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# An Integrated Assessment of Anthropogenic and Ecological Threats to Pangolin Survival in Takamanda National Park, Southwest Region of Cameroon

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## ABSTRACT

Pangolins are the world's most trafficked wild mammals, yet cryptic behaviours hinder the localised, empirical data necessary for effective conservation management. This study provides an integrated assessment of ecological and anthropogenic threats facing three pangolin species (Phataginus tricuspis, P. tetradactyla, and Smutsia gigantea) within Takamanda National Park, Cameroon. Utilizing a mixed-methods approach, we triangulated decades of remote sensing data with local ecological knowledge (LEK) and focus group datasets. Land use/land cover analysis revealed severe habitat fragmentation, with critical dense forest cover declining by 10.34% (6890.83/ha) between 2013 and 2023, driven primarily by inward agricultural encroachment from enclave villages. Logistic regression models confirmed intense pangolin avoidance behaviour toward human activity, revealing powerful deterrent relationships with bush huts (OR = 0.049, p = 0.003) and wire snares (OR = 0.441, p = 0.001). Socio-economic profiles identified pervasive local consumption 80% of respondents have consumed pangolin meat and acute poverty (88.7%) fuelling a highly commercialized bushmeat trade, alongside an active, transnational scale trafficking pipeline driven by foreign traders (5.3%). This immediate hunting pressure is severely compounded by governance deficits arising from the nearly a decade long regional Anglophone Crisis, zero baseline cultural taboos protecting the species, and critical biological misconceptions regarding reproductive rates in high-encroachment zones. Eventually, 28.6% of communities attribute perceived declines in poaching strictly to species scarcity. Reversing this trend requires an immediate transition from reactive enforcement to multi-faceted, community-led management that pairs customary legal integration with sustainable cocoa-livelihood interventions.

## INTRODUCTION

Pangolins (Order Pholidota) hold the distinction of being the most heavily trafficked wild mammals on Earth, subjected to an unprecedented scale of exploitation that threatens all eight extant Afro-Asian species with extinction (Challender *et al.*, 2014; Heinrich *et al.*, 2017). Driven by an insatiable international demand for their keratinous scales in traditional medicine and a domestic appetite for their meat as a luxury or subsistence protein, global pangolin populations have collapsed (Wu *et al.*, 2017; UNODC, 2024). In Central Africa, which serves as a stronghold for three iconic species; the white-bellied pangolin (Phataginus tricuspis), the black-bellied pangolin (Phataginus tetradactyla), and the giant pangolin (Smutsia gigantea) the intensity of this extraction has transitioned from localised hunting to highly organized, transnational commercial supply lines (Ingram *et al.*, 2017; CITES, 2016). Despite their high-profile protection listings, including an absolute ban on international trade under CITES Appendix I, cryptic mammalian species face a compounding crisis: their nocturnal and highly secretive lifecycles restrict the gathering of baseline ecological data, rendering traditional, reactive enforcement mechanisms limited (Challender *et al.*, 2015).

This conservation spot is magnified in the rainforests of the Gulf of Guinea, a global biodiversity hotspot split by the transboundary corridor connecting southwestern Cameroon and southeastern Nigeria. At the centre of this ecosystem lies Takamanda National Park (TNP), an area long celebrated for its exceptional endemism and critical role in the survival of evolutionary distinct megafauna, such as the Cross River gorilla (Gorilla gorilla diehli) (Sunderland *et al.*, 2014). However, protected areas across this landscape are increasingly functioning as structural ecological islands besieged by a complex web of anthropogenic pressures (Adams *et al.*, 2004). Deforestation, driven by smallholder agricultural expansion and a burgeoning, border-adjacent cash-crop market for cocoa (Theobroma cacao) and oil palm, is rapidly degrading the dense primary canopies upon which Pholidota species depend (Kimengsi & Lambi, 2015). When critical forest habitats fragment, wildlife populations become isolated, disrupting gene flow and channelling animals into narrow, accessible corridors where their vulnerability to human encounter easily escalates (Laurance *et al.*, 2007).

Compounding these structural landscape alterations is a profound governance vacuum. The near decade-long socio-political conflict known as the 'Anglophone Crisis' has severely compromised wildlife law enforcement across the South West Region of Cameroon (International Crisis Group, 2017). The unfortunate unplanned absence of

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eco-guards has allowed historic protection mandates to lapse, inviting local communities to reactivate abandoned agricultural clearings and resume unrestricted hunting operations within the park cores areas. In this landscape limited economic stability, acute poverty operates as the primary engine driving natural resource extraction, forcing local communities to exploit the high financial liquidity of the illicit bushmeat and scale trade to secure basic household livelihoods.

Addressing this multi-dimensional crisis requires moving beyond isolated ecological surveys or purely socio-economic perception studies. True conservation efficiency rests on our ability to integrate Local Ecological Knowledge (LEK) the lived, historical insights of indigenous communities who share these forest matrices with empirical spatial and statistical modelling (Berkes, 2008; Mouafo *et al.*, 2021). While communities harbour a profound understanding of localised wildlife presence, their traditional knowledge can be fragmented, occasionally harbouring critical biological misconceptions such as inflated reproductive baselines that mask species vulnerability and inadvertently legitimize over-exploitation (Ingram et al 2018, IFAW, 2024). Furthermore, unlike totemic or ancestral species that possess deeply rooted cultural safeguards within local belief systems, African pangolins lack traditional taboos, leaving them exposed to purely utilitarian extraction (Mouafo *et al.*, 2021; WildAid, 2024b).

To address these critical knowledge gaps, this study explores and presents a comprehensive, integrated assessment of the ecological and anthropogenic threats to pangolin survival within Takamanda National Park. By pairing Land Use and Land Cover (LULC) remote sensing with multiple logistic regression modelling and spatially explicit correspondence analyses, we map the structural landscape changes against quantitative indicators of human pressure (Tataw *et al.*, 2024). Concurrently, we triangulate these spatial datasets with extensive LEK surveys and Focus Group Discussions (FGDs) to unravel the socio-economic drivers, consumer motivations, and governance deficits that sustain the local trade. Finally, this paper aims to provide a robust empirical baseline capable of transitioning TNP's conservation management from a posture of compromised, reactive enforcement to an actionable, community-led framework that bridges local livelihoods with the international legal protection mandates required to safeguard these extraordinary species. This research answers the following sub-questions: How can Local Ecological Knowledge (LEK) be integrated with empirical spatial datasets to reconcile community biological misconceptions and the absence of traditional cultural taboos with international protection mandates? How have land use and land cover (LULC) changes and agricultural expansion fragmented primary forest canopies within Takamanda National Park? In what ways have the governance deficits induced by the 'Anglophone Crisis' interacted with acute household poverty to drive the transition of localised subsistence pangolin hunting into organized, commercialized trade networks? Finaly, this paper provides a robust empirical baseline on anthropogenic and ecological threats to pangolin survival in Takamanda National Park.

