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Conserving Carbon Stocks Under Climate Change: Importance of Trees Outside Forests in Agricultural Landscapes of Mongala Province, Democratic Republic of Congo

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Abstract: This study aimed to evaluate the role of trees outside forests on agricultural land (TOF-AL) in preserving the initial aboveground biomass (*AGB*) of forests within the agricultural landscape of Mongala province in the Democratic Republic of Congo. In 2024, tree inventories were conducted over four months in the forests and agricultural lands of Mongala province to analyse *AGB*. The effects of artisanal logging and charcoal production activities on the *AGB* conservation rate were considered. This study indicates that 78.3% of the trees encountered in agricultural lands were large-diameter trees (diameter at breast height (DBH) $\geq$ 60 cm). In forest areas, large-diameter trees accounted for 55.9% of tree density. The average *AGB*s are 66.8 Mg ha^{-1} for TOF-AL and 373.5 Mg ha^{-1} for forest trees. The *AGB* of TOF-AL accounts for 17.9% of the *AGB* of the total forest trees. The *AGB* conservation rates vary by region, with Lisala having the highest at 22.1%, Bumba the lowest at 11.2%, and Bongandanga at 20.5%. Artisanal logging and charcoal production reduce the *AGB* conservation rate of TOF-AL. The *AGB* conservation rate is positively correlated with the distances to major cities. These results prove that conserving trees in agricultural landscapes can reduce the *AGB* losses associated with slash-and-burn agriculture and contribute to mitigating climate change effects.

Keywords: trees outside forests; agricultural landscapes; aboveground biomass; artisanal logging; charcoal production; Mongala province; DR Congo

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1. Introduction

Covering an estimated area of around 42 million km^2, forests account for a significant portion of the land and store approximately 45% of the terrestrial carbon stock [1,2]. Tropical forests provide approximately two-thirds of this carbon stock [2], making them crucial ecosystems for global climate balance [3–6]. Tropical forests are renowned for their exceptionally rich animal and plant biodiversity, which has long drawn the interest of scientists [7–9]. In addition, they provide habitats for millions of people who live there and rely on them for survival [10–13].

However, these forests are facing unprecedented levels of deforestation due to human activities [14–17]. Traditional and industrial agriculture are the main drivers of deforestation [18,19]. In tropical regions, where much of the population lives below the poverty line, wood energy is the primary domestic energy source and significantly contributes to deforestation [20–24]. Industrial logging also contributes to deforestation and forest degradation in tropical regions [17]. Current trends suggest that this deforestation may continue in the coming years [25,26].

The loss of tropical forests has numerous negative effects on the environment, biodiversity, and the survival of local populations. It results in the loss of biodiversity [27–29], a decline in forest carbon stocks [30–32], and a reduction in livelihoods for local populations [33].

Many options are being considered to mitigate the adverse effects of human activities on forests, biodiversity, climate, and people's livelihoods. Among these options, forest plantations are considered an excellent means to provide forest goods and services while enhancing carbon sequestration [34,35]. Agroforestry and traditional practices of tree conservation on agricultural lands are also being encouraged [36,37]. Indeed, these practices hold great potential to contribute to biodiversity protection, provide wood energy, and offer many non-timber forest products necessary for local populations' survival [38–41]. They can also be vital in carbon sequestration [42–44]. Therefore, thorough studies are essential to guarantee the effectiveness of these practices in addressing current challenges [45].

