations: 55.0%; footprints: 45.0%) exhibited higher levels of chimpanzee activity. Generalized Linear Model (GLM) analysis revealed that ecological variables influenced nesting behavior differently across habitats. In the montane forest, canopy cover had a significant effect on nest height (Omnibus $\chi^2 = 4.471$, $p = 0.034$; Wald $\chi^2 = 4.546$, $p = 0.033$), with a negative relationship ($B = -0.018$), indicating that increased canopy density led to slightly lower nest placement. However, no significant effects were observed in the sub-montane ($\chi^2 = 0.095$, $p = 0.758$) or lowland forests ($\chi^2 = 0.089$, $p = 0.765$), suggesting greater behavioral flexibility in these habitats. Model fit statistics further showed that the sub-montane forest provided the best explanatory model (Deviance/df = 2.71; AIC = 276.29), compared to montane (Deviance/df = 3.32; AIC = 549.15) and lowland forests (Deviance/df = 4.65; AIC = 87.00). Spatial modelling using MaxEnt indicated that habitat suitability ranged from 0 to 1, with no habitat reaching optimal suitability. Suitability was highest in sub-montane and montane zones, influenced by lower temperatures and higher precipitation, highlighting the importance of climatic factors in shaping chimpanzee distribution. Overall, the findings demonstrate that chimpanzees in Mount Cameroon National Park exhibit adaptive habitat utilization, preferentially nesting in montane forests while actively utilizing sub-montane and

lowland forests for foraging and movement. Habitat use is strongly influenced by vegetation diversity, canopy structure, and climatic conditions, reflecting ecological flexibility across elevation gradients.

Keywords:

Nesting ecology, Altitudinal gradients, Vegetation diversity, Habitat suitability modelling.

Introduction

Primates constitute some of the most ecologically significant faunal groups within tropical forest ecosystems, and among them, chimpanzees (*Pan troglodytes*) hold particular importance due to their roles in maintaining forest dynamics and biodiversity. As keystone species, chimpanzees support ecological processes such as seed dispersal, forest regeneration, and trophic interactions, making them integral to the stability of tropical ecosystems (Morgan & Abwe, 2020). Their nesting behavior, a core aspect of daily activity patterns, provides insight into habitat structure, resource use, and ecological adaptation. Consequently, nest site selection has become a widely used indicator for assessing habitat quality, forest structure, and primate population trends across tropical landscapes (Koops *et al.*, 2012).

Nest construction in chimpanzees represents a complex behavioral and ecological decision-making process. Arboreal nests are the most common and are shaped by tree characteristics such as height, diameter at breast height (DBH), crown architecture, and canopy connectivity, all of which enhance safety, stability, and thermal comfort (Hernández-Aguilar *et al.*, 2013). Seasonal conditions further influence nest placement, with chimpanzees selecting higher canopy layers during wet periods to avoid ground moisture and disease vectors, whereas in dry or open woodland ecosystems, nests may be constructed at lower heights for thermoregulation (Pruetz & Bertolani, 2009). The selection of nesting sites thus reflects how chimpanzees adapt to ecological variability, resource availability, and environmental stressors.

Across Africa, studies underscore significant variability in chimpanzee nesting ecology depending on habitat type, floristic composition, and levels of anthropogenic disturbance. Research from Uganda, Tanzania, Côte d'Ivoire, and Senegal demonstrates that nesting preferences are linked to forest maturity, canopy density, tree mechanical properties, and microclimate (Plumptre & Reynolds, 2015; Koops *et al.*, 2012; Pruetz *et al.*, 2008). In landscapes affected by logging or agricultural expansion, nesting patterns shift due to reduced availability of preferred trees and increased habitat fragmentation, as observed in Gabon, Congo, and Sierra Leone (Stokes *et al.*, 2010; Bryson-Morrison *et al.*, 2017). These continental patterns highlight the sensitivity of nesting ecology to human activities and its usefulness for monitoring primate responses to habitat alteration.

Within Cameroon, home to *Pan troglodytes ellioti* and *Pan troglodytes troglodytes*, nesting ecology research has revealed important trends related to habitat degradation and land-use change. Studies in Ebo Forest, Mbam-Djerem, Korup, and Deng Deng National Parks show that chimpanzees generally prefer mature forests with high canopy cover, but increasingly use degraded or marginal environments when forced by anthropogenic disturbances such as poaching, logging and agricultural encroachment (Abwe & Morgan, 2008; Tagg *et al.*, 2013; Willie *et al.*, 2014; Ekobo *et al.*, 2017). These shifts not only affect nesting strategies, but also have implications for long-term population viability and possible extinction within habitat.

Mount Cameroon National Park (MCNP), particularly the West Coast Cluster, provides a unique setting for understanding habitat utilization and nesting ecology due to its highly heterogeneous forest matrix. Its altitudinal gradient from lowland evergreen forests to montane ecosystems supports diverse vegetation types that likely shape chimpanzee nesting decisions (Nkempi *et al.*, 2019). However, escalating anthropogenic pressures, including slash-and-burn agriculture, illegal logging, poaching, and settlement expansion, are fragmenting habitats, altering canopy structure, and reducing the availability of suitable nesting trees. These disruptions pose growing threats to *Pan troglodytes ellioti*, a subspecies already classified as endangered. Despite the ecological importance of the region, systematic research on chimpanzee nesting ecology within MCNP remains limited.

Given that nest counts are central to estimating chimpanzee densities, assessing habitat quality, and guiding conservation interventions, there is a pressing need to understand how chimpanzees utilize available habitats and adapt to increasing disturbances. Therefore, the objective of this study was to assess the habitat utilization of chimpanzees with particular focus on nesting ecology as a proxy for ecological preferences, resource availability, and human impact.

Method

Study area

The Mount Cameroon National Park (MCNP), located within the Fako and Meme Divisions of Cameroon’s South West Region, spans approximately 58,178 hectares between 4.055°–4.378° N and 9.031°–9.294° E. The park shares about 128.73 km of boundaries with five administrative subdivisions: Buea, Limbe II, Muyuka, Idenau, and Mbonge. It lies roughly 2 km from the coastline and is bordered by several protected areas, including Mokoko, Bomboko, Southern Bakundu, and the Meme River Forest Reserves. Additionally, the Etinde, Bakingili, and Woteva Community Forests border the park (MINFOF, 2014; Ekane *et al.*, 2017).

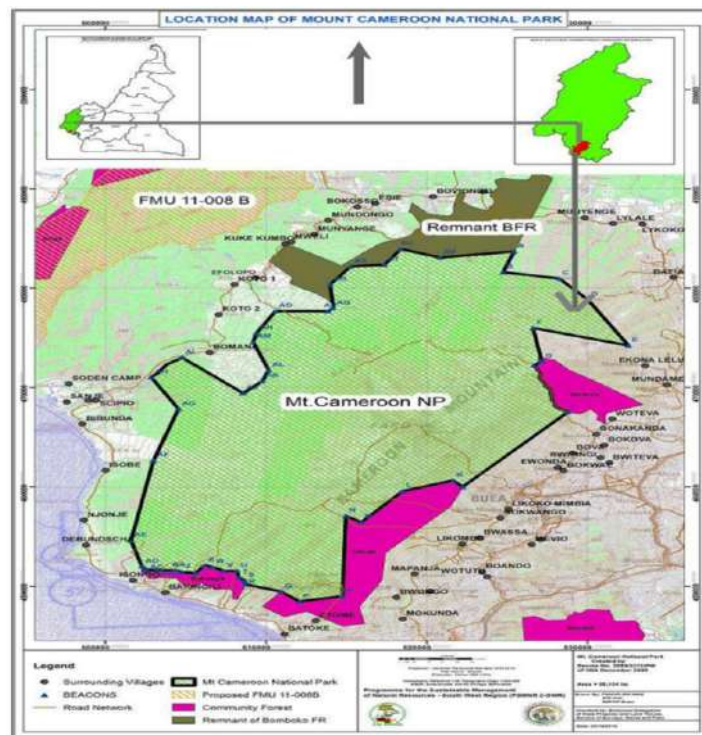


Figure 1: Map of Mount Cameroon National Park

Study design

This study adopted a mixed-method research design that combined ecological field surveys, GPS-based spatial analysis, and community-level surveys to assess chimpanzee (*Pan troglodytes ellioti*) nest site selection and habitat adaptation strategies in the Mount Cameroon National Park (MCNP), West Coast Cluster. The ecological component was field-based and employed systematic transects within stratified grid cells to capture chimpanzee signs, such as nests, feeding remains, fecal deposits, and vocalizations, following the protocols of Andrew Plumptre and Vernon Reynolds (1996). The study area was stratified into three major habitat types: lowland rainforest, sub-montane forest, and montane forest, allowing for comparative analysis across ecological gradients.