## LITERATURE REVIEW

The illegal poaching, trafficking, and sale of Pangolins and their derivatives on the black market constitutes the Pangolin trade. Pangolins are the world's most trafficked mammal, representing as much as 20% of all illegal wildlife trade (Sutter *et al.*, 2014; Kelly *et al.*, 2015; Franchineau *et al.*, 2016). The International Union for Conservation of Nature (IUCN) reported that over a million Pangolins were poached in the decade preceding 2014 (IUCN, 2014).

These animals are primarily trafficked for their scales, which are used in Traditional Chinese Medicine (TCM) for the purported treatment of various health conditions, and are also consumed as a luxury food in Vietnam and China (Mahmood *et al.*, 2019). In Africa, Pangolins are traded as bushmeat, used in rituals and spiritual practices, and incorporated into African Traditional Medicine (ATM). Furthermore, Pangolins are sometimes hunted for their use in clothing and fashion. Despite restrictions on the Pangolin market imposed by the Convention on International Trade in Endangered Species (CITES) since 1975, and the 2016 inclusion of all eight Pangolin species (the highest level of protection for species threatened with extinction) (Carrington *et al.*, 2016; CITES, 2017), the trade continues. All Pangolin species are also listed on the IUCN Red List, with declining populations and conservation statuses ranging from Vulnerable to Critically Endangered (Mahmood *et al.*, 2019).

Ingram *et al.* (2016) suggest a growing trend of Pangolin exploitation for local consumption across Africa. This increase, coupled with rising urban demand for bushmeat and international demand for Pangolin scales, compounded by inadequate law enforcement and socioeconomic factors such as unemployment and poverty, is pushing Pangolins and other species toward extinction. The illegal commercial bushmeat trade, driven by demand from Cameroon's expanding urban populations, and the illegal intercontinental trade in Pangolins, particularly scales destined for East and Southeast Asia, have both increased significantly over the last decade (Challender & Hywood, 2012; Gomez *et al.*, 2016).

In Cameroon and other Central African countries, substantial rural-to-urban migration sees a large proportion of the working-age population leaving rural areas for urban and semi-urban centres. Despite potentially higher costs, many migrants still desire the bushmeat they traditionally consumed in rural areas. Two separate studies conducted in select Cameroonian towns and cities revealed that Pangolin meat was the second most preferred bushmeat among consumers in restaurants, second only to porcupine in both studies (Linh *et al.*, 2019; ZSL & TRAFFIC, 2019). Consumers cited the desirable taste of Pangolin meat as the primary reason for its popularity.

In Asia, Pangolins are believed to possess medicinal properties. Despite the lack of scientific evidence supporting these claims, a WildAid survey conducted in six major Chinese cities revealed that 70% of respondents believed in the medicinal value of Pangolin products (Vallianos *et al.*, 2016). China consumes approximately 25 tonnes of Pangolin scales annually (Vallianos *et al.*, 2016). As Asian Pangolin populations have declined rapidly, making them increasingly scarce, traffickers have turned to Africa to meet Asian demand (Challender & Hywood, 2012), fuelling a surge in international and intercontinental Pangolin trafficking. Cameroon, Ghana, and Ivory Coast were significant exporters of Pangolins in 2017, while in 2018, the largest seizures of African Pangolins in Asia originated from Cameroon, the Republic of Congo, and Nigeria (USAID, 2019). In 2018, 70% of international Pangolin seizures in Asia were exported from Nigeria, primarily destined for China and Vietnam (USAID, 2019). A single seizure of over 5 tonnes of Pangolin scales occurred in Vietnam in May 2019, with the shipment originating from Nigeria (Hywood, 2012). In Cameroon, the focus of the Pangolin trade shifted from meat to scales around 2013 (Ingram *et al.*, 2019).

The spatial ecology of Pangolins within TNP diverse habitats remains poorly understood. While ecological modelling techniques offer valuable insights into species' spatial ecology (Morrison *et al.*, 2006), their application to Pangolins within this specific protected area is lacking. This research aims to elucidate essential aspects such as habitat preferences and resource utilization patterns of Pangolins within the park's unique environmental context. Furthermore, investigating the distribution of different Pangolin species within Takamanda will contribute a more understanding of their distinct ecological requirements in this comparatively understudied region of Africa (Kingdon *et al.*, 2013). While the overarching threats of illegal wildlife trade (poaching) and potential habitat degradation are acknowledged as major drivers of Pangolin decline across Africa (Challender *et al.*, 2019). Mapping Pangolin distribution in relation to these threats will provide essential spatial intelligence for park management and conservation organizations to strategically prioritize conservation efforts and allocate resources effectively (Caro *et al.*, 2004; Wilson & Delahay, 2001).

## MATERIALS AND METHODS

### Study area

Established in 1933 as a Forest Reserve and upgraded to a NP in 2008, Takamanda National Park (Fig. 1), is a crucial part of the Cross River-Korup-Takamanda trans-boundary conservation landscape, which straddles the Cameroon-Nigeria border (UNESCO, 2024). Located in the Southwest Region of Cameroon (5°59' and 6°21' N and 9°11' and 9°30'E) it covers an area of c. 675.99 km² (Takamanda National Park, 2010), sharing a western border with the Okwango Range of Nigeria's Cross River National Park. Its topography varies from less than 25 meters above sea level (ASL) in the south to over 1,725 meters ASL on its sharply steep slopes (Takamanda National Park, 2010). The vegetation is Guinean-Congolian forest, and its climate is humid-tropical, with a short dry season from November to March and a longer wet season from April to October (Takamanda National Park 2010). Over the 2021- 2024 study period, mean annual rainfall for the area was approximately 2,400 mm, with peak rainfall in July and August. Mean monthly temperatures ranged from 24°C in February to 27°C in January, with a maximum of 28.2°C, typically occurring in March. The park's drainage system is dominated by perennial streams and rivers, principally including the Makponi, Magbe, Mapu, and Manyu rivers, which generally flow north to south and eventually empty into the Cross River.

Approximately 10,000 plant species have been identified, including commercially valuable timber and medicinal plants, as well as rare and endemic flora (Sunderland *et al.*, 2023). Takamanda also harbours a significant number of animal species, including 22 large mammals, 313 birds, 75 reptiles and amphibians, and various insect and fish species (Takamanda National Park, 2010; Sunderland-Groves *et al.*, 2021). This includes populations of several threatened and endangered species, notably the Cross River gorilla (Gorilla gorilla diehli; Critically Endangered), Nigeria-Cameroon chimpanzee (Pan troglodytes ellioti; Endangered), forest elephant (Loxodonta cyclotis; Critically Endangered), and three species of pangolins: black-bellied pangolin (Phataginus tetradactyla; Vulnerable), giant ground pangolin (Smutsia gigantea; Endangered), and white-bellied pangolin (Phataginus tricuspis; Endangered) (Sunderland, *et al.*, 2023; Takamanda National Park, 2025).

