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Original Article

Impact of Anthropogenic Activities and Urban Proximity on the Conservation of Trees Outside Forests on Agricultural Lands in the Mongala Province, Democratic Republic of Congo

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ABSTRACT

This study analysed the influence of charcoal production, artisanal logging, and urban proximity on the conservation of Trees Outside Forests on Agricultural Lands (TOF-AL) in the Mongala Province (Democratic Republic of Congo). A stratified random sampling methodology was applied to 45 villages distributed across the three territories of the province (Bongandanga, Bumba, and Lisala). Within each village, an inventory of TOF-AL was conducted using linear transects and systematic sampling, allowing for the evaluation of the conservation index, species richness, density, and diversity of TOF-AL. The practice of extractive activities, including charcoal production and artisanal logging, was documented in each village, and the distance to major cities was determined. The results indicate that charcoal production and artisanal logging have a significant negative impact on all measured conservation parameters of TOF-AL. The conservation index, species richness, density, and diversity of TOF significantly decrease in villages where these activities are associated with slash-and-burn agriculture. The Bumba territory showed the lowest values for the conservation index, species richness, and density. The lowest values observed in Bumba suggest an increased anthropogenic pressure on forest resources in this area. Furthermore, a positive correlation was observed between the distance to major cities and the conservation of TOF-AL. In remote villages, the conservation index, species richness, density, and diversity of TOF-AL were significantly higher than in peri-urban areas. These results suggest that differentiated conservation strategies should be prioritised to ensure the effective conservation of TOF-AL in this region and beyond. These differentiated conservation strategies should consider territorial specificities, socio-economic activities, and spatial dynamics of rural landscapes.

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INTRODUCTION

Tropical forests are crucial in regulating the global climate, acting as essential carbon sinks to mitigate climate change (Heinrich et al., 2023). They harbour invaluable biodiversity and provide vital resources to local communities, ranging from fuelwood to Non-Timber Forest Products (Das & Mallick, 2024; Gentry, 1992). However, deforestation, driven by agricultural expansion, logging, and urbanisation, threatens these essential functions (Giam, 2017; Jayathilake et al., 2021; Sonter et al., 2015). These forest losses lead to increased greenhouse gas emissions, biodiversity erosion, and degradation of local livelihoods (Lawrence et al., 2022; Li et al., 2022).

In this alarming context, conserving trees on agricultural lands can be a complementary strategy to maintain forest ecosystem services (Chakravarty et al., 2019; Pati et al., 2022; Tamang et al., 2019). These trees, considered as Trees Outside Forests (TOF) on agricultural lands (de Foresta et al., 2013), contribute to carbon sequestration, biodiversity conservation, and soil fertility improvement (de Foresta, 2017; Pati et al., 2022; Tamang et al., 2021; Tassew, 2017). In the Democratic Republic of Congo (DRC), a country endowed with vast tropical forests (Galford et al., 2015; Shapiro et al., 2021), the conservation of TOF on agricultural lands is particularly important to mitigate the effects of deforestation and promote sustainable development (Li et al., 2022; Shapiro et al., 2021).

However, the conservation of TOF on agricultural lands faces numerous challenges in this region. Charcoal production and artisanal logging, significant economic activities in the Mongala province, exert considerable pressure on tree resources (Besisa et al., 2017; Brown & Makana, 2010; Schure et al., 2014). Moreover, due to socioeconomic and geographical differences, these anthropogenic pressures vary among the three territories of this province (Bongandanga, Bumba, and Lisala) (OSFAC, 2020). Thus, a comprehensive analysis of the factors influencing the conservation of TOF is imperative for developing sustainable management strategies adapted to the specific local conditions of the Mongala province and beyond.

This study investigates the impact of socioeconomic and geographical factors on the conservation of TOF within agricultural landscapes in Mongala Province. This research hypothesises that charcoal production, artisanal logging, and urban proximity significantly influence TOF conservation in these areas. Specifically, this research addresses the following questions: (1) How do charcoal production and artisanal logging affect the conservation index, species richness, density, and diversity of TOF? (2) How does urban proximity impact TOF conservation on agricultural land? (3) Are there significant territory-based differences in TOF conservation across the province? By answering these questions, this study aims to enhance the understanding of factors influencing TOF conservation and provide crucial information for developing sustainable tree resource management strategies in Mongala Province and other similar regions.

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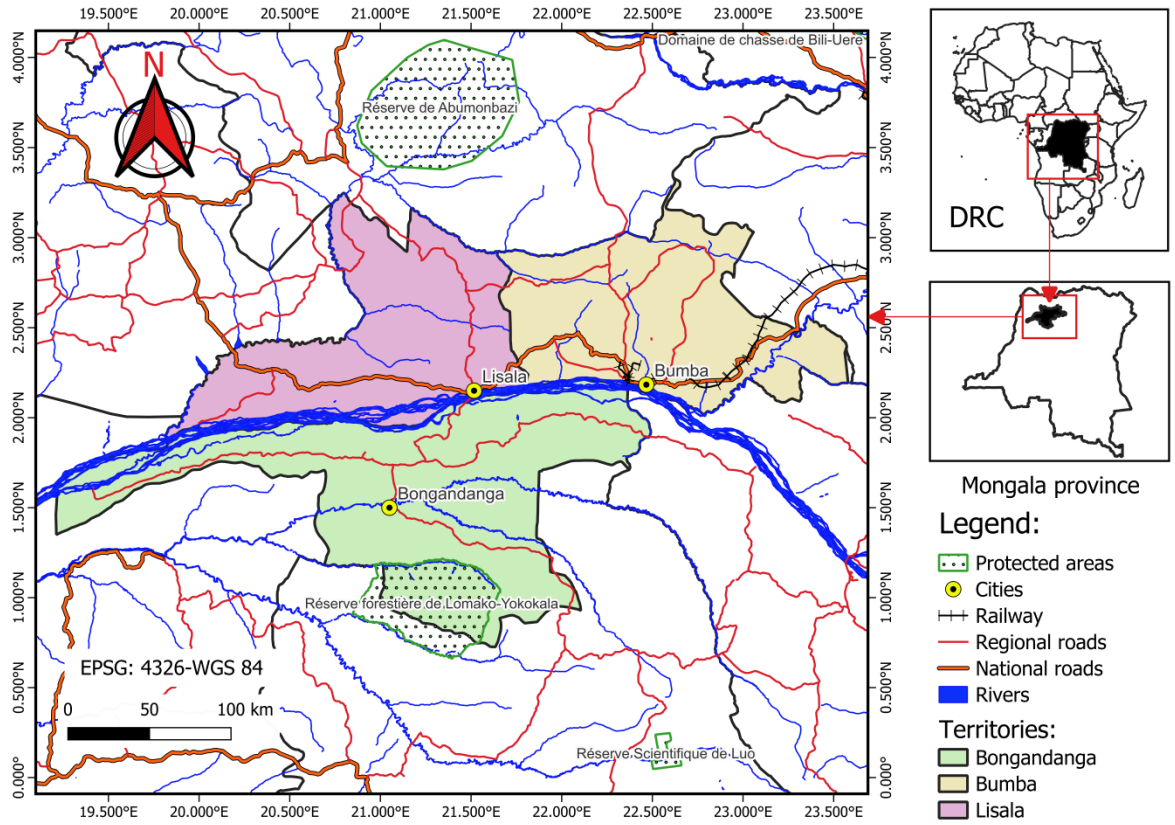
MATERIALS AND METHODS