This research is of utmost importance in this context as it focuses on the role of trees outside forests on agricultural land (TOF-AL) in preserving carbon stocks in the Mongala province of the Democratic Republic of Congo (DRC). As is the case throughout the country, Mongala province faces significant deforestation, primarily due to slash-and-burn agriculture, logging, and wood energy [46,47]. Due to the province's inaccessibility, deforestation is focused in its three main towns: Bumba, Bongandanga, and Lisala [47]. For the population of this province, predominantly poor and reliant on forests, this deforestation results in numerous socio-economic challenges [48]. Additionally, deforestation leads to the destruction of forest carbon stocks in this province [47]. However, there is also a recurring practice of conserving certain tree species on agricultural land. These trees, referred to as "trees outside the forest on agricultural land," are generally preserved for the various socio-economic benefits that populations attribute to them [49]. Indeed, as demonstrated in many other tropical regions, retaining these trees on agricultural land, despite their dispersed distribution, can collectively form a substantial carbon sink. This may not only help mitigate carbon losses linked to deforestation in Mongala province but also contribute to broader climate change mitigation efforts [50,51]. Therefore, the main hypothesis of this research is that TOF-AL plays a significant role in conserving aboveground biomass (*AGB*) stock in the agricultural landscapes of Mongala province in the DRC. This conservation helps mitigate carbon losses associated with slash-and-burn agriculture and enhances resilience to climate change. However, the effectiveness of this conservation may be negatively affected by human pressures, such as artisanal logging and charcoal production. Additionally, it is positively correlated with the distance from major urban centres. This study seeks to assess the significance of TOF-AL in preserving carbon stocks within the agricultural landscapes of Mongala province. It aims to understand the impact of human activities and proximity to urban areas on this conservation function while also providing evidence that supports initiatives for the conservation and sustainable management of tree resources in the agricultural landscapes of this region.

2. Materials and Methods

2.1. Study Area

This research was conducted in Mongala province (Figure 1). Covering an estimated area of 58,141 km^2, it is the smallest of the 26 provinces in the DRC. However, it is larger than some countries, such as Belgium, Burundi, Gambia, and Togo. Mongala province is divided into three territories, Bongandanga, Bumba, and Lisala, which are characterised by extensive forested areas [52,53]. From an administrative perspective, every territory is segmented into collectivities, with each collectivity further subdivided into groups that encompass a collection of villages. About two-thirds of the territory of Mongala province is covered by dense, humid forests or forests on hydromorphic soil. It is crossed by the Congo River from west to east, thus forming two more or less distinct physical entities. In the northern part (Bumba and Lisala), characterised by dense humid forests, there is a considerable number of agricultural complexes (about 22% of the area). The southern part is dominated by humid tropical forests associated with forests on hydromorphic soils along the hydrographic network [54]. There is a wide variety of soil types, but the most dominant are sandy soil, sandy clay soil, and lateritic soil. These are generally acidic soils, with a *pH* between 4 and 6. Its basic vegetation is the evergreen rainforest. However, numerous agricultural pressures have increased secondary forest areas, with a tendency towards savannah in some places [54]. The population is primarily rural and mainly engages in slash-and-burn agriculture for livelihood [55]. Bumba is the smallest of the three territories but the most highly populated [54], where agricultural activities are particularly intense, leading to substantial deforestation [44,48]. The Bongandanga territory retains much of its forest cover, primarily due to the lack of road infrastructure in the region. In this territory and the two adjacent ones, local communities rely on forests for their livelihoods [47].