Within each 1 km × 1 km grid cell, five parallel transects were established, spaced 200 m apart, with three randomly selected for data collection using the raking method. The raking method was employed because it enhances detectability of subtle and ground-level chimpanzee signs (such as footprints, fecal matter, and feeding remains) that are often obscured by leaf litter and dense understory vegetation in tropical forests. By systematically disturbing the forest floor along transects, this method minimizes observation bias and improves the accuracy and reliability of indirect sign detection, thereby providing a more comprehensive assessment of chimpanzee presence and activity patterns. This approach facilitated systematic recording of chimpanzee nesting, feeding, and activity signs within a 100 m radius on either side of the transect. Forest structural parameters, including canopy cover, tree species composition, DBH, nest tree characteristics, and understory density, were also documented. Spatial analysis using GIS software (ArcGIS/QGIS) enabled the mapping of chimpanzee presence, encounter rates, and overlap with human disturbance zones, while habitat suitability modelling was conducted using MaxEnt (Phillips *et al.*, 2006).

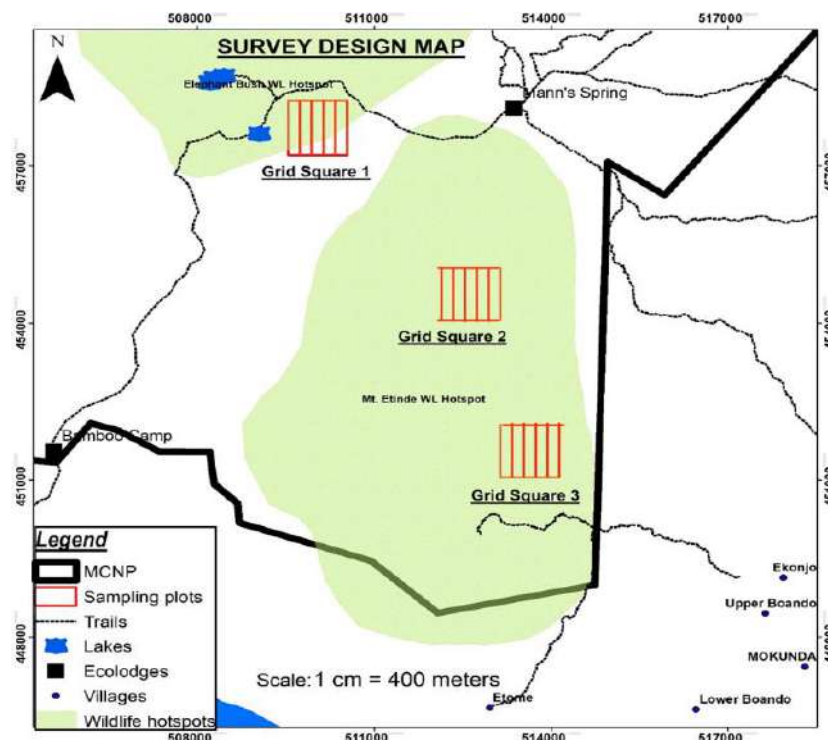


Figure 2: Survey Design Map

Sampling Techniques and Sample size

A stratified random sampling approach was used to ensure ecological and socio-economic representativeness within the Mount Cameroon National Park (West Coast Cluster). The study area was stratified into three habitat types based on elevation: lowland (0–800 m), sub-montane (800–1600 m), and montane forest (1600–1900 m).

For the ecological component, 1 km × 1 km grid cells were systematically established across chimpanzee hotspots. Each grid contained five parallel transects, of which three were randomly selected. Along these transects, the raking method (adapted from Andrew Plumptre and Vernon Reynolds) was applied within a 100 m radius to enhance detection of indirect chimpanzee signs such as nests, feces, feeding remains, footprints, and vocalizations. Key environmental variables, including canopy cover, elevation, DBH, nesting characteristics, and tree species, were recorded and georeferenced for spatial and habitat suitability analysis.

For the socio-economic component, six communities (Ekonjo, Upper Boando, Mapanja, Bokwango, Etome, and Bakingili) were purposively selected. Respondents were stratified by occupation (hunters, forest users, and park rangers) and randomly sampled. A total of 300 semi-structured questionnaires (50 per community) and key informant interviews were conducted to capture Indigenous Ecological Knowledge on chimpanzee behavior, habitat use, and threats.

The sample size for the questionnaire survey was determined using Cochran's, (1977) formula for sample size calculation in large populations:

$$n_0 = \frac{Z^2 \cdot p \cdot q}{e^2}$$

Where:

- n_0 = required sample size
- Z = standard normal deviate at 95% confidence level (1.96)
- p = estimated proportion of the population (0.5, assuming maximum variability)
- $q = 1 - p = 0.5$
- e = desired margin of error

Substituting values:

$$n_0 = \frac{(1.96)^2 \times (0.5) \times (0.5)}{(0.0566)^2}$$

$$n_0 = \frac{3.8416 \times 0.25}{0.003201} = 300$$

Thus, the calculated sample size was 300 respondents. To ensure equitable geographic representation, the sample was distributed across the six selected communities, with 50 respondents per community. Within each community, respondents were proportionally drawn from poachers, forest users, and eco-guardians to capture diverse perspectives. A buffer of 10% additional questionnaires was prepared to account for non-response or incomplete surveys, ensuring the final usable dataset meets the target of 300.

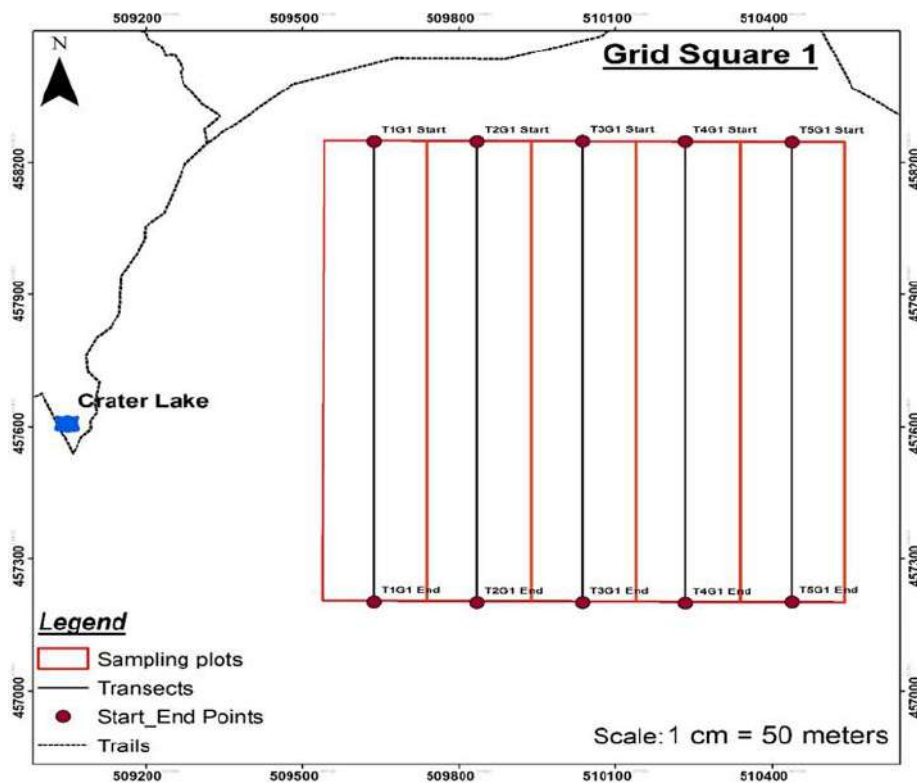
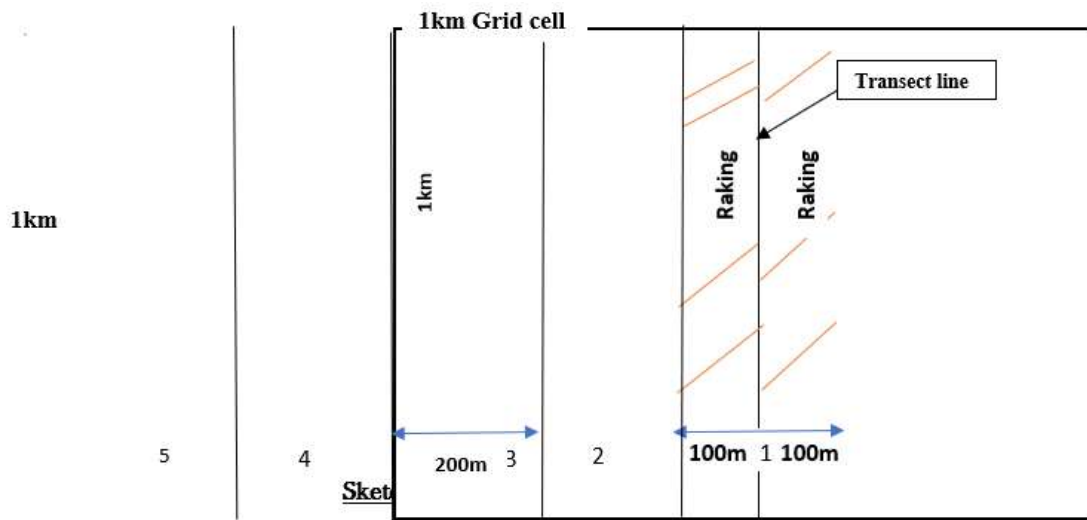


Figure 3: Laying of transects within grid cells

Data Analysis

Habitat utilization was analyzed using data on nest locations, habitat types, and elevation to determine chimpanzee distribution patterns. Descriptive and inferential statistics (means, standard deviations, frequencies, percentages, correlations, box plots, and encounter rates) were used to assess activity levels across vegetation zones. Spatial analysis in ArcGIS mapped the distribution of nests and feeding signs, while the MaxEnt model (Phillips *et al.*, 2006) was applied to generate habitat suitability maps based on ecological variables such as canopy cover,

altitude, slope, and proximity to water. This approach helped identify chimpanzee activity hotspots and patterns of habitat selection.