Study Area

The Mongala province covers an estimated area of 58,141 km², exceeding the landmass of countries such as Togo, Burundi, Rwanda, and the Gambia. The administrative subdivision of Mongala province comprises three territories: Bongandanga, Bumba, and Lisala (*Figure 1*). These territories are characterised by extensive areas of dense tropical rainforest (Balandi et al., 2020; Ewango et al., 2019). Each territory is further subdivided into collectivities, containing many villages. For the predominantly rural population, slash-and-burn agriculture constitutes the primary household activity (Bosakabo, 2024). Principal agricultural products include rice, cassava, maize, and peanuts, with the province serving as a significant supplier of rice and maize to the urban centres of Kinshasa and Kisangani (Enabel, 2020; MINAGRI, 2021). Notably, the Bumba territory, while the smallest in area, exhibits the highest population density and the most intensive agricultural activity, resulting in substantial deforestation (Balandi et al., 2020; OSFAC, 2020). In contrast, Bongandanga, the most geographically isolated area, experiences lower pressure on its forest resources. However, the limited availability of alternative livelihoods makes its population heavily dependent on these resources (OSFAC, 2020).

Figure 1: Study Area in the Democratic Republic of Congo



The province has a hot and humid equatorial climate, with annual rainfall ranging from 1800 to 2000 mm (Enabel, 2020). Its climatic regime is characterised by two dry seasons and two rainy seasons. The average temperature varies between 24°C and 25°C, with a maximum of 30°C and a minimum of 19°C. The climate does not vary significantly in the different territories (World Bank, 2025).

Experimental Design and Data Collection

To ensure a robust and unbiased assessment of TOF on agricultural land, a standardised and systematic inventory protocol was implemented

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across 45 villages, stratified within nine collectivities, with a uniform distribution of 3 collectivities per territory. To minimise selection bias, five villages were selected within each collectivity, employing a stratified random sampling approach based on a pre-defined distance gradient from major consumption centres (Bumba, Bongandanga, and Lisala).

In each selected village, a linear transect was rigorously established, extending from the village periphery to the nearest contiguous forest edge. Along these transects, TOF inventories were conducted in agricultural fields, adhering to a strict systematic sampling protocol. To reduce subjectivity in field selection, each encountered field was assigned a sequential numerical identifier, and only fields with even-numbered identifiers and confirmed TOF presence were included in the inventory. This method ensured consistent sampling intensity and minimised observer bias. The number of fields encountered that lacked TOF before reaching the 20 inventoried fields was meticulously recorded, providing a quantitative measure of TOF absence. Within each inventoried field, the TOF abundance and species richness were assessed using standardised measurement techniques. Using a Garmin 62s GPS, the area of each inventoried field was estimated. At once, the presence or absence of charcoal production and artisanal logging activities within each village was objectively documented based on direct observation and standardised criteria. Furthermore, the distance to the nearest major consumption centre was precisely determined using geospatial tools, ensuring accuracy and consistency across all sampling points.

This precise and objective protocol resulted in the systematic inventory of 900 agricultural fields exhibiting TOF. In comparison, 457 fields lacking TOF were observed and recorded, providing a comprehensive and unbiased dataset for subsequent analysis.

Data Processing and Analysis

To quantify TOF conservation within each village, a Conservation Index (CI) was calculated using the following formula:

$$CI = \frac{IF}{OF} \quad (1)$$

Where: *CI* represents the Conservation Index of TOF in agricultural fields; *IF* is the number of fields inventoried, standardised at 20 agricultural fields per village; and *OF* represents the total number of agricultural fields observed within the village until 20 fields containing TOF were inventoried, encompassing both fields with and without TOF presence.

Furthermore, to assess TOF species diversity on agricultural lands within each village, Shannon's diversity index (H') and Pielou's evenness index (J') were employed (Bandeira et al., 2013; Shannon & Weaver, 1949). These indices were computed using PAST software (Hammer et al., 2001), providing a robust species richness and evenness analysis.

Statistical analyses evaluated variations in tree conservation indices, abundance, and species richness across the three territories. Analysis of variance (ANOVA) was employed to assess inter-territorial variations. Depending on the data distribution and variance homogeneity, Fisher's or Kruskal-Wallis tests were used, facilitated by the "*ggbetweenstats*" function within the "*ggstatsplot*" package (Patil, 2021). Comparative analyses were performed to examine the influence of charcoal production and artisanal logging on tree abundance, species richness, Shannon's diversity index, Pielou's evenness index, and the tree conservation index. The Student's t-test or the Wilcoxon and Mann-Whitney test were applied, depending on data distribution and assumptions of normality. In instances where homogeneity of variances was not met, a Welch approximation was employed to ensure robust comparisons.