The park is surrounded by 18 villages, with three enclaves located fully within its boundaries, inhabited by diverse ethnic groups including the Anyang, Assumbo, Avande, Basho and Boki. The northern part of the park is also interspersed with the Mbororo indigenous people, who are primarily cattle herders. The park is also within 5-10 km proximity of other 18 villages in Cameroon and Nigeria. For collaborative management and conservation, the peripheral villages are organized into five clusters: Northern, Southwestern, Eastern, Southeastern, and Western. Each cluster elects a Cluster Facilitator (CF) with a monthly stipend to serve as a key collaborator. The CFs represent their communities in activities supported by the MINFOF-funded Program for the Sustainable Management of Natural Resources in the Southwest Region (PSMNR). MINFOF (Ministry of Forestry and Wildlife) is a government ministry in Cameroon whose primary mandate is to develop, implement, and evaluate the country's forest and wildlife policy. This includes the management and protection of national forests, the promotion of reforestation, and the enforcement of laws against forest crimes. MINFOF also works with national and international partners to promote sustainable management of Cameroon's rich biodiversity.

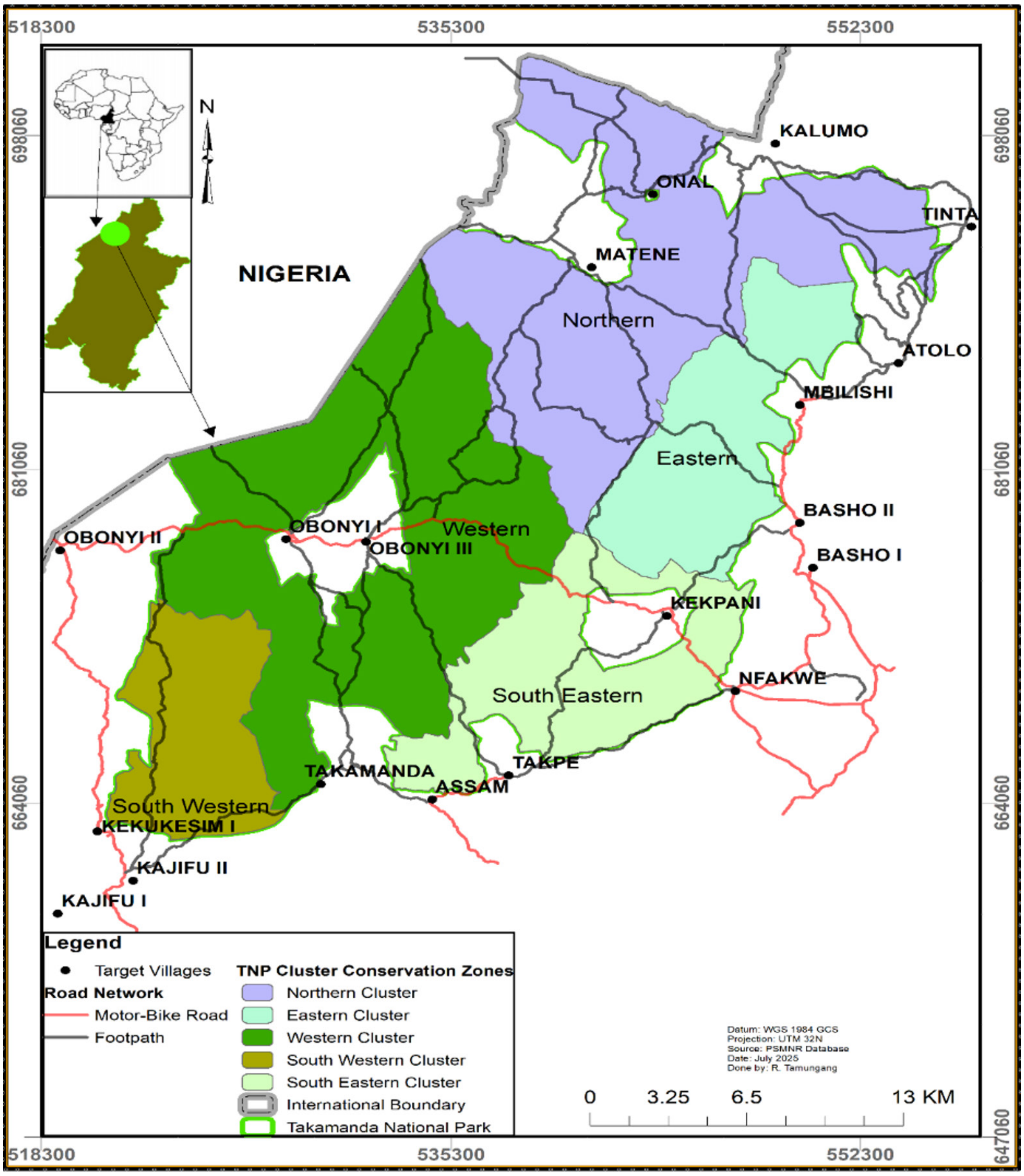


**Figure 1:** Map of Takamanda National Park and villages associated with pangolin data collection, South West Region, Cameroon.

## Methods

### Community-led linear transects

Data on Anthropogenic and ecological threats were collected from May 2023 to April 2024 across six village sites (Takamanda, Obonyi I, Takpe, Kekpani, Basho II, and Mbilishie) selected for accessibility, security, habitat representation, and known pangolin presence based on local ecological knowledge disclosed through the CFs and citizen scientists. Data collection was carried out over three clusters (Western, South Eastern, and Eastern) through field surveys utilizing line transects across primary forest, secondary forest, and farmland habitats. At each sampling site, a binary presence/absence protocol for pangolins was implemented alongside an exhaustive anthropogenic threat assessment, recording direct hunting indicators (snares, bullet shells) and human signs (footpaths, machete wounds etc) to evaluate spatial patterns of human disturbance.

To quantify agricultural encroachment and habitat degradation within Takamanda National Park, a hybrid methodology integrating satellite remote sensing with community-level socio-ecological field mapping was deployed. A local-scale assessment of land use change was conducted through the visual interpretation and processing of Landsat satellite imagery. Specifically, Enhanced Thematic Mapper (ETM) data from December 2013 and Operational Land Imager (OLI) data from January 2023 (Landsat 8) were used to map land cover transformations (Tataw *et al.*, 2024, Taboko *et al.*, 2026). These images were freely obtained from the United States Geological Survey (USGS) web portals (glovis.usgs.gov and earthexplorer.usgs.gov) (Tataw *et al.*, 2024, Taboko *et al.*, 2026). Land use change analysis further incorporated administrative, topographic, and forest maps obtained from the Ministry of Forestry and Wildlife. Ground truthing of spatial data was conducted on 99 plots (111.6

hectares) using a GPS (Garmin 64S- model). Meanwhile, the FAO 2016 land cover classification framework was used, table 3. Ground control points (GCPs) were established at known latitude, longitude, and elevation. These GCPs were distributed across the study area to avoid clustering. A minimum of ten GCPs were collected along the periphery of each village, encompassing high, medium, and low elevation zones through a Garmin 420 handheld GPS data logger. GCPs were positioned at least 50 meters apart near stable and identifiable features. Assessment of land use change at the local level was done through eleven peripheral park communities. Here, satellite imagery for 2013 and 2023 were interpreted alongside 99 plots. These plots had been assessed for land use activities as part of the ground-truthing process conducted between 2022 and 2023 in the study area. The African landcover nomenclature map as described by Pare *et al.*, (2008) and Mukete *et al.*, (2018b) were used. To facilitate visual interpretation, four land use classes were described which included dense forests, secondary forests farmlands and settlements, table 2. Furthermore, ArcMap 10.2, ERDAS IMAGINE 2014 and ENVI 5.1 as described by Abdul *et al.*, (2019) were used to perform image pre-processing, geometric corrections and mapping (Tataw *et al.*, 2024, Taboko *et al.*, 2026).