Results

Description of Chimp Nesting Pattern in MCNP, West Coast Cluster

The study recorded a total of 225 chimpanzee nests across all habitat types within the study area. The analysis revealed clear differences in species composition and diversity across habitat types in the Mount Cameroon National Park. The montane forest recorded the highest number of individuals (N = 135) but lower diversity (H' = 2.08) and evenness (E = 0.90), indicating dominance by a few key canopy species such as *Podocarpus latifolius*, *Ficus sur*, and *Polyscias fulva*, which are important for nesting and feeding.

In contrast, the sub-montane forest showed the highest diversity and evenness (H' = 2.68; E = 0.99), reflecting a more balanced species distribution and greater habitat complexity that supports flexible chimpanzee habitat use. The lowland forest recorded the fewest individuals (N = 20) with moderate diversity (H' = 2.35) but high evenness (E = 0.98), suggesting a relatively uniform yet sparse vegetation structure dominated by secondary forest species table 1).

Overall, high evenness values (>0.90) across all habitats indicate good species distribution, but the sub-montane forest provides the most favorable conditions for chimpanzee habitat utilization. These findings highlight the species' ecological flexibility in exploiting different forest types depending on vegetation structure, resource availability, and elevation.

Table 1a: Frequency between Nest by Forest Type in MCNP West Coast Cluster

Habitat type	S/N	Common Name of species	Scientific Name of species	Family	n	%	p_i $\ln(p_i)$	p_i^2
Montane forest	1	African Cherry	<i>Newtonia buchananii</i>	Fabaceae	16	11.9	-0.253	0.0140
	2	Waterberry	<i>Prunus Africana</i>	Rosaceae	7	5.2	-0.155	0.0027
	3	Umbrella Tree	<i>Podocarpus latifolius</i>	Podocarpaceae	15	11.1	-0.244	0.0123
	4	Bush Fig	<i>Podocarpus latifolius</i>	Podocarpaceae	17	12.6	-0.260	0.0159
	5	Nile Trumpet	<i>Ficus sur</i>	Moraceae	14	10.4	-0.235	0.0108
	6	African Olive	<i>Schefflera abyssinica</i>	Araliaceae	12	8.6	-0.214	0.0079
	7	Parasol Tree	<i>Ficus sur</i>	Moraceae	15	11.1	-0.244	0.0123
	8	Peacock Flower Tree	<i>Prunus Africana</i>	Rosaceae	13	9.6	-0.225	0.0092
	9	Forest Newtonia	<i>Syzygium guineense</i>	Myrtaceae	10	7.4	-0.193	0.0055
	10	Yellowwood	<i>Polyscias fulva</i>	Araliaceae	16	11.9	-0.253	0.0142
Total					135	100	H' = 2.08	$\Sigma p^2 = 0.1048$
Sub-montane	11	Peacock Flower Tree	<i>Albizia gummifera</i>	Fabaceae	7	9.9	-0.230	0.010
	12	Cape Macaranga	<i>Macaranga capensis</i>	Euphorbiaceae	6	8.5	-0.208	0.007
	13	Yellowwood	<i>Podocarpus latifolius</i>	Podocarpaceae	3	4.2	-0.136	0.002

	14	Umbrella Tree	<i>Schefflera abyssinica</i>	Araliaceae	5	7.0	-0.186	0.005
	15	African Olive	<i>Olea capensis</i>	Oleaceae	3	4.2	-0.136	0.002
	16	Kikuyu Polyscias	<i>Polyscias kikuyuensis</i>	Araliaceae	8	11.3	-0.249	0.013
	17	Nile Trumpet	<i>Markhamia lutea</i>	Bignoniaceae	3	4.2	-0.136	0.002
	18	African Soapberry	<i>Allophylus africanus</i>	Sapindaceae	6	8.5	-0.208	0.007
	19	Bush Fig	<i>Ficus sur</i>	Moraceae	5	7.1	-0.186	0.005
	20	African Cherry	<i>Prunus Africana</i>	Rosaceae	7	9.9	-0.230	0.010
	21	Parasol Tree	<i>Polyscias fulva</i>	Araliaceae	1	1.4	-0.059	0.0002
	22	Forest Nuxia	<i>Nuxia congesta</i>	Stilbaceae	8	11.3	-0.249	0.013
	23	Forest Newtonia	<i>Newtonia buchananii</i>	Fabaceae	3	4.2	-0.136	0.002
	24	Waterberry	<i>Syzygium guineense</i>	Myrtaceae	4	5.5	-0.162	0.003
	25	Zenker's Celtis	<i>Celtis zenkeri</i>	Cannabaceae	2	2.8	-0.101	0.001
	Total				70	100	H' = 2.68	Σp² = 0.081
Lowland	26	Oil Palm	<i>Elaeis guineensis</i>	Arecaceae	2	10	-0.230	0.010
	27	Pattern Wood	<i>Alstonia boonei</i>	Apocynaceae	1	5	-0.150	0.003
	28	Zenker's Celtis	<i>Celtis zenkeri</i>	Cannabaceae	1	5	-0.150	0.003
	29	African Piptadenia	<i>Piptadeniastrum africanum</i>	Fabaceae	2	10	-0.230	0.010
	30	African Padauk	<i>Pterocarpus soyauxii</i>	Fabaceae	3	15	-0.285	0.023
	31	African Corkwood	<i>Musanga cecropioides</i>	Moraceae	3	15	-0.285	0.023
	32	Ivory Terminalia	<i>Terminalia ivorensis</i>	Combretaceae	3	15	-0.285	0.023
	33	Red Mahogany	<i>Khaya anthotheca</i>	Meliaceae	2	10	-0.230	0.010
	34	Sandpaper Fig	<i>Ficus exasperate</i>	Moraceae	1	5	-0.150	0.003
	35	Iroko	<i>Milicia excelsa</i>	Moraceae	1	5	-0.150	0.003
	36	African Breadfruit	<i>Treculia africana</i>	Moraceae	1	5.0	-0.150	0.003
	Total				20	100	H' = 2.35	Σp² = 0.112

Table 1b: Summary table

Habitat Type	Total Individuals (N)	Species (S)	Shannon (H')	Simpson (1-D)	Evenness (E)
Montane	135	10	2.08	0.895	0.90
Sub-Montane	70	15	2.68	0.919	0.99
Lowland	20	11	2.35	0.888	0.98

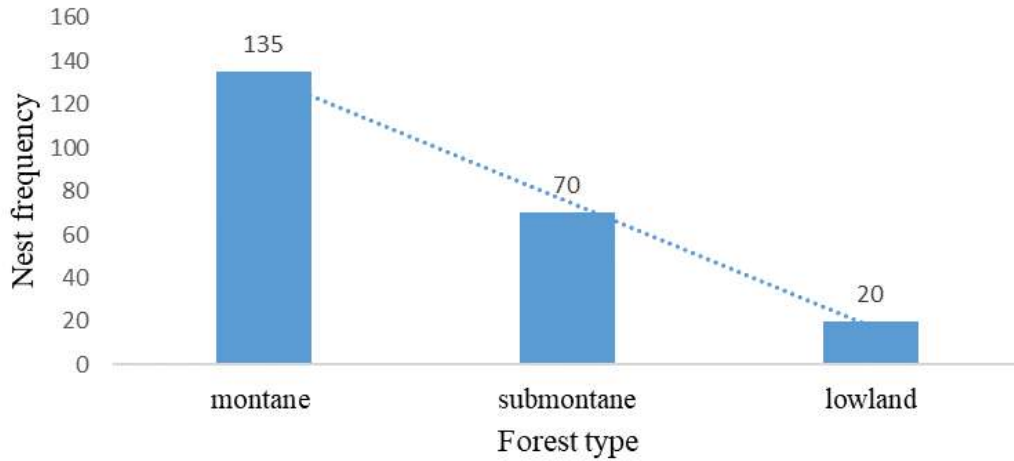


Figure 4: Nest Distribution across Forest Types

ii. Nest Characteristics

Nest characteristics were consistent across habitats, with mean nest heights ranging from 11.5 to 11.7 m, indicating a preference for elevated nesting positions. Canopy cover averaged 68–71%, reflecting selection for moderately dense canopies, while DBH ranged from 65 to 68 cm, showing preference for mature, sturdy trees. Overall, these findings suggest stable nesting behavior across forest types in the Mount Cameroon National Park (table 2).

Table 2. Nest Characteristics across Habitat Types in the Mount Cameroon National Park.