The relationship between urban proximity and key ecological metrics, including tree abundance, species richness, Shannon's diversity index, Pielou's evenness index, and the tree conservation

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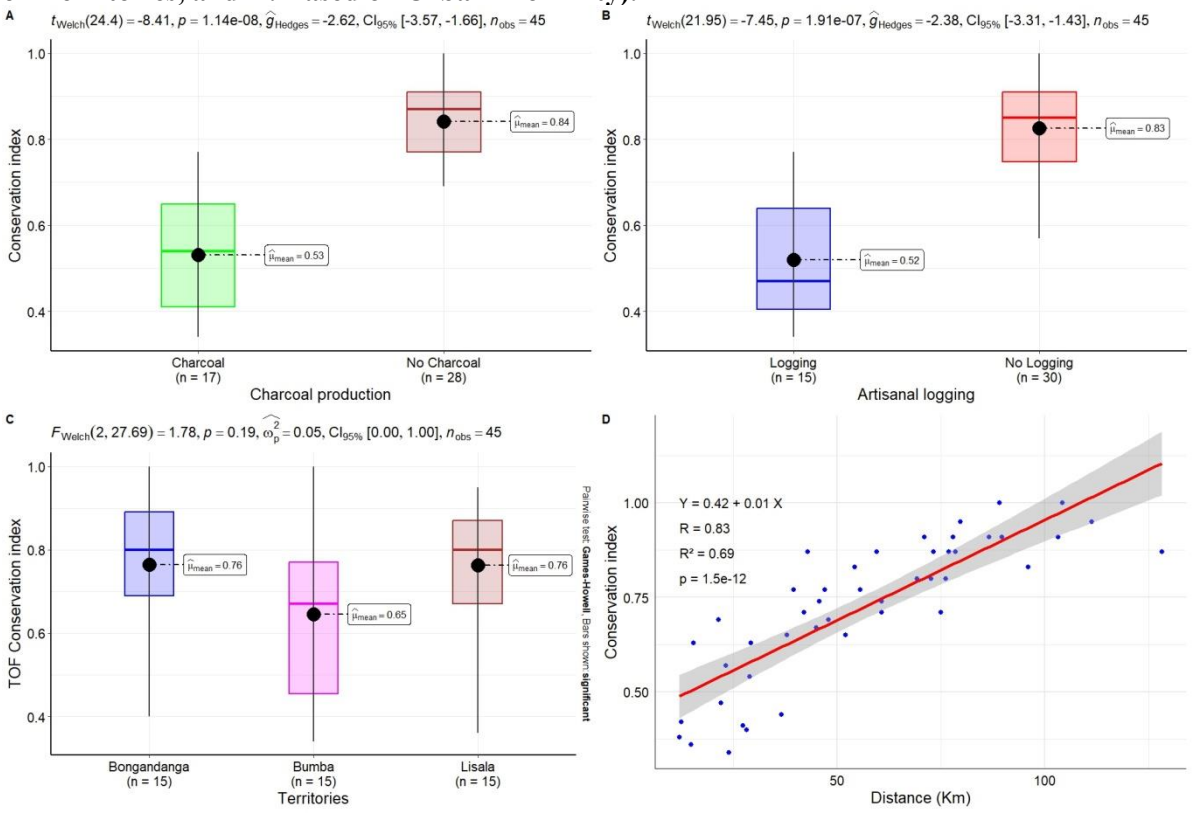
index, was investigated using simple linear regression. Diagnostic tests were conducted to validate the assumptions of linear regression. Specifically, the linearity assumption was subsequently validated using the Ramsey RESET test. The Durbin-Watson test was used to assess residual autocorrelation, the Breusch-Pagan test was used to evaluate homoscedasticity, and the Shapiro-Wilk test was used to confirm residual normality. These diagnostic analyses were performed using the "*lmtest*" package (Zeileis & Hothorn, 2002). Data visualisation was performed using the "*ggplot2*" package (Wickham, 2016). All statistical analyses were performed using **R software** version 4.4.3.

RESULTS

Conservation Index of Trees Outside Forests on Agricultural Land

The TOF Conservation Index in the agricultural lands of the Mongala province is 0.72, indicating that at least one tree is found in 72% of fields in this province. However, as shown in Figure 2, the TOF conservation index varies from territory to territory, depending on additional activities carried out in the areas and the distance from the major urban centres.

Figure 2: Variation of TOF Conservation Index in the Agricultural Landscapes of the Mongala Province in DRC (A: Based on Charcoal Production, B: Based on Artisanal Logging, C: Based on Territories, and D: Based on Urban Proximity).



The lowest TOF Conservation Index in agricultural fields is observed in the Bumba territory (0.65), compared to 0.76 in the Bongandanga and Lisala territories (Figure 2C). However, as shown by the results of the variance analysis (F_{Welch} = 1.78; p-value = 0.19), this index does not vary significantly between these three territories. In villages where charcoal production is practised, the TOF Conservation Index in fields is 0.53, compared to 0.84 in villages where it is not practised (Figure 2A). The mean comparison test performed on these two groups of villages shows that the TOF Conservation Index on agricultural land is significantly negatively influenced by charcoal production (t_{Welch} = -8.41; p-value = 1.14e-08). The same applies to artisanal logging, significantly decreasing the TOF Conservation Index in the agricultural fields (t_{Welch}

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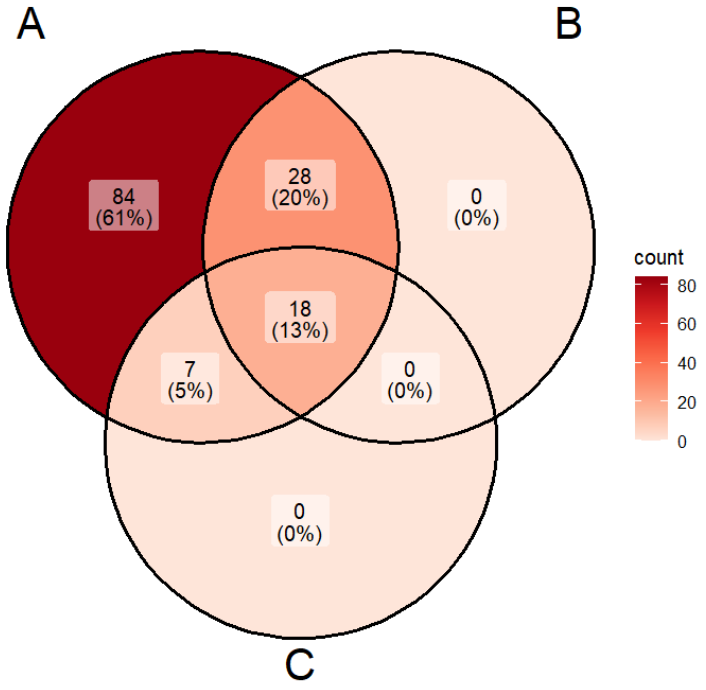
= -7.45; p-value = 1.91e-07). Indeed, in areas where artisanal logging is not practised, the TOF Conservation Index in the agricultural fields is 0.83; however, it drops to 0.52 in villages where this exploitation is practised (Figure 2B). Finally, a significant link is observed between the TOF Conservation Index in the agricultural fields and the distance from major urban centres (Figure 2D). Across the Mongala province, it has been observed that the TOF Conservation Index in the agricultural fields increases with increasing distance from major urban centres (R^2 = 0.69; p-value = 1.51e-12). This shows that in villages far from major urban centres, farmers are more inclined to conserve trees in their agricultural fields, unlike farmers in villages near major urban centres.