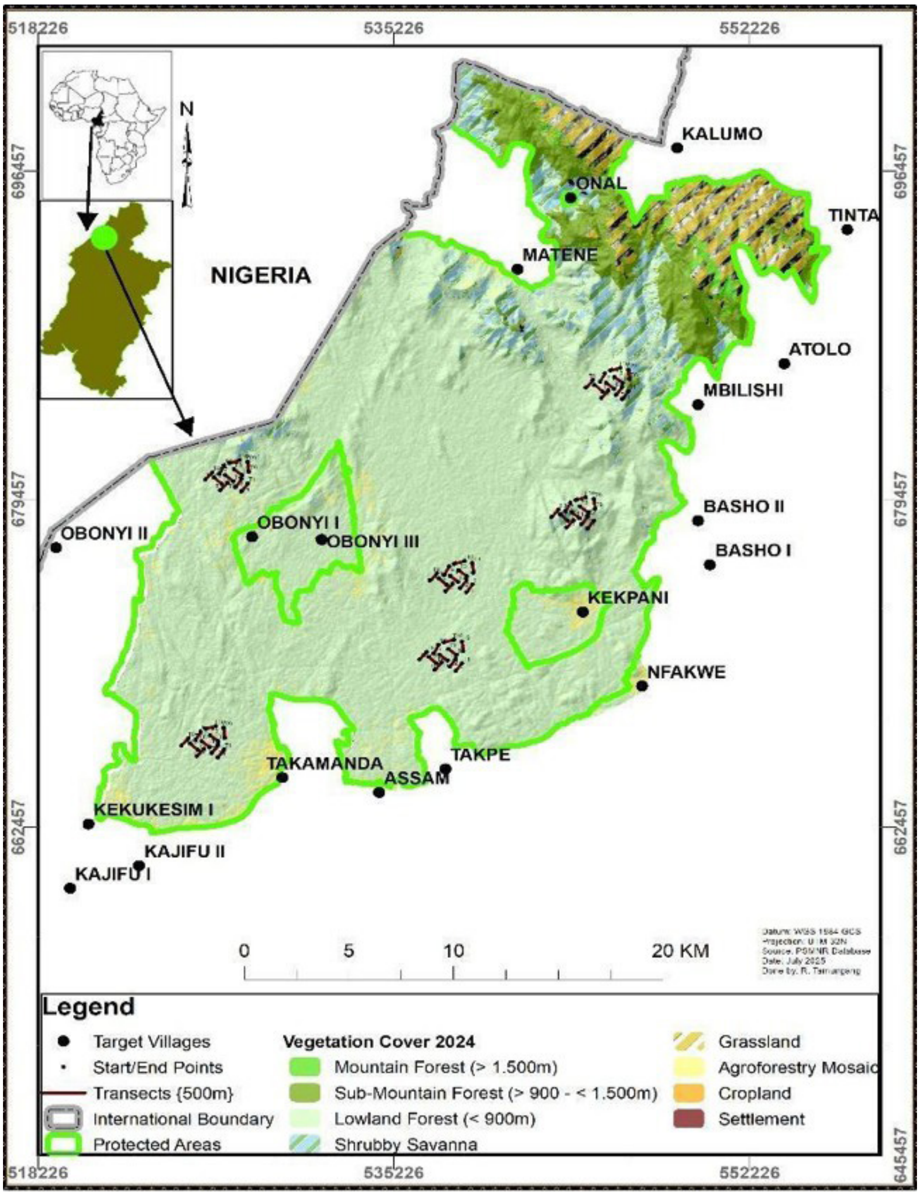


**Figure 2:** Proximate locations of linear transects of data collection

**Analyses**

Statistical analyses were executed using a multi-stage approach. Categorical frequency distributions of wildlife sightings were evaluated using Chi-Square (Chi2) tests of equality of proportions. To assess the simultaneous predictive impact of habitat type and human encroachment on the probability of species occurrence, a binary multiple logistic regression model was fit, with model fit evaluated via McFadden's pseudo-R2 and effect sizes expressed as Odds Ratios (OR). Finally, to visualize geographic variation in threat composition across park clusters, a Simple Correspondence Analysis (CA) was performed to extract orthogonal dimensions of variance and map spatial associations via a two-dimensional ordination biplot.

**Data analysis for land use and land cover change**

After each land use type was delineated, its area and proportion of each land use cover to the total area was computed. The net change in each land-use type during the study period was calculated as the difference in total area between the two assessment periods relative to the initial baseline year. To normalise these transitions, the annual rate of change was calculated by dividing the relative change by the precise time interval (Puyravaud, 2003):

Relative Change (ha) = A2 - A1........................................................(1)

Relative Change (%) = (A2 - A1/A1) x 100..................................(2)

Annual Rate of Change (ha/year) = (A2 - A1) / (T2 - T1).........(3)

Where A1 represents the specific land-cover area (ha) at the initial baseline year (T1 = 2013),

A2 represents the land-cover area (ha) at the final monitoring year (T2 = 2023), and T2 - T1 denotes the 10-year temporal interval.

In order to obtain the overall accuracy, the satellite images of 2013 and 2023 which were interpreted accompanied by 99 plots assessed for land use activities as part of the ground-truthing process conducted at the study site were used. This accuracy of digital land cover classifications was quantitatively expressed by building and interpreting a classification error matrix according to Esam *et al.*, (2012) since the error matrix compares data from a classified image or land cover map to ground-truthing data (Tataw *et al.*, 2024).

Generally, classification accuracy is the degree of similarity between the remotely sensed data and ground truthing information. To evaluate the thematic reliability of the digital land-cover classifications, a classification error matrix was constructed by comparing the classified satellite pixels against the 99 ground-truthing plots (Esam *et al.*, 2012). From this matrix, the overall accuracy and the Cohen's Kappa coefficient (K) were calculated to measure the level of agreement between the remotely sensed data and actual ground reality. The Kappa statistic was calculated using the standard formulation (Stehman & Foody, 2019):

K=1−Pe-Po/1-Pe

Where Po represents the observed proportion of correct agreement (the overall classification accuracy), and Pe represents the expected proportion of agreement arriving purely by chance. A Kappa value above 70% was targeted as the threshold for acceptable thematic map consistency.