Habitat Type	N (Valid)	Mean Nest Height (m)	SD	Mean Canopy Cover (0–100)	SD	Mean DBH (cm)	SD
Montane Forest	135	11.68	1.85	68.72	18.14	67.56	28.28
Sub-Montane Forest	71	11.67	1.64	70.62	18.81	65.77	24.42
Lowland Forest	19	11.53	2.10	68.37	17.69	66.43	26.46

Nest height variation across habitats was minimal, with median values between 11 and 12 m. Montane and sub-montane forests showed slightly higher medians, while the lowland forest exhibited greater variability (figure 5). Overall ranges (8–15 m) indicate that chimpanzees adjust nesting heights based on tree availability, but maintain generally consistent preferences across habitats in the Mount Cameroon National Park.

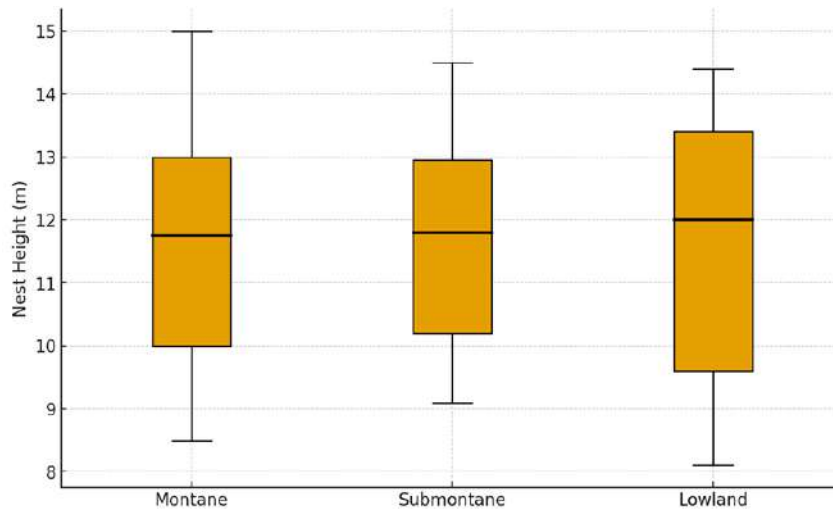


Figure 5: Boxplots showing nest height variation by forest type

Indicators of Habitat Utilization

Study results revealed clear spatial differences in chimpanzee habitat utilization indicators across forest types. Vocalizations and footprints were least frequent in the montane forest, where only 4.4% of vocalizations and 11.9% of footprints were recorded, suggesting minimal surface chimp activity despite the high nest abundance observed there. In contrast, the submontane and lowland forests exhibited greater evidence of active use, with vocalizations recorded in 47.1% and 55.0% of observations respectively, and footprints in 37.1% and 45%. These patterns indicated that while montane habitats were primarily used for nesting, submontane and lowland forests served as active feeding or movement zones, reflecting broader habitat utilization and behavioral flexibility by chimpanzees across elevation gradients (table 3).

Table 3: Indicators of Habitat Utilization by Chimpanzees across Habitat Types

Habitat Type	Indicator	N (Valid)	Presence (Y)	% Presence	Absence (N)	% Absence
Montane Forest	Vocalization	135	6	4.4	129	95.6
Montane Forest	Footprint	135	16	11.9	119	88.1
Sub-Montane Forest	Vocalization	70	33	47.1	38	53.5
Sub-Montane Forest	Footprint	70	26	37.1	45	63.4
Lowland Forest	Vocalization	20	11	55.0	8	42.1
Lowland Forest	Footprint	20	9	45	10	52.6

The chart shows that chimpanzee activity varied across habitats in the Mount Cameroon National Park, with the sub-montane forest recording the highest level of indirect signs. In this

habitat, vocalizations dominated (22; 73.3%) compared to footprints (8; 26.7%), indicating high social and communication activity.

The montane forest showed moderate activity, with footprints (12; 66.7%) more frequent than vocalizations (6; 33.3%), suggesting use mainly for movement or occasional activity. In the lowland forest, overall signs were lowest, with vocalizations (10; 58.8%) slightly higher than footprints (7; 41.2%), reflecting reduced activity or detectability. In all, chimpanzees utilized all habitats but were most active in the sub-montane forest, likely due to more favorable ecological conditions.

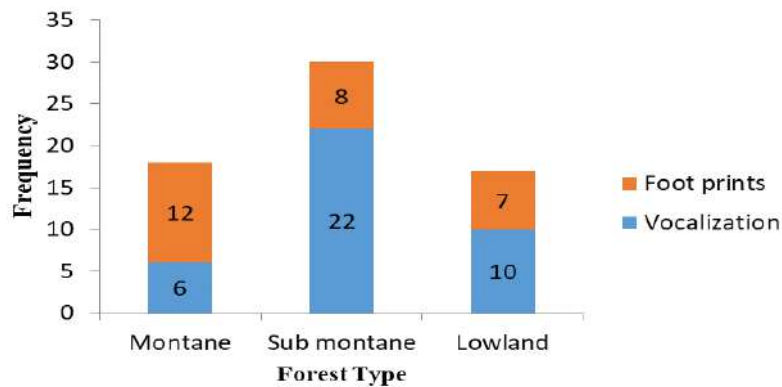


Figure 6: Stacked bar chat comparing indirect signs

Influence of Ecological Variables on Nesting Ecology

GLM results indicated slight variation in nest height and canopy cover across habitats in the M.C.N.P, showing that ecological factors influenced nesting behavior. Nest heights were consistent across forests (11.5–11.7 m), though variability was greatest in the lowland forest (SD = 2.10). Canopy cover was similar across habitats (68–71%), with slightly higher values in the sub-montane forest (70.62%), suggesting a preference for moderately dense canopies (table 4). Overall, canopy density positively influenced nest site selection, while minor differences across habitats reflected chimpanzees’ ecological flexibility.

Table 4: Generalized Linear Model Summary for Nest Height and Canopy Cover across Forest Types

Forest Type	N (Samples)	Nest Height (m) – Min	Nest Height (m) – Max	Mean Nest Height (m)	SD (Nest Height)	Canopy Cover (%) – Min	Canopy Cover (%) – Max	Mean Canopy Cover (%)	SD (Canopy Cover)
Montane	135	8.5	15.0	11.68	1.85	40	100	68.72	18.14
Sub-montane	70	9.1	14.5	11.67	1.64	40	100	70.62	18.81
Lowland	20	8.1	14.4	11.53	2.10	44	99	68.37	17.69

Generalized Linear Model (GLM) results showed that the influence of ecological factors on nest height varied across habitats in the Mount Cameroon National Park. The sub-montane forest had the best model fit (Deviance/df = 2.71; AIC = 276.29), indicating that canopy cover

and nest type strongly and consistently explained nesting patterns. The montane forest showed a moderate fit (Deviance/df = 3.32; AIC = 549.15), suggesting additional environmental factors influenced nesting. In contrast, the lowland forest had the weakest fit (Deviance/df = 4.65; AIC = 87.00), indicating greater influence of other factors such as disturbance. Overall, canopy cover influenced nest site selection across habitats, but its effect was strongest in sub-montane and weakest in lowland forests, reflecting chimpanzees' ecological flexibility.

Table 5: Generalized Linear Model (GLM) Goodness-of-Fit Summary for Nest Height across Forest Types

Forest Type	Deviance	df	Deviance/df	Pearson Chi-Square	Pearson/df	Log Likelihood	AIC	AICC	BIC	CAIC	Dependent Variable	Model Variables
Montane	441.743	133	3.321	441.743	3.321	-271.575	549.149	549.333	557.865	560.865	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)
Sub-montane	187.113	69	2.712	187.113	2.712	-135.145	276.291	276.649	283.079	286.079	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)
Lowland	79.026	17	4.649	79.026	4.649	-40.501	87.001	88.601	89.834	92.834	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)

The results showed that ecological variables influenced nesting behavior differently across habitats in the Mount Cameroon National Park. The model was statistically significant in the montane forest ($\chi^2 = 4.471$, $p = 0.034$), with canopy cover also having a significant effect on nest height (Wald $\chi^2 = 4.546$, $p = 0.033$), indicating that nesting height was strongly influenced by canopy structure.

In contrast, the sub-montane ($\chi^2 = 0.095$, $p = 0.758$) and lowland forests ($\chi^2 = 0.089$, $p = 0.765$) showed no significant effects, suggesting that other ecological or human-related factors played a greater role. Overall, canopy cover significantly influenced nesting only in the montane forest, while chimpanzees in lower elevations exhibited greater behavioral flexibility.

Table 6: GLM Omnibus and Model Effects Summary for Nest Height across Forest Types

Forest Type	Omnibus Test (Likelihood Ratio Chi-Square)	df	Sig. (p-value)	Wald Chi-Square (Canopy Cover)	df	Sig. (p-value)	Wald Chi-Square (Intercept)	Sig. (Intercept)	Effect of Nest Type	Dependent Variable	Model Variables
Montane	4.471	1	0.034*	4.546	1	0.033*	447.478	0.000	Not computable	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)
Sub-montane	0.095	1	0.758	0.095	1	0.758	230.808	0.000	Not computable	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)
Lowland	0.089	1	0.765	0.089	1	0.765	32.781	0.000	Not computable	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)

Values ≤ 0.05 indicate statistically significant

GLM results showed that the effect of canopy cover on nest height varied across habitats in the Mount Cameroon National Park. In the montane forest, canopy cover had a significant negative effect (B = -0.018, p = 0.033), indicating that nests were built lower as canopy density increased.