Species Richness of Trees Outside Forests on Agricultural Land

A total of 137 TOF species were identified on agricultural land throughout the province (Appendix 1). However, as shown in Figure 3, TOF species richness varies according to the additional activities practised on agricultural land.

Figure 3: Effects of Differentiated Exploitation Practices on Trees Outside Forests Species Distribution in the Agricultural Landscape of Mongala Province (A: No Charcoal Production and No Artisanal Logging in Villages; B: Charcoal Production in Villages; C: Charcoal Production and Artisanal Logging in Villages).



Of the 137 TOF species encountered, 18 are ubiquitous. These are: *Albizia ferruginea* (Guill. & Perr.) Benth., *Anonidium mannii* Engl. & Diels, *Amphimas pterocarpoides* Harms, *Chrysophyllum africanum* A.DC., *Chrysophyllum lacourtianum* De Wild., *Canarium schweinfurthii* Engl., *Drypetes gossweileri* S. Moore, *Entandrophragma candollei* Harms, *Entandrophragma cylindricum* (Sprague) Sprague, *Erythrophleum suaveolens* (Guill. & Perr.) Brenan, *Entandrophragma utile* (Dawe & Sprague) Sprague, *Garcinia kola* Heckel, *Nauclea diderrichii* (De Wild.) Merr., *Piptadeniastrum africanum* (Hook. f.) Brenan, *Pycnanthus angolensis* (Welw.) Warb., *Petersianthus macrocarpus* (Poir.) Merr., *Ricinodendron heudelotii* (Baill.) Heckel, and *Sterculia tragacantha* Lindl. These species represent 13% of the species identified in the three village groups.

Between site A, where neither charcoal production nor artisanal logging is practised, and site B, where charcoal production is practised, 28

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common TOF species are found, representing 20% of the total species richness of these two sites (A and B). These species are *Albizia adianthifolia* (Schumach.) W. Wight, *Alstonia boonei* De Wild., *Amphimas ferrugineus* Pellegr., *Anthonotha fragrans* (Baker) J. Léonard, *Antrocaryon nannanii* De Wild., *Bridelia atroviridis* Müll.Arg., *Beilschmiedia congolana* (De Wild. & T. Durand) Robyns & R. Wilczek, *Blighia welwitschii* (Radlk.) Exell & Mendonça, *Cola acuminata* (P. Beauv.) Schott & Endl., *Cola altissima* Oliv., *Dacryodes yangambiensis* (Louis ex Troupin) Pierlot, *Entandrophragma angolense* (Welw. ex C.DC.) C.DC., *Funtumia africana* (Benth.) Stapf, *Grewia oligoneura* Sprague, *Hua gabonii* Pellegr., *Irvingia grandifolia* (Engl.) Engl., *Klainedoxa gabonensis* Pierre ex Engl., *Mammea africana* G. Don, *Myrianthus arboreus* P. Beauv., *Margaritaria discoidea* (Baill.) G.L. Webster, *Maesopsis eminii* Engl., *Macaranga monandra* Müll.Arg., *Pericopsis elata* (Harms) Meeuwen, *Pancovia harmsiana* Gilg, *Pentaclethra macrophylla* Benth., *Pterocarpus soyauxii* Taub., and *Trilepisium madagascariense* Thouars. These 28 TOF species were not observed in site C.

Finally, there are seven common TOF species between sites A and C, where charcoal production and artisanal logging are practised. These TOF species are *Afzelia bipindensis* Harms, *Allanblackia floribunda* Oliv., *Afrostyrax lepidophyllus* Mildbr., *Anthonotha macrophylla* P. Beauv., *Chlamydocola chlamydantha* (Baill.) Floret, Troupin & A. Raynal, *Guarea thompsonii* Sprague & Hutch., and *Prioria balsamifera* (Vermoesen) Breteler. These 7 species represent 5% of the total species richness of these two sites. The complete list of 84 species found only in villages where neither charcoal production nor artisanal logging is practised can be accessed in Appendix 1.

Figure 4 presents the variation in species richness of TOF on agricultural land according to territories, distance from major urban centres, and additional activities practised on agricultural land.

Figure 4: Influence of Socio-Economic and Geographical Factors on TOF Species Richness in the Agricultural Landscapes of the Mongala Province in DRC (Variations Based on: (A) Charcoal Production Practices, (B) Artisanal Logging Practices, (C) Territories, and (D) Urban proximity).