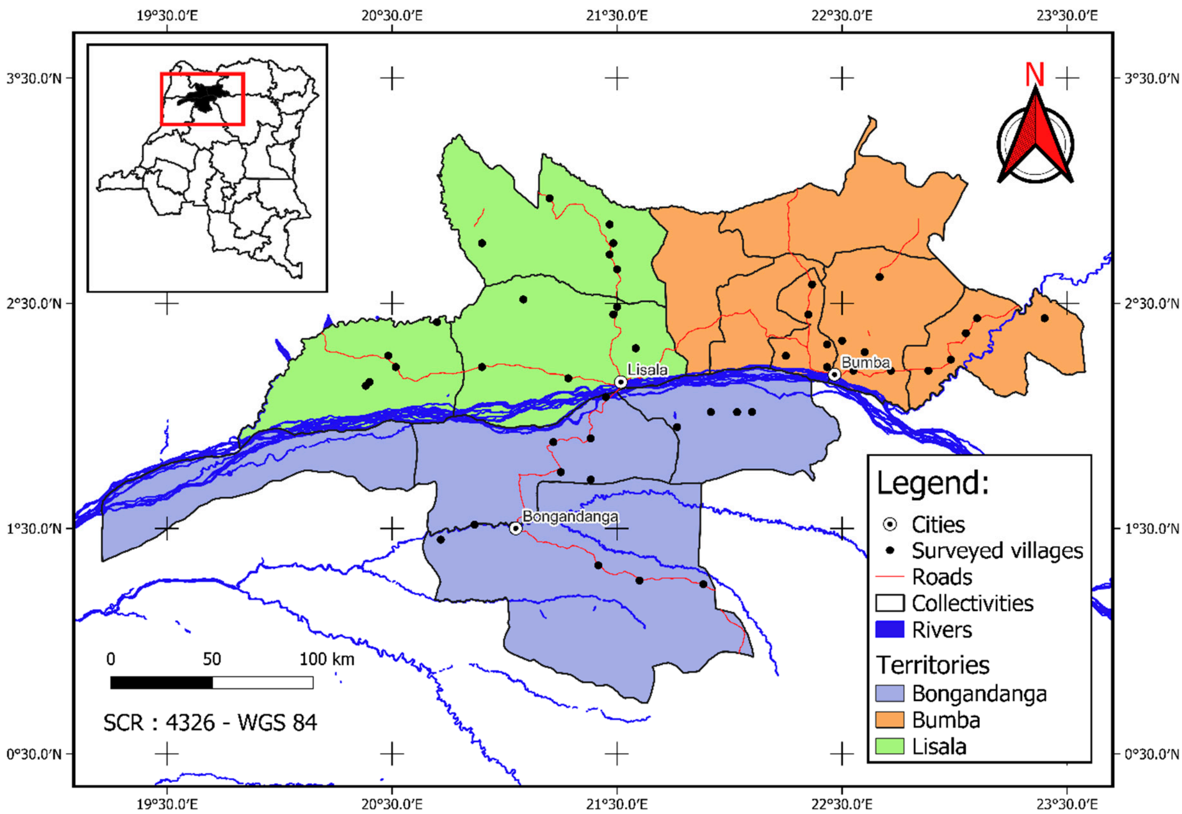

Figure 1. Map of study area in Mongala province, DR Congo.

The province experiences a hot and humid equatorial climate, with annual precipitation ranging from 1800 to 2000 mm [54]. The climate is characterised by two dry seasons and two rainy seasons. The average temperatures range from 24 °C to 25 °C, with the maximum temperatures reaching 30 °C and the minimums dropping to 19 °C.

2.2. Sampling Design and Data Collection

As defined by [56], trees outside forests (TOFs) can be conceptualised as trees located neither within forests nor on other wooded lands. According to de Foresta (2017) [57], trees outside forests on agricultural lands (TOF-AL) constitute one of the three primary categories of TOFs. This category encompasses all trees and/or shrubs on lands predominantly utilised for agricultural purposes, irrespective of their spatial arrangement (linear, clustered, dispersed), area, strip width, or vegetation cover [57].

A stratified random sampling approach was employed to ensure the representative sampling of trees outside forests on agricultural lands (TOF-AL) across the province. An inventory was conducted in 45 villages, distributed across nine collectivities, with three collectivities selected per territory. Collectivities were chosen to encompass the province's ecological and socio-economic conditions. Five villages were selected within each collectivity using a spatially balanced random sampling design, ensuring even geographical distribution and minimising clustering bias. This design considered the villages' relative distance from major urban centres, specifically Bumba, Bongandanga, and Lisala, without predetermining specific distance thresholds.

A linear transect was systematically established in each selected village, extending from the village periphery to the nearest intact forest edge. TOF-AL were inventoried within 20 agricultural fields along each transect, utilising a systematic sampling method. Fields were assigned sequential numbers from the village to the forest edge to mitigate selection bias. Only fields with even-numbered assignments containing TOF-AL were included in the inventory, ensuring objectivity and preventing subjective field selection. This consistent approach was maintained across all 45 villages.