In contrast, the sub-montane (B = 0.003, p = 0.758) and lowland forests (B = 0.008, p = 0.765) showed non-significant positive relationships, suggesting that canopy cover had little influence on nest height. Overall, canopy structure was an important determinant only in the montane forest, while other factors influenced nesting in lower elevations.

Table 7: GLM Parameter Estimates for Nest Height across Forest Types

Forest Type	Parameter	B (Estimate)	Std. Error	95% Confidence Interval (Lower–Upper)	Wald Chi-Square	df	Sig. (p-value)	Scale	Dependent Variable	Model Variables
Montane	Intercept	12.946	0.6120	11.747 – 14.146	447.47	1	0.000	3.272	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)
	Canopy cover	-0.018	0.0086	-0.035 – -0.001	4.546	1	0.033*	—	—	—
Sub-montane	Intercept	11.447	0.7535	9.971 – 12.924	230.80	1	0.000	2.635	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)
	Canopy cover	0.003	0.0103	-0.017 – 0.023	0.095	1	0.758	—	—	—
Lowland	Intercept	10.971	1.9162	7.216 – 14.727	32.78	1	0.000	4.159	Nest Height (m)	(Intercept), Nest type, Canopy cover (0–100)
	Canopy cover	0.008	0.0272	-0.045 – 0.061	0.089	1	0.765	—	—	—

Correlation Analyses (Scatterplot with regression line.)

Correlation results across habitats in the Mount Cameroon National Park showed generally weak relationships between nest height, canopy cover, and DBH, with variations by forest type. In the montane forest, weak negative correlations were observed, indicating that nest height slightly decreased with increasing canopy cover and DBH, suggesting a modest influence of canopy density on nesting height. In the sub-montane forest, correlations were near zero, showing that canopy cover and tree size had little to no influence on nest height, reflecting high behavioral flexibility and reliance on other ecological or social factors. In the lowland forest, weak positive relationships were recorded, indicating a slight increase in nest height with canopy cover and DBH, though the effect remained minimal. In all, these findings suggest that while vegetation structure has some influence in montane areas, chimpanzees exhibit flexible nesting strategies across habitats, with other environmental factors playing a stronger role in sub-montane and lowland forests.

Figure 7: Correlation for nest height/canopy cover/DBH (Montane Forest)

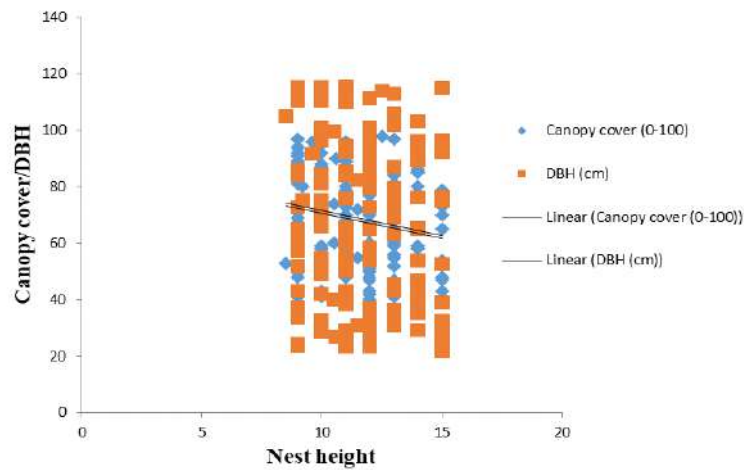
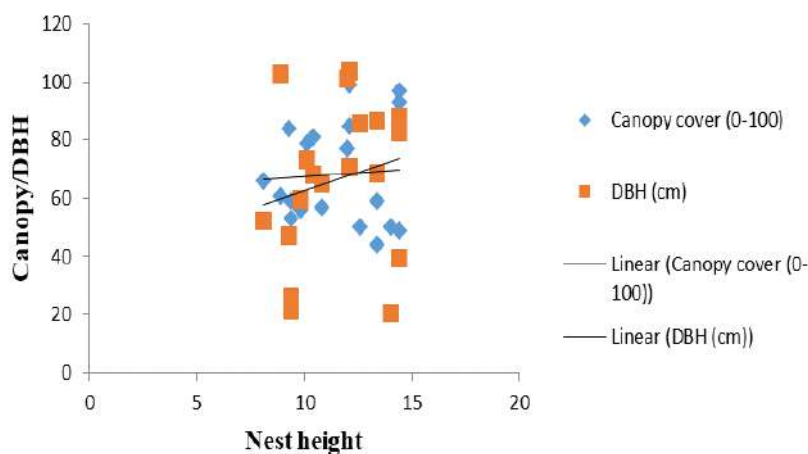


Figure 8: Correlation for nest height/canopy cover/DBH (Submontane Forest)



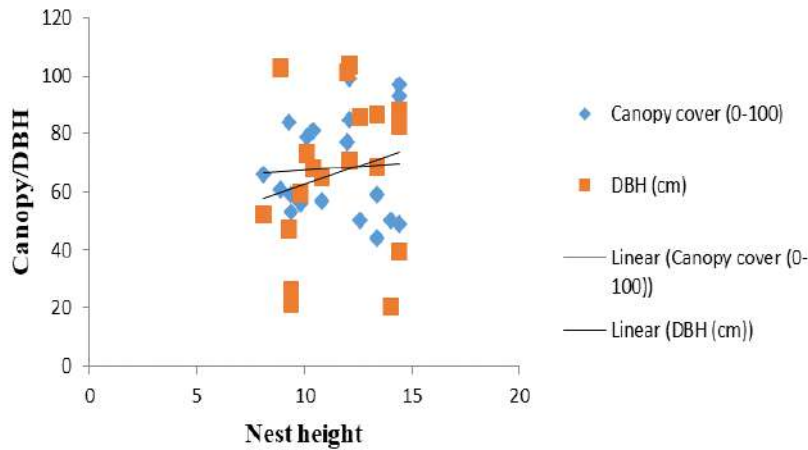
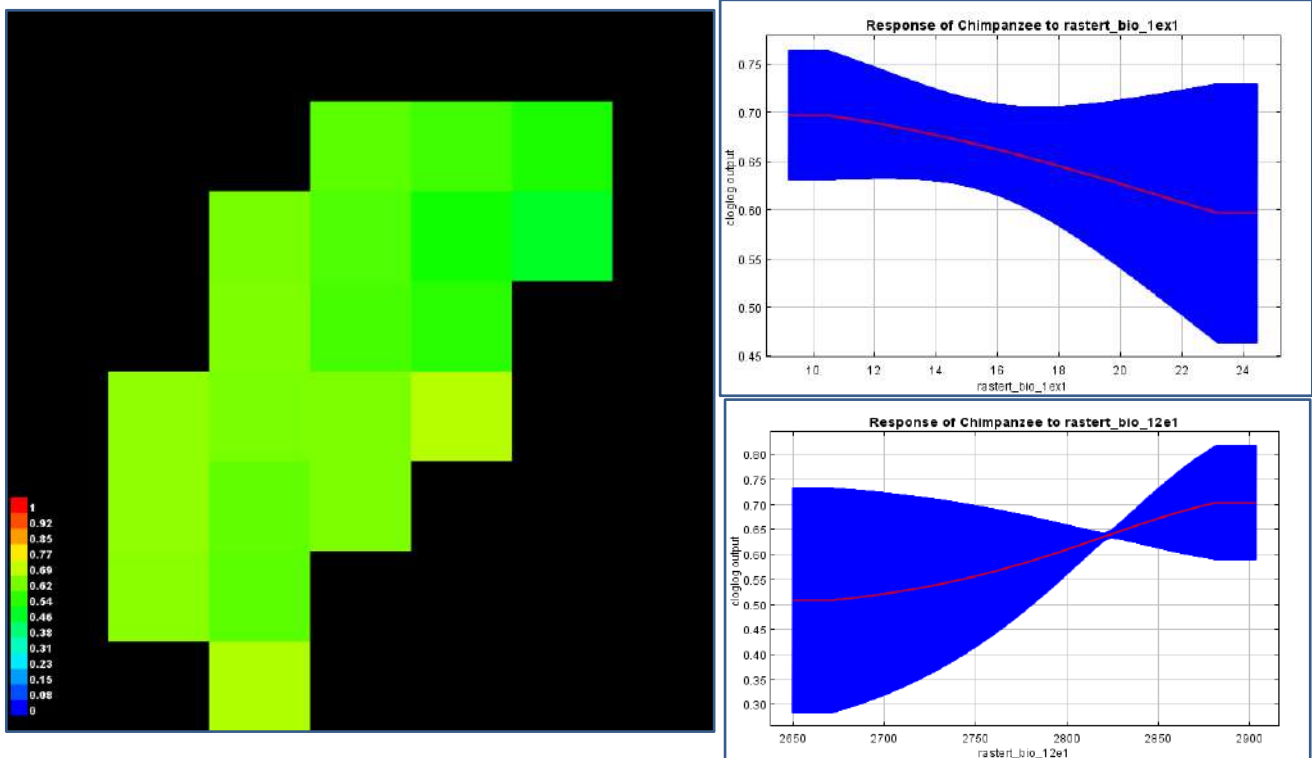


Figure 9: Correlation of nest height/canopy cover/DBH for Lowland.