## RESULTS AND DISCUSSION

**Threats to pangolin populations**

Pangolin sightings varied significantly in relation to anthropogenic features (Table 1). The vast majority of sightings (92.1%) occurred in primary forest, with only 4.5% in secondary forest and 3.4% in farmland, a highly significant difference ($\chi^2 = 1216.9$, $p < 0.001$). This indicates a strong preference for intact, undisturbed habitats and a likely sensitivity to forest degradation.

Regarding direct human signs, 64.9% of pangolin sightings were associated with areas absent of anthropogenic indicators. Among areas with signs of human activity, the most frequent were machete marks (13.3%) and bullet shells (6.7%). More subtle indicators such as trails, wire snares, tracks, and combinations of these accounted for a much smaller proportion of sightings (<5% each). The association between anthropogenic signs and pangolin presence was highly significant ($\chi^2 = 3495.6$, $p < 0.001$), reinforcing that human disturbance is a major threat to pangolin populations in the park.

Pangolins are highly sensitive to human disturbance. Sightings were overwhelmingly concentrated in undisturbed, primary forest zones, while areas bearing signs of hunting or forest exploitation (machetes, bullet shells, snares) were significantly avoided. This pattern confirms that anthropogenic pressure is a key threat to pangolin survival in the park and should be a central focus of conservation interventions (Table 1).

**Table 1:** Threats to pangolins population as indicated by Forest types and Anthropogenic indices of habitat disturbance.

| Parameter | Subcategories | Frequency | Percentage | $X^2$-Statistic | P-value[1] |
|---|---|---|---|---|---|
| Types of forest | Farmland | 26 | 3.43 | 1216.9 | <0.001 |
| | Primary | 698 | 92.08 | | |
| | Secondary | 34 | 4.49 | | |
| Anthropogenic signs | Bullet shell | 51 | 6.73 | 3495.6 | <0.001 |
| | Bush hut | 1 | 0.13 | | |
| | Footprint | 9 | 1.19 | | |
| | Machet | 101 | 13.32 | | |
| | None | 492 | 64.91 | | |
| | Old dress | 6 | 0.79 | | |
| | Track | 4 | 0.53 | | |
| | Trail & bullet shell | 7 | 0.92 | | |

| | | | | | |
|---|---|---|---|---|---|
| | Trail & bush hut | 7 | 0.92 | | |
| | Trail & wire snare | 7 | 0.92 | | |
| | Trails | 37 | 4.88 | | |
| | Wire snare | 36 | 4.75 | | |

*Chi Square Test of Equality of Proportions*

A multiple logistic regression model was conducted to examine the influence of anthropogenic signs and forest type on the probability of pangolin presence within Takamanda National Park. The model yielded a McFadden's pseudo-$R^2$ of 0.03, indicating that while the included predictors contributed to the model, they explained only a small proportion (3%) of the variation in pangolin presence. Nevertheless, several predictors showed statistically significant effects (Table 2).

Among the anthropogenic signs, the presence of bush huts, footprints, machetes, tracks, trails, and wire snares were all significantly associated with reduced odds of pangolin presence ($p<0.01$). For example, pangolins were approximately 95% less likely to be found in areas with bush huts (OR = 0.049, p = 0.003), and over 80% less likely where footprints (OR = 0.186) or wire snares (OR = 0.441) were present. These results suggest pangolins actively avoid areas with visible signs of human activity or hunting.

In terms of habitat, both primary forest (OR = 0.490, p = 0.002) and secondary forest (OR = 0.277, $p < 0.001$) were associated with significantly lower odds of pangolin presence compared to the baseline category (likely 'farm bush' or 'disturbed vegetation'). This unexpected finding may reflect increased human activity in otherwise intact forest areas or a shift in pangolin habitat use toward more edge or disturbed environments where detection rates may be higher.

Overall, the model highlights the strong negative association between pangolin presence and direct or indirect signs of human disturbance. While the model explains a modest amount of variation, the significant predictors provide critical insights into the impacts of anthropogenic pressure on pangolin distribution in the park (Table 2).

**Table 2:** Multiple logistics regression - predicting pangolin presence based anthropogenic signs and forest type

| **Term** | **Odds ratio** | **Std. Error** | **Statistic** | **P-Value** |
|---|---|---|---|---|
| (Intercept) | 1.0421 | 0.288 | 0.143 | 0.886 |
| Anthropogenic_signs (Bush hut) | 0.0490 | 1.027 | -2.937 | 0.003 |
| Anthropogenic_signs (Foot path) | 0.0010 | 359.695 | -0.044 | 0.965 |
| Anthropogenic_signs (Footprint) | 0.1859 | 0.388 | -4.334 | <0.001 |
| Anthropogenic_signs (Machet) | 0.3952 | 0.204 | -4.560 | <0.001 |
| Anthropogenic_signs (Machet wounds) on trees | 0.0010 | 508.245 | -0.031 | 0.975 |
| Anthropogenic_signs (None) | 0.2742 | 0.178 | -7.267 | <0.001 |
| Anthropogenic_signs (Old dress) | 30677624 | 979.600 | 0.018 | 0.986 |
| Anthropogenic_signs (Old green cap) | 0.0010 | 979.610 | -0.017 | 0.986 |
| Anthropogenic_signs (Plastic) | 0.0010 | 1199.772 | -0.013 | 0.989 |
| Anthropogenic_signs (Sound of gunshot) | 0.0010 | 565.578 | -0.028 | 0.978 |
| Anthropogenic_signs (Track) | 0.1633 | 0.548 | -3.306 | 0.001 |
| Anthropogenic_signs (Trail & bullet shell) | 0.9800 | 0.494 | -0.041 | 0.967 |
| Anthropogenic_signs (Trail & bush hut) | 0.9800 | 0.494 | -0.041 | 0.967 |
| Anthropogenic_signs (Trail & wire snare) | 1.1115 | 0.500 | 0.211 | 0.833 |
| Anthropogenic_signs (Trails) | 0.3860 | 0.250 | -3.812 | <0.001 |
| Anthropogenic_signs (Wire snare) | 0.4412 | 0.251 | -3.255 | 0.001 |
| Types_of_Forest (Primary) | 0.4896 | 0.231 | -3.085 | 0.002 |
| Types_of_Forest (Secondary) | 0.2773 | 0.291 | -4.407 | <0.001 |

**Simple correspondence analysis of anthropogenic influence and cluster**

The analysis revealed that the first two dimensions accounted for 100% of the total inertia, with Dimension 1 capturing 60.4% of the variation and Dimension 2 explaining 39.6% (Table 3). This indicates that a two-dimensional solution sufficiently represents the relationships in the data.

**Table 3:** Proportion of variation explained by each dimension

| Parameter | Dim. 1 | Dim. 2 |
|---|---|---|
| Eigenvalue | 0.142 | 0.094 |
| Percentage variance | 60.4 | 39.6 |
| Cumulative percentage variance | 60.355 | 100 |

The biplot (Figure 3) shows that anthropogenic signs were more closely associated with the South Eastern and Eastern clusters, whereas the Western cluster was more aligned with the absence of anthropogenic activity. This spatial pattern may reflect varying degrees of human pressure across the park, with Western areas experiencing relatively lower disturbance.