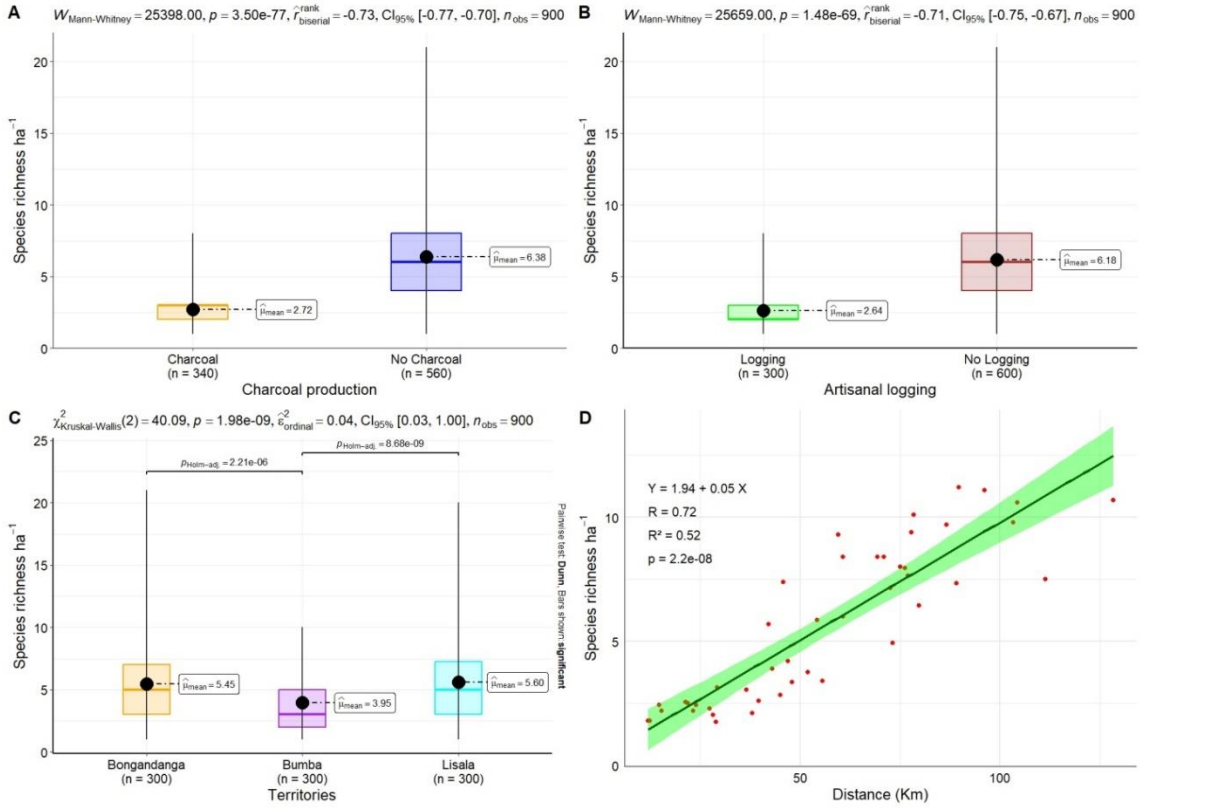

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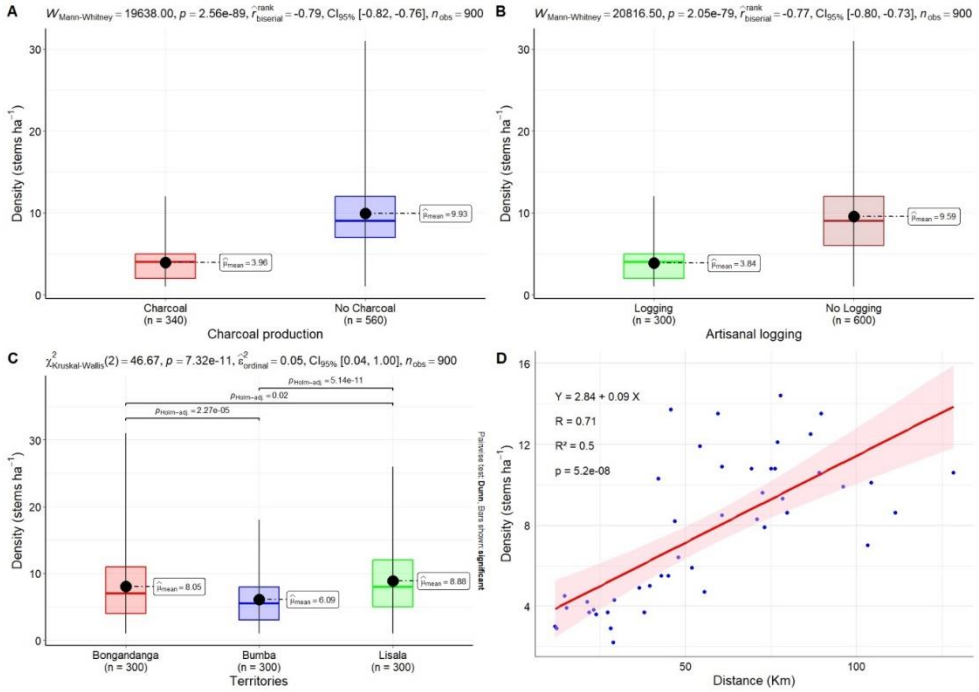
Figure 4A shows that charcoal production negatively impacts the TOF species richness on agricultural land in the Mongala province. In villages where trees are not felled for charcoal production, the average TOF species richness on agricultural land is 6.38 species per hectare. However, in villages where farmers fell trees to produce charcoal, this species richness falls to 2.72 species per hectare. As highlighted by the results of the mean comparison test, charcoal production significantly reduces the TOF species richness on agricultural land in this province ($W = 25398.00$; $p < 0.001$). The same trend is observed with artisanal logging (Figure 4B). Indeed, in villages where artisanal logging is not practised, the TOF species richness on agricultural land is 6.18 species per hectare. However, it falls to 2.64 species per hectare in villages where artisanal logging is practised. Like charcoal production, artisanal logging significantly negatively influences the TOF species richness in the Mongala province ($W = 25659.00$; $p < 0.001$).

Figure 4C shows that TOF species richness varies significantly according to territories ($\chi^2 = 40.09$; $p < 0.001$). The territory of Bumba is where the lowest species richness was observed (3.95 species per hectare). The species richness values in the Bongandanga and Lisala territories are 5.45 and 5.6 species per hectare, respectively. As shown by the results of the Dunn test for pairwise comparison, there is no significant difference in TOF species richness between the Lisala and Bongandanga territories. Still, both territories have significantly higher species richness values than the Bumba territory (Figure 4C). Like what was observed for the TOF Conservation Index, Figure 4D shows that the TOF species richness on agricultural land significantly increases with increasing distance from major urban centres ($R^2 = 0.72$; $p < 0.001$). Species richness is low in villages near major urban centres and higher in more remote and less accessible villages.

Density of Trees Outside Forests on Agricultural Land

Figure 5 presents the density of TOF on agricultural land in the Mongala province, according to socio-economic and geographical factors.