Habitat Suitability and Spatial Analysis (GIS + MaxEnt)

The MaxEnt habitat suitability model showed that chimpanzee distribution in the Mount Cameroon National Park is strongly influenced by climatic factors, particularly temperature and precipitation, across altitudinal zones. Suitability values ranged from 0 to 1, with higher suitability concentrated in the montane and sub-montane forests, although no habitat reached optimal suitability. Response curves indicated that habitat suitability decreased with increasing temperature but increased with higher precipitation, suggesting a preference for cooler and wetter environments. Overall, the results highlight that chimpanzee habitat utilization is shaped by climatic gradients, with adaptable use of multiple vegetation strata across the park.



*Suitability range from 0 to 1 (0 = habitat not suitable, 1 = habitat very suitable) *

Figure 10: MaxEnt habitat suitability model

Figure 11 shows that chimpanzee nests in the Mount Cameroon National Park were unevenly distributed and clustered within specific grid cells across montane, sub-montane, and lowland forests. Higher nest densities occurred in the montane and sub-montane zones, indicating more favorable nesting conditions such as suitable canopy structure and food availability, while the lowland forest recorded fewer nests, likely due to human disturbance and reduced habitat quality.

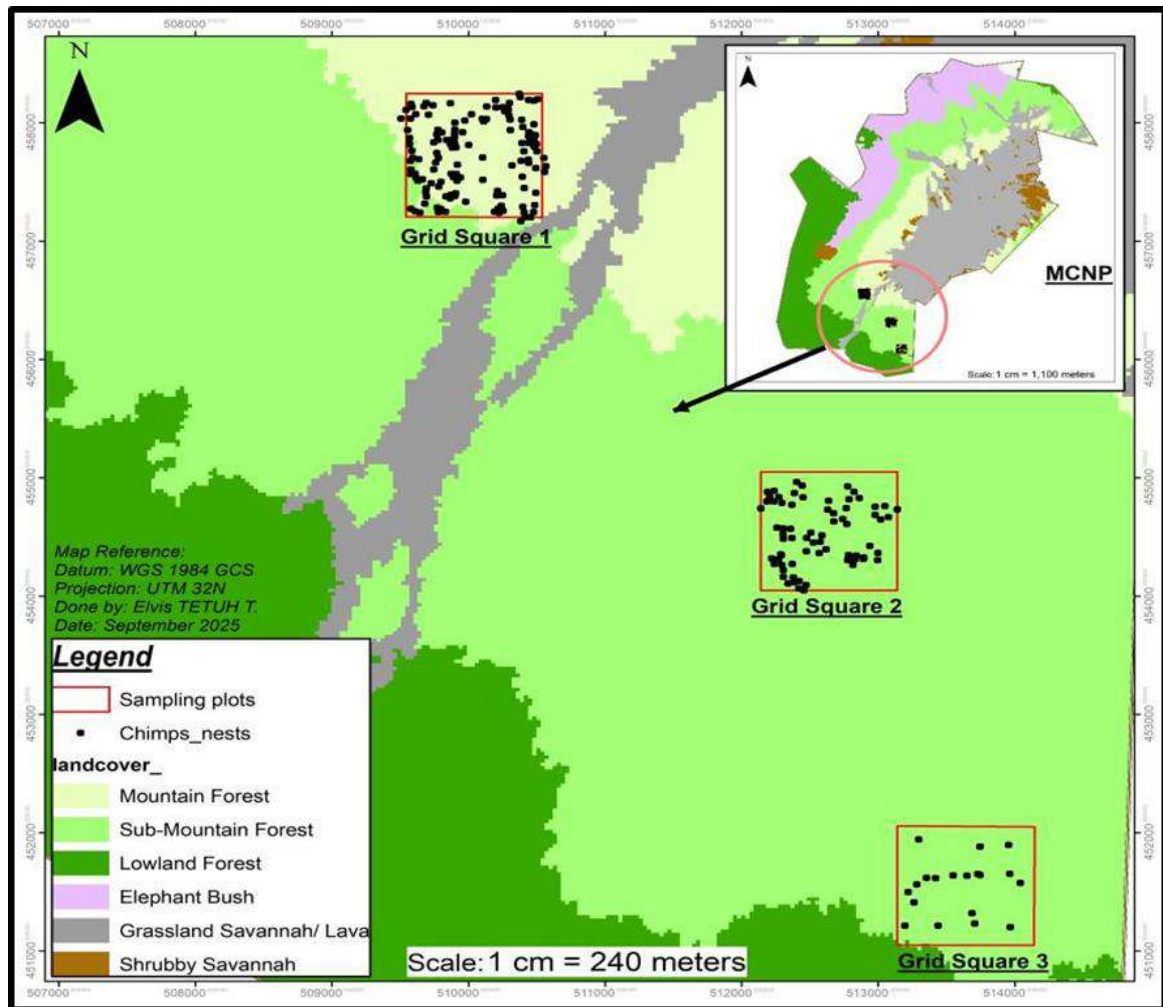


Figure 11: Map showing chimp nests distribution across different forest types

Figure 12 shows that human activities (traps and wire snares) were present across all habitat types in the Mount Cameroon National Park, with higher concentrations observed in the sub-montane and lowland forests compared to the montane zone. This pattern indicates greater human pressure in more accessible areas, which coincide with zones of high chimpanzee activity particularly the sub-montane forest thereby increasing the risk of human–chimpanzee interactions. The clustering of traps near trails and water sources such as Crater Lake and Mann’s Spring further highlights accessibility as a key driver of anthropogenic disturbance.

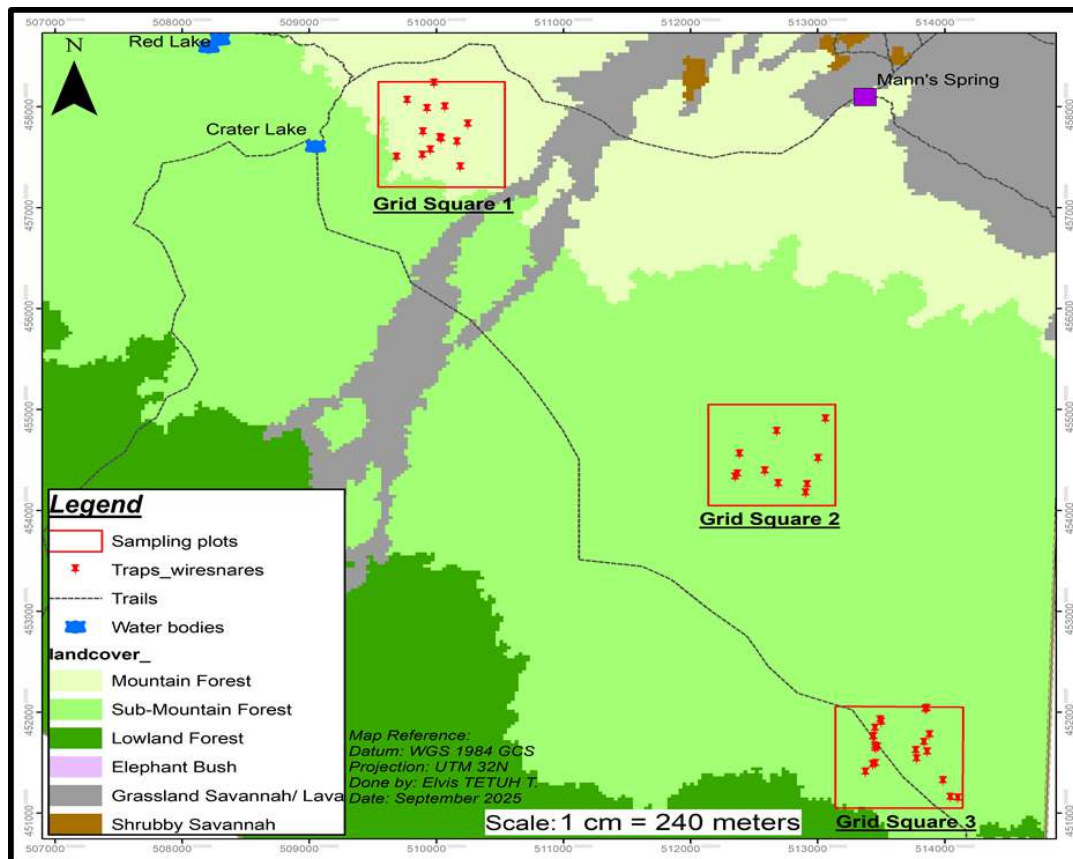


Figure 12: Map showing human activities across different forest types

Discussion

The study assessed nest site selection and habitat adaptation strategies of *Pan troglodytes ellioti* within the Mount Cameroon National Park (MCNP), West Coast Cluster. A total of 225 nests were recorded across all habitat types, with the montane forest supporting the highest number of nests (135), followed by the submontane (70) and lowland forests (20). This distribution indicates a clear preference for montane habitats, which are characterized by dense canopy cover, large tree sizes, and minimal human disturbance. Similar findings have been reported in other montane regions of Nigeria and Cameroon, where chimpanzees preferentially use high-elevation forests as core nesting zones due to their relative safety and ecological stability (Dutton *et al.*, 2017; Fotang *et al.*, 2021). Studies conducted in Ngel Nyaki and Ebo Forest likewise observed that chimpanzee nesting density increases with elevation and distance from human activities (Fotang *et al.*, 2021). Conversely, research in Mbam–Djerem and Kagwene indicates higher nesting densities in lowland forests, suggesting that habitat use may vary locally depending on forest structure and disturbance levels (Kamgang *et al.*, 2018). These differences underscore the adaptability of *P. t. ellioti* to different ecological contexts while reaffirming that in MCNP, montane forests provide the most suitable nesting habitat.