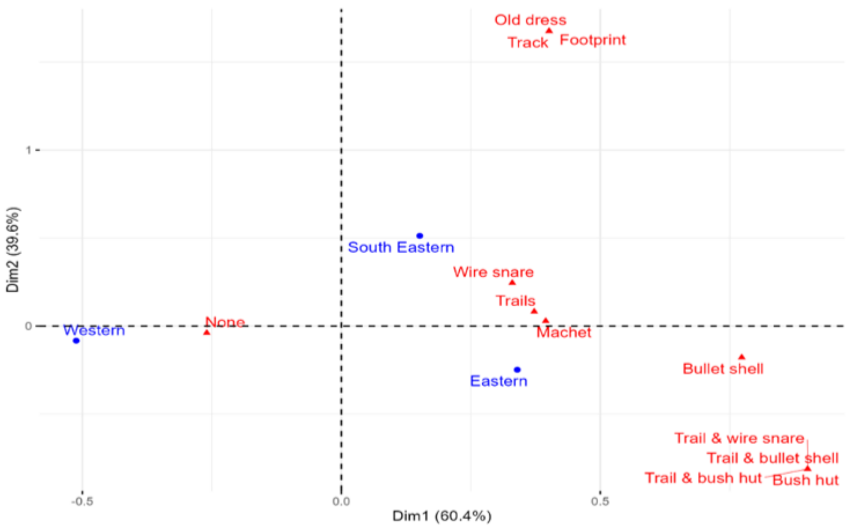


**Figure 3:** Correspondence analysis biplot

Further, the greatest contributor to Dimension 1 was the absence of anthropogenic signs ('None'), accounting for 31.13%, followed by bullet shells (27.51%) and machetes (14.33%), suggesting a gradient from undisturbed to more heavily disturbed areas along this axis. In Dimension 2, footprints made the largest contribution (34.74%), followed by old dresses (worn out clothes) (23.26%) and tracks (15.44%), indicating that this dimension may capture variability related to recent human presence or transit activity (Table 4). Overall, the correspondence analysis highlights clear spatial differentiation in anthropogenic influence across clusters, with vital implications for pangolin conservation and patrol planning in more threatened zones.

**Table 4:** Contribution of variables to the different dimensions

| Anthropogenic sign | Dim. 1 | Dim. 2 |
|---|---|---|
| Bullet shell | 27.51 | 2.22 |
| Bush hut | 0.73 | 0.91 |
| Footprint | 1.31 | 34.74 |
| Machet | 14.33 | 0.12 |
| None | 31.13 | 1.05 |
| Old dress | 0.87 | 23.26 |
| Track | 0.58 | 15.44 |
| Trail & bullet shell | 5.12 | 6.35 |
| Trail & bush hut | 5.12 | 6.35 |
| Trail & wire snare | 5.12 | 6.35 |

**Assessment of encroachment**

A spatial analysis of encroachment showed an estimated 111.6 hectares (ha) of which 100.4 ha are active farmland (old and new), 4.5 ha of farm extensions, and 6.9 ha of fallow land to have been cleared within the park especially around the Western, Eastern, and Southeastern zones, figure 2.

Generally, 78 individuals were found to have encroached with 99 farms into the park. As shown in table 1 below, 7 old and inactive (deserted) farms were found around the western and southeastern clusters of Obonyi I, Obonyi III, Takpe, and Nfakwe. Meanwhile, over 35 old and active farms were found inside the park, primarily around the western cluster of Obonyi I and III. After several years of abandonment, these farms were observed to have recently been re-cleared by their owners to resume cultivation. Similarly, around the western cluster, 32 newly encroached farms were recorded. Here, 14 owners of existing farms were found clearing new parcels of land within the park. With regards to fallows, two types of fallow lands were identified including parcels cleared for speculative purposes and abandoned or previously cultivated cocoa farms left to fallow for extended periods. A total of 5 speculative and 13 fallow farms were recorded. Additionally, several instances of farm extensions were observed. The expansion of existing farms is a common local practice, with extensions often matching the size of the original plots, table 5.

**Table 5:** Number of encroached farms in Takamanda National Park

| No | Village | No of farmers | No of farms | Encroachment type |
|---|---|---|---|---|
| 1 | Obonyi l | 23 | 33 | 4 extensions and 29 fallows |
| 2 | Obonyi ll | 0 | 0 | No encroachment |
| 3 | Obonyi lll | 26 | 39 | 31 new farms, 3 extensions and 5 fallows |
| 4 | Takamanda | 0 | 0 | No encroachment |
| 5 | Assam | 0 | 0 | No encroachment |
| 6 | Takpe | 3 | 3 | 2 old active farms and 1 new farm |
| 7 | Nfakwe | 5 | 5 | 4 old active farms and 1 inactive farm |
| 8 | Kekpani | 9 | 9 | 9 extensions |
| 9 | Basho 1 | 0 | 0 | No encroachment |
| 10 | Basho ll | 10 | 10 | 4 new farms and 6 old active farms |
| 11 | Mbilishe | 2 | 2 | 2 deserted farms |
| | Total | 78 | 99 | |

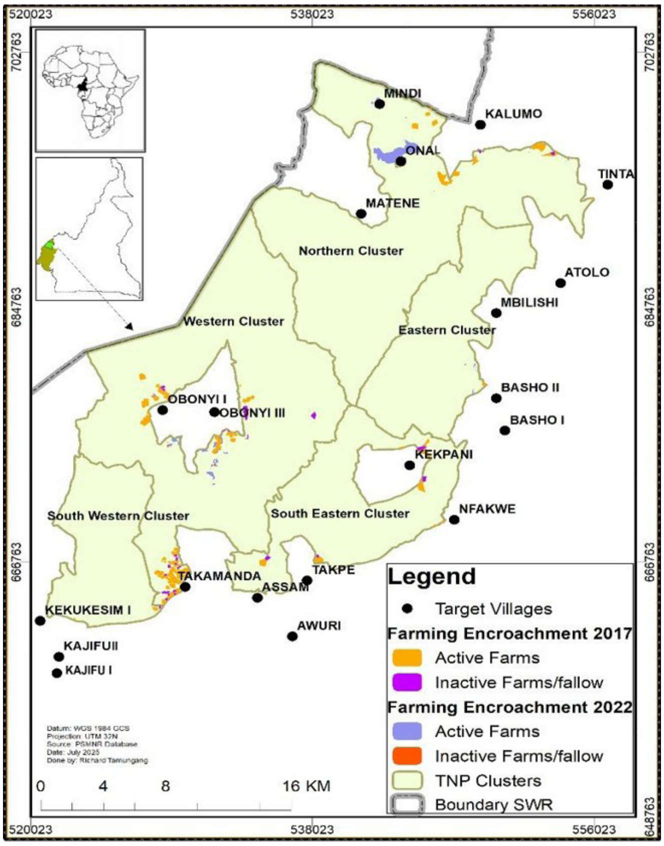


**Figure 4:** Encroachment into the Takamanda National Park

### Landuse and landcover changes around the TNP

Between 2013 and 2023, dense forests dropped from 88.01% to 77.64% representing an estimated loss of 6890.83ha. Similarly, open forests increased from 1752.3ha in 2013 to 4592.05ha in 2023 corresponding to an increase of 2839.75ha or an annual change rate of 283.9ha. Meanwhile, from a mere 3.27ha in 2013, shrubby savannah increased to 4000.78ha in 2023. This corresponds to an increase of 3997.53ha or an annual change rate of 399.75ha. Additionally, during the same period, settlements increased from 5.32ha to 10.48ha corresponding to an annual rate of change of 0.516ha, (table 6).