Figure 5: Influence of Socio-Economic and Geographical Factors on the density of Trees Outside Forests on Agricultural Land in the Mongala Province of the DRC (Variations in Trees Outside Forest Densities based on (A) Charcoal Production Practices, (B) Artisanal Logging Practices, (C) Territories, and (D) Urban Proximity).



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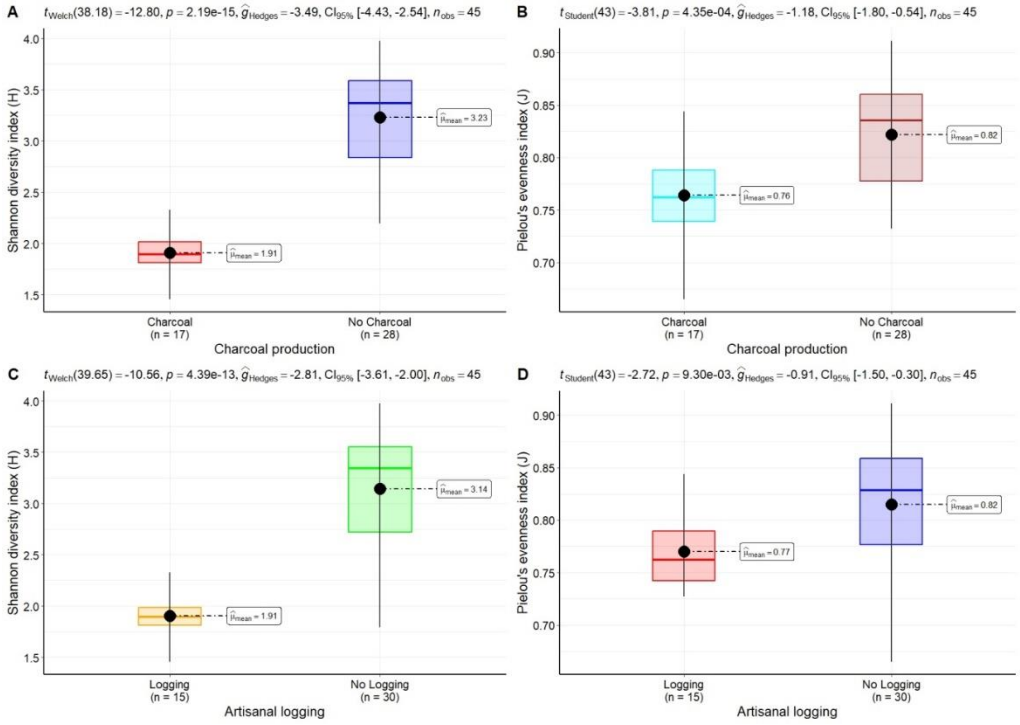
In the Mongala province, Figure 5A shows that charcoal production significantly reduces the density of TOF on agricultural land (W = 19638.00; $p < 0.001$). Indeed, the density of TOF on agricultural land is much higher in villages where farmers do not fell trees to produce charcoal (9.93 stems ha^{-1}) than in villages where trees are felled for charcoal production (3.93 stems ha^{-1}). The same applies to artisanal logging (Figure 5B). In villages where this exploitation is not practised, the average density of TOF on agricultural land is 9.59 stems per hectare. Lower values (3.84 stems per hectare) are observed in villages where it is practised. The Wilcoxon and Mann-Whitney test confirms that artisanal logging negatively impacts the density of TOF on agricultural land in Mongala (W = 20816.5; $p < 0.001$). Figure 5C shows that, as for TOF species richness, the density of TOF on agricultural land varies significantly according to territories ($\chi^2 = 46.67$; $p < 0.001$). In the Bongandanga and Lisala territories, the average densities of TOF on agricultural land are 8.05 and 8.88 stems per hectare, respectively. The Dunn test for pairwise comparison indicates that there is no significant difference in the density of TOF on agricultural land between these two territories. However, the Bumba territory is the territory where the density of TOF on agricultural land is significantly lower than the other two, with an average of 6.09 stems per hectare (Figure 5C). Finally, Figure 5D shows that, as for TOF species richness, the density of TOF on agricultural land increases with increasing distance to major urban centres ($R^2 = 0.71$; $p < 0.001$). TOF densities are higher in villages located further from these major urban centres. Thus, urban proximity leads to a decrease in both the stem density and species richness of TOF on agricultural land.

Diversity of Trees Outside Forests on Agricultural Land

In the Mongala province, the diversity of TOF species increases with distance from major urban centres. However, regardless of distance, Figure 6 shows that charcoal production and artisanal logging reduce this diversity.

Figure 6: Influence of Socio-Economic and Geographical Factors on the Diversity of Trees Outside Forests on Agricultural Land in the Mongala Province, DRC. (A: Variation of Shannon's Diversity Index According to Charcoal Production. B: Variation of Pielou's Evenness Index According to Charcoal Production. C: Variation of Shannon's Diversity Index According to Artisanal Logging. D: Variation of Pielou's Evenness Index According to Artisanal Logging).



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As shown in Figure 6A, in villages where tree felling for charcoal production is not practised, Shannon's diversity index is 3.23 compared to 1.91 in villages where it is practised. Thus, as highlighted by the results of the mean comparison test (t_{Welch} = -12.8; p-value = 2.19e-15), charcoal production activity significantly reduces the diversity of TOF species on agricultural land in this province. Looking at Pielou's evenness indices between these two groups of villages, this research comes to the same conclusion ($t_{Student}$ = -3.81; p-value = 4.35e-04). Indeed, in villages where charcoal production is not practised, TOF abundances on agricultural land are distributed more homogeneously than in villages where charcoal production is practised. Artisanal logging also has the same negative effect on the diversity of TOF species on agricultural land (Figures 6C and 6D). In areas where artisanal logging is practised, TOF diversity is significantly lower than in villages where it is not practised (t_{Welch} = -10.56; p-value = 4.39e-13). Similarly, Pielou's evenness index indicates lower evenness in villages where artisanal logging is practised than in villages where it is not practised ($t_{Student}$ = -2.72; p-value = 9.30e-03). This figure, therefore, leads to the conclusion that in the Mongala province, wood extraction activities such as charcoal production and artisanal logging negatively impact the diversity of TOF species on agricultural land.