Chimpanzees in the MCNP demonstrated a selective preference for particular tree species when constructing nests. The most frequently used species; *Newtonia buchananii*, *Ficus sur*, *Prunus africana*, *Olea capensis*, *Markhamia lutea*, and *Albizia gummifera* share similar structural attributes, including strong branching systems, high canopies, and large diameters. The diameter at breast height (DBH) of nesting trees ranged from 23 to 115 cm, indicating flexibility in tree selection while maintaining an emphasis on mechanical stability and branch support. This observation corroborates findings by Lacroux, (2023) and Fotang *et al.*, (2021), who noted

that chimpanzees exhibit non-random selection of tree species based on branch strength and structural integrity. The recorded average nest height (9–15 m) further aligns with reports from Dutton *et al.*, (2017) and Hernandez-Aguilar *et al.*, (2020), who found that chimpanzees typically construct nests in the lower canopy or upper understory to balance safety from terrestrial predators and access to favorable microclimatic conditions.

The predominance of platform-type nests in this study mirrors the general nesting trend observed among wild chimpanzee populations across Africa (Baldwin *et al.*, 1981). Variations such as leaf-and-branch or branch-only nests reflect adaptive flexibility in construction, depending on the availability of nesting materials and tree architecture (Kyrrestad, 2014). The wide range of canopy cover (40%–100%) associated with nest sites further demonstrates behavioral adaptability. Chimpanzees appear to select both moderately open and dense canopies, likely to regulate temperature, minimize wind exposure, and enhance concealment (Anderson, 1998; Dutton *et al.*, 2017). Such findings affirm the capacity of *P. t. ellioti* to adjust nesting strategies to environmental conditions within their habitat.

Evidence from the field also indicates that human disturbance significantly influences chimpanzee nesting ecology. Few direct signs of chimpanzee activity, such as vocalizations and footprints, were recorded in the montane zone, suggesting that these areas may serve as nocturnal or low-disturbance nesting refuges. These results are consistent with Fotang *et al.*, (2021) and van Dijk (2021), who reported that chimpanzees preferentially nest in remote, elevated, and steep areas to minimize encounters with humans. McCarthy *et al.*, (2017) further observed that anthropogenic pressure such as logging and hunting can lead to reduced nest densities and shifts in nesting locations. Therefore, the high nest abundance and evidence of continued use of montane sites in MCNP suggest that chimpanzees may be avoiding more accessible, disturbed lowland forests, relying instead on less disturbed high-elevation habitats for regular nesting.

Most nests in this study were found at elevations between 1600 and 1900 m above sea level, corresponding with areas of dense vegetation and strong canopy structure. The presence of nests of varying ages (fresh, recent, and old) within the same localities implies frequent reuse of preferred nesting zones. This pattern reflects long-term site fidelity, an attribute previously reported by Fruth and Hohmann (1994), and suggests that these sites serve as central nesting areas rather than transient refuges. Repeated nesting in the same zones also implies proximity to reliable feeding resources. Dutton *et al.*, (2017) and Sánchez-Megías *et al.*, (2024) similarly reported that chimpanzees often construct nests near fruiting trees and other food sources, thereby minimizing energy expenditure during foraging. Although water proximity varied from 10 to over 400 m in this study, it did not appear to be a determining factor in nest placement, which supports earlier conclusions by Barca *et al.*, (2018) and Hernandez-Aguilar *et al.*, (2020) that water availability has limited influence compared to tree structure and safety.

In all, the findings of this study corroborate earlier research that identifies montane and primary forests as critical nesting habitats for *Pan troglodytes ellioti*. The results confirm that nest site selection is strongly influenced by forest structure, tree species composition, elevation, and the degree of human disturbance (Fotang *et al.*, 2021; Dutton *et al.*, 2017; Lacroux, 2023). The consistent reuse of nest sites, preference for large and sturdy trees, and avoidance of disturbed areas collectively highlight the importance of conserving montane forests within MCNP. These habitats provide the structural and ecological requirements essential for chimpanzee nesting, feeding, and long-term survival. Therefore, targeted conservation measures such as limiting

logging, hunting, and agricultural encroachment in high-elevation zones are vital to maintaining viable chimpanzee populations in the Mount Cameroon National Park, West Coast Cluster.

The analysis of habitat utilization by chimpanzees in the Mount Cameroon National Park revealed clear variations in species composition and diversity across the three forest types. The montane forest, with the highest number of individual trees (135), exhibited dense vegetation structure and a higher abundance of tall canopy species such as *Podocarpus latifolius*, *Ficus sur*, and *Polyscias fulva*. This finding supports earlier studies that highlight the importance of tall, sturdy trees for nesting and feeding, as they provide both protection and suitable platforms for nest construction (Dutton *et al.*, 2017; Fotang *et al.*, 2021). Similar observations in the Ngel Nyaki and Ebo Forests revealed that *Pan troglodytes ellioti* consistently select large-canopy trees in montane zones, demonstrating a preference for structurally stable habitats with minimal disturbance (Dutton *et al.*, 2017; Kamgang *et al.*, 2018). The high density of suitable nesting trees in the montane forest therefore explains the concentration of nests recorded in this habitat, indicating that vegetation structure plays a pivotal role in chimpanzee habitat selection.

The sub-montane forest, although having fewer individual trees (70), exhibited the highest species diversity ($H' = 2.68$) and evenness ($E = 0.99$). This balanced distribution of species suggests a heterogeneous environment offering a wider range of nesting and feeding opportunities. High habitat diversity has been linked to increased foraging efficiency and behavioral flexibility among chimpanzees (Lacroux, 2023; Fotang *et al.*, 2021). The dominance of species such as *Nuxia congesta*, *Polyscias kikuyuensis*, and *Albizia gummifera* reflects the habitat's structural complexity and ecological stability, conditions that favor chimpanzee adaptation. Dutton *et al.*, (2017) similarly reported that sub-montane forests act as transitional zones where chimpanzees exhibit adaptive nesting behaviors, selecting from a variety of available tree species depending on food availability and canopy structure.

In contrast, the lowland forest recorded the fewest trees (20) and moderate diversity ($H' = 2.35$), although evenness remained high ($E = 0.98$). The dominance of *Pterocarpus soyauxii*, *Musanga cecropioides*, and *Terminalia ivorensis* indicates a more open and possibly disturbed environment, consistent with previous findings that chimpanzees adjust to secondary or degraded forests by utilizing available vegetation and scattered trees (McCarthy *et al.*, 2017; van Dijk, 2021). Such flexibility demonstrates the ecological resilience of *P. t. ellioti*, enabling them to exploit habitats with reduced canopy cover and altered forest composition when necessary. Comparable patterns were reported in fragmented forest landscapes where chimpanzees used regenerating vegetation for nesting despite human disturbances (McCarthy *et al.*, 2017).

The consistently high evenness values ($E > 0.9$) and Simpson indices (>0.88) across all habitats suggest a generally balanced forest composition that provides chimpanzees with adaptable resource options. However, the sub-montane forest appears to offer optimal ecological conditions, combining high species diversity with structural heterogeneity. These findings align with earlier observations that chimpanzees favor structurally complex habitats that ensure nesting stability, thermal comfort, and diverse food resources (Fotang *et al.*, 2021; Lacroux, 2023). Overall, the results demonstrate that chimpanzees in the MCNP exhibit adaptive flexibility in habitat use, exploiting diverse forest types based on resource availability and ecological structure. This capacity for ecological adjustment underscores their resilience, but also highlights the importance of maintaining habitat heterogeneity for the long-term conservation of *Pan troglodytes ellioti* in the region.

The study found that nest characteristics were consistent across habitats, with mean nest heights ranging from 11.5 to 11.7 meters, showing chimpanzees' preference for elevated sites that offer safety and visibility. Canopy cover averaged 68–71%, indicating a tendency toward moderately dense forests that provide both concealment and ventilation. The average DBH of nesting trees (65–68 cm) reflected a preference for mature, sturdy trees capable of supporting nest weight. These patterns align with findings by Dutton *et al.*, (2017) and Fotang *et al.*, (2021), who reported that *Pan troglodytes ellioti* consistently select tall, robust trees within moderately dense canopies for nesting stability and predator avoidance. Similar stability in nesting traits across elevations suggests that chimpanzees maintain consistent nesting strategies regardless of habitat type, a behavior also noted in studies by McCarthy *et al.*, (2017) and van Dijk (2021), emphasizing their adaptive but selective nesting preferences.