**Table 6:** Landuse and landcover change between 2013 and 2023 in the Takamanda national park

| Land cover type | 2013 cover (ha) | 2013 cover (%) | 2023 cover (ha) | 2023 cover (%) | Relative change 2013-2023 (ha) | Relative change 2013-2023 % | Annual rate of change (ha) |
|---|---|---|---|---|---|---|---|
| Dense Forests | 58473 | 88.008 | 51582.13 | 77.64 | 6890.83 | 10.34 | 6890.8 |
| Open Forests | 1752.3 | 2.64 | 4592.05 | 6.912 | 2839.75 | 4.272 | 283.98 |
| Shrubby Savanna | 3.25 | 0.005 | 4000.78 | 6.022 | 3997.53 | 6.017 | 399.75 |
| Grassland | 4116.44 | 6.196 | 4058.98 | 6.109 | 57.46 | 0.086 | 5.746 |
| Agroforestry Mosaic | 2043.81 | 3.076 | 2146.73 | 3.231 | 102.92 | 0.155 | 10.292 |
| Settlements | 5.32 | 0.008 | 10.48 | 0.016 | 5.16 | 0.008 | 0.516 |
| Water | 46.36 | 0.07 | 49.24 | 0.074 | 5.16 | 0.004 | 0.516 |
| Total | 66440.4 | | 66440.4 | | | | |

### Accuracy assessment

From the random sampling process, the accuracy assessment showed an overall accuracy for the 2013 image to be 74.3% and 79% for 2023 while the Kappa coefficient was 69% (2013) and 70% for (2023).

## Discussion

### Habitat specialization and the methodological modelling paradox

The empirical results from this study demonstrate a significant concentration of pangolin sightings within primary forest habitats (92.08%, chi2 = 1216.9, $p < 0.001$). These findings directly agree with and support the macro-ecological assessments of Challender *et al.* (2020), providing robust, localized validation that Central Africa's Pholidota species the white-bellied (Phataginus tricuspis), black-bellied (Phataginus tetradactyla), and giant (Smutsia gigantea) pangolins function as strict structural primary forest obligates.

Furthermore, our field observations strongly corroborate the habitat models developed by Swart *et al.*, (1999) and Ingram *et al.*, (2018). Undisturbed, closed-canopy primary rainforests offer critical, specialized ecological micro-niches such as mature hollow tree cavities, extensive root complexes, and stable, mounds that are biologically necessary for reproductive breeding, and continuous specialized foraging. The lower frequencies of sightings recorded in secondary forests (4.49%) and active agricultural farmlands (3.43%) further substantiate our alignment with these authors, demonstrating that severe anthropogenic habitat degradation limits structural niche availability and collapses habitat suitability for these sensitive, specialized mammals.

However, a superficial reading of the multiple logistic regression model introduces an apparent methodological paradox. Both primary forest (OR = 0.490, $p = 0.002$) and secondary forest (OR = 0.277, $p < 0.001$) exhibit significantly lower odds of pangolin presence when evaluated against the baseline landscape matrix (comprising highly disturbed farm bush ecotones). In spatial ecology and wildlife monitoring, our field data confirms that this pattern signals a classic detection and edge-exploitation paradox rather than a true biological preference for disturbed habitats, reinforcing the empirical warnings raised by Laurance *et al.* (2007). Within the dense, continuous core interiors of primary forests, the highly cryptic, nocturnal, and fossorial behaviours of pangolins severely suppress direct human visual detection rates during standardized linear transect surveys (Challender *et al.*, 2015).

Conversely, as agricultural encroachment actively perforates the national park's boundaries evidenced by the 99 distinct operational farm plots documented across the surveyed zones pangolins are systematically dislodged from disrupted core habitats and channelled into narrow, forest fragments and agroforestry mosaics. Our data explicitly confirms that this landscape alteration drives an inflation of detection metrics. Within these highly open edge ecotones, increased canopy perforation enhances ground-level visibility while forcing human foot traffic and wildlife movements into the same spatial corridors. This spatial overlap creates elevated human encounter and detection rates within highly disturbed zones despite a lower underlying population density, exposing the remaining populations to severe, unsustainable ecological traps (Broadbent *et al.*, 2008; Laurance *et al.*, 2007).

**Landuse change and agricultural Encroachment**

The remote sensing analysis between 2013 and 2023 exposes an alarming structural conversion of Takamanda National Park's core interior. The net loss of 6,890.83 hectares of dense forest (10.34% relative decline) directly mirrors a simultaneous surge in open forests (2,839.75 ha) and a massive expansion of shrubby savanna (3,997.53 ha). This rapid landscape transition from closed-canopy primary ecosystems to degraded, highly fragmented successional vegetation is heavily driven by smallholder cash-crop cultivation, specifically cocoa (Theobroma cacao) by youths who encroach on pretext of fertile land shortage particularly in the wester cluster and human settlement in the northern cluster around the Mateve stream, This observation in TNP conforms with Kimengsi & Lambi, (2015) who reported massive deforestation elsewhere in the South West region for smallholders cultivation for cocoa and oil palm (Elaeis guineensis).

The field-level agricultural survey data directly validates this spatial trend. Seventy-eight (78) individual farmers were found operating ninety-nine (99) encroaching plots inside the park, encompassing over 100 hectares of active farmland, alongside active farm extensions (4.5ha) and fallow clearings (6.9ha). This encroachment is heavily concentrated around specific community hubs in the western Cluster with close ties to cross-border cash-crop markets, such as Obonyi I (33 farms/fallows) and Obonyi III (39 total farms, including 31 newly established plots). This border-adjacent agricultural expansion exploits Takamanda's immediate proximity to southeastern Nigeria, where a lucrative market for cash crops surpasses the local domestic economy (Sunderland *et al.*, 2014). The documentation of 35 old, active farms that were recently re-cleared after years of abandonment, alongside 32 entirely new farms, highlights a shifting landscape where historical protection boundaries are being systematically redrawn from the ground up. These agricultural vectors advancement, observed in TNP definitely transform continuous primary habitats into isolated structural ecological islands, disrupting gene flow and exposing remaining pangolin populations to severe edge effects and escalated human contact as earlier reported by Fahrig, (2003) elsewhere.