However, in addition to these two activities, Figure 7 shows the impact of urban proximity in reducing the diversity of TOF in the agricultural lands of Mongala province.

Figure 7: Effect of Urban Proximity on the Diversity of Trees Outside Forests Species on Agricultural Land in the Mongala Province, DRC (A: Effect of Distance from Major Urban Centres on Shannon's Diversity Index; B: Effect of Distance from Major Urban Centres on Pielou's Evenness Index).

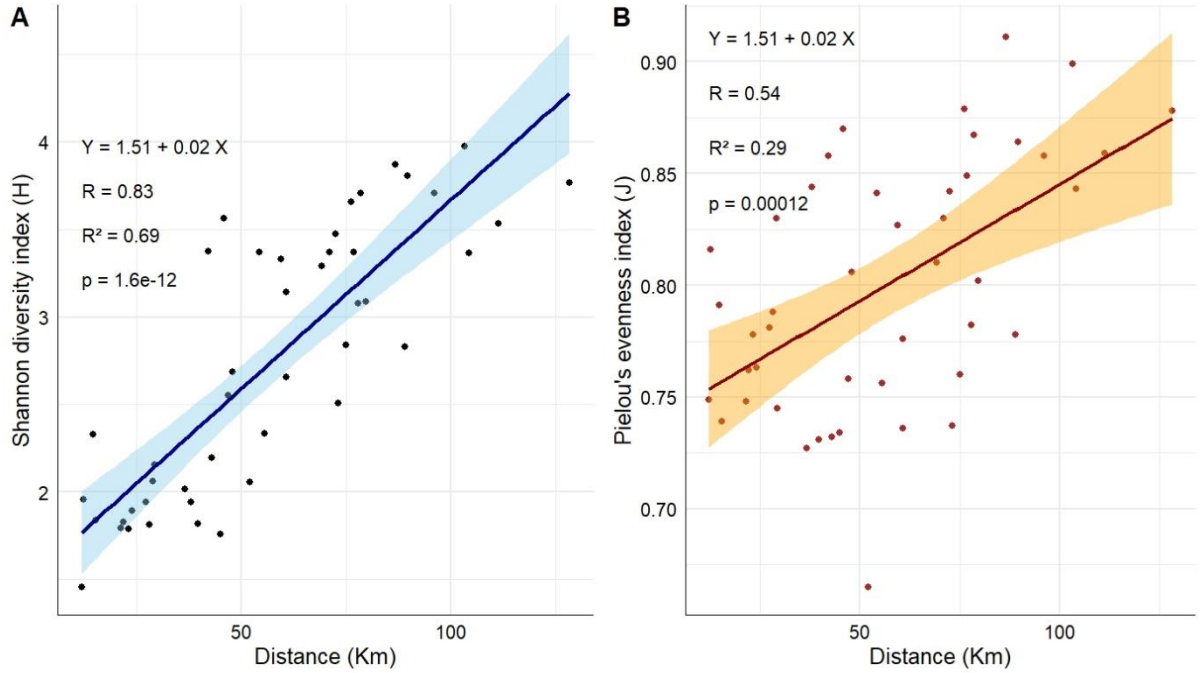

Figure 7 shows that urban proximity determines approximately 69% of the TOF's diversity on agricultural land in the Mongala province (R^2 = 0.69; p-value = 1.6e-12). However, its influence on evenness is low, as shown in Figure 7B (R^2 = 0.29; p-value = 0.00012). The distribution of TOF abundances among different species on agricultural land does not significantly vary with distance. However, as previously noted, both TOF species richness and abundance increase considerably as the distance from major urban centres increases. This trend contributes to the strong relationship between distance and Shannon's diversity index (Figure 7A).

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DISCUSSION

Territory-Based Variations in the Conservation Index, Species Richness, and Density of Trees Outside Forests in Mongala Province

This study reveals significant variations in the conservation of TOF among the three territories of the Mongala province. Although the overall conservation index (0.72) indicates a notable presence of trees on agricultural land, significant territorial differences were observed.

The Bumba territory showed the lowest conservation index, species richness, and TOF density compared to Bongandanga and Lisala. This disparity could be attributed to socio-economic and ecological factors specific to Bumba. Indeed, it has been reported that in the Bumba territory, agricultural activities are more intensive and demographic pressures are higher than in the other two territories, which could explain the lower trend to TOF conservation in this territory (Enabel, 2020; FONAREDD, 2024; OSFAC, 2020). Bumba is also the economic hub of the Mongala province. The need for charcoal and timber is greater there than in the other territories due to the city of Bumba, where the population is larger and development is more rapid than in the other territories (Enabel, 2020; FONAREDD, 2024).

On the contrary, the Bongandanga and Lisala territories present higher and similar conservation indices, species richness, and TOF densities. This similarity suggests comparable socio-economic and ecological conditions, favouring the conservation of TOF. Indeed, the Bongandanga and Lisala territories are characterised by less significant economic activities, low agricultural pressures, and lower deforestation rates (Enabel, 2020; FONAREDD, 2024; OSFAC, 2020).

These results highlight the importance of considering territorial specificities in TOF conservation strategies. Differentiated approaches, considering local contexts, are necessary to ensure effective and equitable TOF conservation throughout the Mongala province. Even if climatic and edaphic conditions are homogeneous throughout the province (World Bank, 2025), it is necessary to analyse their influence on the species richness and density of TOF on agricultural land in this province. Several studies have demonstrated that these factors influence species' geographical distribution (Franklin, 2013; Hao et al., 2019; Isaac et al., 2020; Jinga & Ashley, 2019; Oliver & Morecroft, 2014).

Effects of Wood Extraction Activities on the Conservation Index, Species Richness, and Density of TOF on Agricultural Lands in Mongala Province

This study highlights the significant negative impact of charcoal production and artisanal logging on TOF conservation. The results showed that villages where these activities are practised have significantly lower conservation indices, species richness, and TOF densities than those where they are absent.

Indeed, charcoal production, requiring tree felling, directly reduces TOF density and diversity in agricultural fields. Similarly, artisanal logging, targeting trees of commercial value, decreases TOF species richness and density. Indeed, in some regions of the DRC, it has already been observed that charcoal production and artisanal logging first target trees present on agricultural land (Benneker et al., 2012; Mbuangi et al., 2021; Nghonda et al., 2023), making them a serious threat to TOF conservation on agricultural land. Artisanal loggers and charcoal producers, lacking sufficient means to conduct forest prospecting or transport their products, often settle for trees available on agricultural land, where access is easy and cheaper (Adeniji et al., 2022; Bamwesigye et al., 2020; Benneker et al., 2012; Chiteculo et al., 2018).