The study revealed distinct spatial variations in chimpanzee habitat use across the forest types. Vocalizations and footprints were least frequent in the montane forest (4.4% and 11.9%, respectively), suggesting limited surface activity despite high nest abundance, implying that this zone was primarily used for resting or night nesting. In contrast, higher frequencies of vocalizations and footprints in the submontane (47.1% and 37.1%) and lowland forests (55.0% and 45%) indicated more active daytime use, likely for feeding and movement. These findings suggested that chimpanzees used the montane forest mainly for nesting, while lower elevations supported foraging and social activities. Similar spatial partitioning of behavior was reported by Kühl *et al.*, (2019) and Wessling *et al.*, (2020), who found that chimpanzees adjust their use of habitat zones based on resource availability and microclimatic conditions. Likewise, Reynolds (2023) and Pruetz (2021) observed that chimpanzees display strong ecological flexibility, exploiting different forest strata for nesting and feeding to optimize safety and energy efficiency. These results therefore reflect adaptive habitat use patterns in response to ecological gradients and human pressure within the Mount Cameroon landscape.

The Generalized Linear Model (GLM) analysis showed that nest height and canopy cover varied slightly across the three forest types, indicating that ecological conditions influenced chimpanzee nesting behavior in the area. Mean nest heights ranged narrowly between 11.5 and 11.7 meters, showing consistent preference for elevated nesting positions, though greater variation in the lowland forest ($SD = 2.10$) suggested more heterogeneous vegetation or human disturbance. Canopy cover averaged between 68% and 71%, indicating a preference for moderately dense canopies that offer shade, concealment, and protection from rainfall. The slightly higher canopy cover in the submontane forest (70.62%) corresponded with higher vocalization rates, implying favorable nesting and social conditions in this habitat. Similar findings were reported by Wessling *et al.*, (2020) and Kühl *et al.*, (2019), who observed that chimpanzees select nesting sites with intermediate canopy density to balance visibility and protection. Moreover, Lehmann and Boesch (2021), noted that minor variations in canopy structure often reflect habitat-specific adaptations to local microclimates and disturbance. Overall, the results indicated that chimpanzees in MCNP displayed ecological flexibility in nest site selection while maintaining consistent structural preferences across habitats.

The Goodness-of-Fit results from the GLM analysis showed that the relationship between ecological factors particularly canopy cover and nest type and nest height varied across forest types. The submontane forest model had the best fit (Deviance/df = 2.71; AIC = 276.29), indicating that ecological variables such as canopy density and nest structure strongly influenced nest height in this habitat. This suggested that chimpanzee nesting behavior in the submontane zone was more predictable and ecologically driven. The montane forest model

showed a moderate fit (Deviance/df = 3.32; AIC = 549.15), implying that additional factors such as wind exposure or tree height variability at higher altitudes may have influenced nesting decisions. The lowland forest model, with the poorest fit (Deviance/df = 4.65; AIC = 87.00), reflected higher variability likely caused by human disturbance and selective logging. These findings align with those of Wessling *et al.*, (2020) and Gruber *et al.*, (2021), who reported that environmental stability and canopy structure strongly shape nesting patterns in chimpanzees, while anthropogenic pressures increase behavioral variability. Similarly, Pruett (2021) and Lehmann and Boesch (2021) emphasized that chimpanzees exhibit adaptive flexibility in response to habitat quality, adjusting nest height and site selection to optimize safety and comfort. Overall, the results highlighted the submontane forest as the most ecologically stable and preferred nesting environment for chimpanzees within MCNP.

The results showed that ecological factors influenced chimpanzee nesting differently across forest types. In the montane forest, canopy cover significantly affected nest height ($\chi^2 = 4.546$, $p = 0.033$), indicating that chimpanzees preferred denser canopies at higher elevations for protection and stability, consistent with findings by Tagg *et al.*, (2022) and Hockings and McLennan (2019). In contrast, sub-montane and lowland forests showed no significant effects of canopy cover on nest height ($p > 0.05$), suggesting that other factors such as food availability, tree species composition, or human disturbance shaped nesting behavior in these habitats, in line with observations by Kühl *et al.*, (2019) and Sakamaki *et al.*, (2021).

The GLM parameter estimates indicated that the relationship between canopy cover and nest height varied across forest types. In the montane forest, canopy cover had a significant negative effect on nest height ($B = -0.018$, $p = 0.033$), suggesting that denser canopies allowed chimpanzees to build slightly lower nests while maintaining protection and stability, consistent with observations by Tagg *et al.*, (2022) and Hockings and McLennan (2019). In the sub-montane and lowland forests, the effects of canopy cover on nest height were positive but non-significant ($B = 0.003$, $p = 0.758$; $B = 0.008$, $p = 0.765$), indicating that nesting height in these habitats was influenced more by other factors such as food availability, terrain, or human disturbance rather than canopy density, as reported by Kühl *et al.*, (2019) and Sakamaki *et al.*, (2021). Overall, the results demonstrated habitat-specific ecological influences on nesting behavior, with canopy cover being a key determinant in montane areas but less important in lower-elevation or more disturbed forests.

The scatter plot for the montane forest showed a slight negative correlation between nest height and canopy cover, indicating that as canopy density increased, chimpanzees tended to build nests slightly lower. This suggested that in denser canopies, mid-level branches provided adequate shelter and thermal protection, reducing the need for higher nests. Similarly, nest height and tree DBH exhibited a weak negative relationship, implying that trunk size was less important than branch structure and canopy stability in tree selection. Overall, these weak but ecologically meaningful trends supported the GLM results, showing that canopy cover modestly influenced nesting height in montane habitats, consistent with findings by Tagg *et al.*, (2022) and Hockings and McLennan (2019).

In the sub-montane forest, canopy cover and tree DBH showed very weak or near-zero correlations with nest height, as indicated by the almost flat regression lines. This suggested that variations in canopy density or tree size had little influence on vertical nest placement. The weak associations indicated that chimpanzees in sub-montane habitats used a broader range of tree types and canopy conditions, reflecting greater behavioral flexibility in nest site selection. These patterns also implied that other ecological or social factors, such as fruit availability,

nesting tradition, or proximity to feeding areas, likely had a stronger influence on nest placement than structural vegetation features, consistent with observations by Kühl *et al.*, (2019) and Sakamaki *et al.*, (2021).

In the lowland forest, correlation analysis indicated a weak positive relationship between nest height, canopy cover, and tree DBH, suggesting that taller nests were slightly associated with denser canopies and larger trees. However, the relationship was weak, indicating that chimpanzees used a variety of trees for nesting rather than being highly selective for specific canopy densities or trunk sizes. This pattern reflected behavioral flexibility and adaptation to the available habitat, with other factors such as safety, comfort, or tree species likely influencing nest site selection more strongly than canopy cover or DBH alone, consistent with findings by Kühl *et al.*, (2019) and Sakamaki *et al.*, (2021).

The MaxEnt habitat suitability model indicated that chimpanzee distribution was strongly influenced by climatic factors, particularly temperature and precipitation, across lowland, sub-montane, and montane forests. Areas of higher suitability, primarily in montane and sub-montane zones, corresponded to cooler temperatures and higher rainfall, reflecting chimpanzees' preference for environments that provide adequate food resources, vegetation cover, and thermal comfort. No habitat reached perfect suitability, suggesting that chimpanzees utilized a range of habitats rather than being restricted to optimal zones. These findings align with studies by Kühl *et al.*, (2019) and Tagg *et al.*, (2022), which reported that chimpanzee distribution is shaped by environmental gradients, with cooler and wetter areas supporting higher activity and nesting.

The spatial distribution map showed that chimpanzee nests were clustered rather than uniformly distributed across montane, sub-montane, and lowland forests. Higher nest densities occurred in montane and sub-montane zones, reflecting more favorable nesting conditions such as suitable tree structure, canopy cover, and food availability. In contrast, the lowland forest had fewer nests, likely due to human encroachment and lower resource availability. The human activity map revealed that traps and wire snares were present across all forest types, with higher concentrations in sub-montane and lowland areas, often near trails and water sources, suggesting that accessibility influenced hunting pressure. These patterns indicate that chimpanzee nesting distribution is shaped by both ecological suitability and anthropogenic disturbance, consistent with findings by Kühl *et al.*, (2019) and Hockings and McLennan (2019), who reported that human activity can restrict habitat use and influence nesting site selection.

5. Conclusion

Chimpanzees in the Mount Cameroon National Park use their habitats selectively and adaptively, showing a strong preference for montane and sub-montane forests. Montane areas serve mainly as secure, long-term nesting zones due to their dense vegetation, sturdy trees, and favorable microclimates, even though direct activity signs are limited. Sub-montane and lowland forests function more as feeding and movement areas. Across all forest types, chimpanzees display flexibility in nest construction and tree choice, allowing them to exploit diverse ecological conditions. Climatic factors especially cooler temperatures and higher rainfall at higher elevations further influence habitat selection. In all habitat use is shaped by vegetation structure, safety, resource availability, and environmental conditions, highlighting the importance of conserving high-elevation forests for chimpanzee survival.

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