**Governance deficits, conflict, and spatial threat**

The severe negative associations revealed by the multiple logistic regression model between pangolin presence and direct human markers such as bush huts (OR= 0.049, p = 0.003), footprints (OR= 0.186, p < 0.001), and wire snares (OR = 0.441, p = 0.001) quantify a landscape heavily defined by intense hunting pressure. This pervasive human footprint must be contextualized within the broader institutional and socio-political crisis of the region. As reported by the International Crisis Group (2017), the near decade-long 'Anglophone Crisis' has generated a profound governance vacuum across the South West Region of Cameroon. Our field observations confirm that this regional instability directly precipitated the absence of eco-guards and the subsequent suspension of routine anti-poaching patrols within Takamanda National Park.

This pattern closely mirrors the historical protection lapses documented by Masozera *et al.*, (2007) in Nyungwe National Park, Rwanda, and Sayer *et al.*, (2012) across reserves in the Central African Republic. In those contexts, as in Takamanda, the sudden collapse of formal state enforcement prompted local communities to reactivate abandoned agricultural clearings and scale up unrestricted hunting operations within critical park core zones. Furthermore, the high frequency of machete marks (13.32%) and bullet shells (6.73%) encountered during our surveys confirms that both passive wire-snaring and active night-hunting with gunshot are widespread across specific sectors of the park. These high extraction indices strongly validate the socio-economic models of Wilkie *et al.*, (2011) and Lindsey *et al.*, (2014), which assert that under conditions of severe economic instability and acute poverty, local actors systematically leverage the illicit bushmeat and trade as a crucial financial safety net, translating harvested pangolin body parts into highly liquid household income.

The simple correspondence analysis provides a clear, nuanced spatial roadmap of this multi-faceted threat landscape, resolving important distinctions between formatting pressures. Dimension 1 (60.4% variance) maps a distinct gradient of human disturbance, separating the park into highly differentiated operational zones based on the type of anthropogenic pressure present. Crucially, while our land-use surveys show that the Western cluster faces severe agrarian boundary creep via cocoa cultivation, the correspondence analysis demonstrates that it remains largely decoupled from active, direct poaching signs, aligning tightly with the absence of hunting indicators ('None', 31.13% contribution). Consequently, while the Western cluster is highly unsecured from a structural habitat perspective, it functions as a relative micro-refuge from direct harvesting pressure.

In contrast, the Eastern and Southeastern clusters align heavily with active hunting indicators, notably bullet shells (27.51% contribution) and machetes (14.33%). This spatial differentiation reveals that while the West faces intense land conversion, the East and Southeast serve as the primary, highly compromised poaching zones. Dimension 2 (39.6% variance) captures fine-scale human transit patterns through footprints (34.74%) and abandoned clothing items (23.26%). This spatial association strongly corroborates the trade path frameworks of Ingram *et al.* (2017) and the UNODC (2024), illustrating active, illicit cross-border transit corridors that link the park's heavily hunted interior directly to transnational commercial scale supply chains.

**Methodological validity and conservation management implications**

The accuracy assessments for the remote sensing classifications (74.3% overall accuracy for 2013 and 79.0% for 2023, with Kappa coefficients of 0.69 and 0.70, respectively) provide a statistically reliable empirical foundation for immediate management interventions. Furthermore, the low McFadden's pseudo-R2 value (0.03) yielded by our logistic regression model is typical when modelling highly cryptic, wide-ranging, and mobile mammals. This statistical threshold directly aligns with the predictive habitat frameworks of Guisan and Zimmermann (2000), indicating that while anthropogenic features and broad forest types function as highly significant spatial drivers, supplementary unmodeled fine-scale ecological variables such as localized prey availability, soil moisture gradients, and localized microclimate variables concurrently influence fine-scale pangolin distribution across the landscape.

The clear spatial segregation of distinct threats highlights that a generic, uniform management approach across Takamanda National Park will ultimately fail. Traditional, top-down reactive law enforcement is both operationally unfeasible and counterproductive given the ongoing socio-political conflict and deep-seated local livelihood dependencies, a reality that strongly validates the conservation-poverty frameworks of Adams *et al.* (2004). Instead, protection strategies must adopt a highly nuanced, framework tailored to the specific pressures hitting each sector.

Because our empirical data reveals that the Western cluster is heavily encroached by smallholder agrarian expansion (notably cocoa plots around the Obonyi enclaves), this western sector must be designated as an agricultural boundary enforcement zone. Management here must focus on participatory mapping and community-led co-management to formalize hard agricultural boundaries, halt further eastward farm extensions, and integrate customary land agreements (Berkes, 2008).

Concurrently, because the Eastern and Southeastern clusters are heavily compromised by direct extraction indicators rather than crop clearings, these clusters must be prioritized for intelligence-led community ranger patrols specifically targeted at dismantling wire snare lines and deterring night-hunting. Bridging local livelihood security with international legal mandates like CITES Appendix I through this split-spatial approach is the only viable pathway to stabilize boundary creep and reverse the population collapse of Central Africa's iconic pangolin species within this vital transboundary national park.

## CONCLUSION

This multi-scale assessment reveals a severe conservation crisis for pangolins in Takamanda National Park, driven by rapid anthropogenic expansion and regional instability. The loss of 6,890.83 hectares of dense forest interior between 2013 and 2023 exposes a shifting landscape driven by smallholder cash-crop cultivation (cocoa) and human settlements, heavily concentrated near cross-border market around enclave communities.

Importantly, our simple correspondence analysis untangles these complex pressures by separating the park into distinct operational zones based on threat composition. The Western cluster stands out as a critical agricultural frontier heavily impacted by smallholder cocoa encroachment but remains a relative micro-refuge from high-intensity harvesting signatures. In contrast, the Eastern and Southeastern clusters serve as heavily compromised, cross-border commercial transit corridors dominated by pervasive snaring and gunshot hunting pressure.

These findings demonstrate that conventional, uniform conservation models are no longer viable within conflict-affected, transboundary landscapes. Reversing this population collapse requires an immediate strategic shift.The agriculturally threatened areas must be prioritized for community-led co-management, Local Ecological Knowledge and participatory mapping to formalize hard boundaries and halt further eastward agrarian encroachment. Securing a future for pangolins in Takamanda National Park depends on bridging local livelihood security with international legal mandates, transforming adjacent communities from reluctant agents of habitat degradation into frontline stewards of biodiversity conservation.

**Author contributions**

Kirensky Jerry Mbi, Melle Ekane Maurice, Athanasius Fuashi Nkwatoh, Longonje Simon Ngomba and Guilen-Noel Tataw led the conceptualization, methodology, formal analysis, investigation, data curation and writing, Melle Ekane Maurice, Athanasius Fuashi Nkwatoh and Longonje Simon Ngomba provided valuable input in validation, writing and supervision. Mukete Beckline and Guilen-Noel Tataw assisted with methodology, formal analysis, writing, investigation and project administration. Longonje Simon Ngomba, Mukete Beckline and Guilen-Noel Tataw offered resources and visualization support. Kirensky Jerry Mbi is the principal researcher and wrote the manuscript. All authors read and approved the final manuscript.

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**Competing interests**

The authors declare that they have no competing interests.

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