These results confirm the hypothesis that these extractive activities constitute a major threat to TOF conservation. Pursuing short-term income through charcoal production and artisanal logging compromises the sustainability of tree resources and associated ecosystem services (Ciza et al., 2015; Schure et al., 2014; Sonter et al., 2015).

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In the Mongala province, most of the population lives below the poverty line, charcoal is the main source of domestic energy for urban households, and artisanal logging is the main source of timber for the urban market (Enabel, 2020). In this context, sustainable management of TOF on agricultural land requires the development of sustainable economic alternatives, such as the promotion of agroforestry, the use of improved stoves, and the valorisation of NTFPs to reduce dependence on these destructive activities and promote TOF conservation. However, the success of this conservation requires precise knowledge of the profitability and potential adoption of alternatives such as agroforestry, improved stoves, and the valorisation of NTFPs. Considering social, economic, and environmental factors, assessing the costs and benefits of these alternatives for local communities is necessary. Further research is expected to explore the links between poverty, access to resources, traditional knowledge, and exploitation practices. Finally, assessing the effectiveness of existing forest management laws and policies on TOF conservation on agricultural land is important. In the context of the DRC and the Mongala province, this will allow for the identification of gaps and opportunities to improve forest governance and promote the sustainable exploitation of tree resources.

Effect of Urban Proximity on the Conservation Index, Species Richness, and Density of TOF on Agricultural Lands in Mongala Province

The study revealed a positive relationship between urban proximity and TOF conservation on agricultural land. Villages far from major urban centres showed higher conservation indices, species richness, and TOF density than villages near these urban centres.

Several factors may explain this trend. In remote rural areas, local people's dependence on natural resources, including TOF, is often stronger. Local communities may have developed traditional sustainable TOF management practices, ensuring long-term conservation (Bit & Banerjee, 2013; Soe & Yeo-Chang, 2019). This could help ensure the sustainability of the goods and services obtained from these trees, despite the initial impression that reliance on forest resources leads to their depletion (Amuyou et al., 2021; Bhatia & Yousuf, 2013; Salehi, 2009).

Moreover, anthropogenic pressure, particularly the demand for firewood and timber, is generally lower in remote rural areas. Limited access to urban markets can also reduce the incentive to exploit TOF intensively (Gollin & Wolfersberger, 2024). In opposition, proximity to major urban centres increases the demand for natural resources and intensifies agricultural activities and other anthropogenic pressures, leading to TOF degradation (Xiong et al., 2020).

These results highlight the importance of considering the spatial dimension in TOF conservation strategies on agricultural land. Considering the socio-economic and ecological dynamics of peri-urban and rural areas, specific approaches are necessary to ensure effective TOF conservation throughout the Mongala province.

Impact of Extractive Activities and Urban Proximity on the Diversity of Trees Outside Forests on Agricultural Land

This study demonstrates that charcoal production and artisanal logging significantly negatively impact TOF diversity in the Mongala province. The reduction of Shannon's diversity index and Pielou's evenness in areas where these activities are practised indicates a loss of species richness and a homogenization of the remaining species.

These results are consistent with other studies conducted in similar contexts, where unsustainable exploitation of forest resources leads to biodiversity degradation (Chervier et al., 2024; Lawson, 2014).

Urban proximity appears to be a determining factor in TOF diversity in this province. The strong negative correlation between distance to major urban centres and Shannon's diversity index suggests that anthropogenic pressure is more intense near urban centres. This observation is consistent with the province's socioeconomic context, which depends on wood energy and

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timber exploitation for the urban market (Enabel, 2020; OSFAC, 2020).

Prevalent poverty in the Mongala province exacerbates the population's dependence on forest resources for subsistence (FONAREDD, 2024; Kranz et al., 2018; UNICEF, 2021). Wood energy remains the main domestic energy source, and timber exploitation constitutes an essential source of income (Schure et al., 2010). However, these activities lead to environmental degradation and biodiversity loss when not managed sustainably, as in the Mongala province.

Faced with these challenges, promoting sustainable alternatives to reduce pressure on TOF is crucial. Once again, these results show the need to promote alternative and renewable energy sources to reduce dependence on charcoal. Awareness and education of local populations on the importance of TOF conservation and the benefits of sustainable natural resource management are also paramount in the Mongala province. Further research is needed to assess the long-term impact of these activities on forest ecosystems and identify the most effective conservation strategies. Integrating local knowledge and traditional practices into conservation efforts is also important.

CONCLUSION

This study revealed significant variations in TOF conservation on agricultural land in the Mongala province of the DRC, influenced by territorial differences, socio-economic activities, and proximity to urban areas. Although relatively high (0.72), the overall conservation index masks significant territorial disparities, with a lower index in the Bumba territory. Species richness and TOF abundance show similar trends, highlighting the influence of local factors on TOF conservation in agricultural lands.

The results confirmed the negative impact of charcoal production and artisanal logging on TOF conservation. The study showed that these activities, motivated by short-term income, significantly reduce TOF species richness, abundance, and diversity. Dependence on these extractive practices, exacerbated by poverty and the lack of economic alternatives, compromises the sustainability of TOF resources and associated ecosystem services. Additionally, the study highlighted a positive relationship between distance from major cities and TOF conservation on agricultural land. Remote rural areas, characterised by increased dependence on local resources and lower anthropogenic pressure, exhibit higher conservation indices. This trend underscores the importance of considering the spatial dimension in TOF conservation strategies. These results highlight the need to adopt differentiated approaches, considering territorial specificities, socio-economic activities, and distance from major urban centres. Promoting sustainable economic alternatives, such as agroforestry, using improved stoves, and valorising non-timber forest products, is essential to reducing dependence on extractive activities and promoting TOF conservation.

However, further research is needed to deepen our understanding of the factors influencing TOF conservation on agricultural land. Studies on the economic viability of sustainable alternatives, the impact of policies and regulations, and management models adapted to local contexts are also crucial.

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