In total, 900 fields containing TOF-AL were inventoried. The area of each field was accurately determined using a Garmin 62s GPS device. Diameter at breast height (DBH) measurements for all trees within each field were taken. Only trees with a DBH of 10 cm or greater were included in the analysis to maintain comparability with existing tropical forest carbon storage studies. Qualitative data on charcoal production and artisanal logging presence were collected through semi-structured interviews with field owners in each village, ensuring consistent data collection protocols were followed. The distance from each village to the nearest major city was meticulously recorded.

A standardised one-hectare inventory plot was established in the nearest intact forest to each village to establish a comparative baseline with forest data. All trees with a DBH of 10 cm or greater were identified and measured within these plots, ensuring consistency with the TOF-AL inventory. This resulted in 45 hectares of forest inventory, representing the full range of tropical forest types within the central Congolese basin, including monodominant and mixed forests. The application of consistent methodologies across all sampling points ensured the robustness and reliability of the data collected.

2.3. Data Processing

The tree density in the field is determined by the corresponding tree counts and area of each field, as outlined below:

$$T_{dens} = \frac{N}{S}. \tag{1}$$

T_{dens}: tree density in the field; N: number of all trees over 10 cm; S: area in hectares.

To estimate the aboveground biomass of trees, we used the two-way allometric equation from Fayolle et al. [58]:

$$AGB = \rho \times e^{-1.183+1.940\times \ln(D)+0.239\times(\ln(D))^2-0.0285\times(\ln(D))^3}. \quad (2)$$

This equation estimates the aboveground biomass (*AGB*, in kg) of each tree based on the diameter at breast height (DBH, represented as D in cm) and the specific wood density (represented as ρ in g/cm^3). Wood density data were sourced from the Global Wood Density Database [59]. The average density values for each species were used. If there was no correspondence at the species level, the average values for the genus level were employed [60]. According to their diameter, trees were classified into small (DBH 10–40 cm), medium (DBH 40–60 cm), and large (DBH $\geq$ 60 cm) to allow for a comparison with other pan-tropical studies [61,62].

The calculated *AGB* in kg was then converted to megagrams (Mg) by dividing by 1000. By knowing the area of each field, the total *AGB* for the field was adjusted to express it in *AGB* per hectare (*AGB* ha^{-1}), and the average was calculated for each village. In total, 45 observations of *AGB* ha^{-1} were obtained for the trees in question. The *AGB* conservation rate (AGB_{CR}) of trees outside forests on agricultural land, expressed as a percentage, was then calculated using the following formula:

$$AGB_{CR} = \frac{AGB_{TOF}}{AGB_F} \times 100. \quad (3)$$

AGB_{TOF} represents the average *AGB* per hectare of TOF-AL, while AGB_F indicates the *AGB* per hectare of trees in undisturbed forests.

The Kruskal–Wallis test was employed to compare the aboveground biomass conservation rates (AGB_{CR}s) among the three territories. The Wilcoxon and Mann–Whitney test was used to analyse the effects of charcoal production and artisanal logging on the conservation of *AGB*. These analyses were conducted using the “ggbetweenstats ()” function from the “ggstatsplot” package [63]. A linear regression model was employed to assess the relationship between the distance from major urban centres and the aboveground biomass conservation rate (AGB_{CR}). Prior to model evaluation, the normality of the model residuals was examined using the Shapiro–Wilk test. The initial analysis revealed a deviation from normality in the residuals’ distribution. Consequently, a square root transformation was applied to the AGB_{CR} variable, implemented via the “sqrt ()” function within the R statistical software environment. The linearity assumption of the linear regression model was subsequently validated using the Ramsey RESET test. To ensure the robustness of the model, diagnostic tests were conducted to evaluate potential violations of key assumptions. Specifically, the Durbin–Watson test was utilised to detect autocorrelation in the residuals, and the Breusch–Pagan test was employed to assess the presence of heteroscedasticity. The Ramsey RESET, Durbin–Watson, and Breusch–Pagan tests were performed using the “lmtest” package [64]. The visualisation of the model was achieved using the “ggplot2” package [65]. All statistical analyses were executed within the R 4.4.3 software environment (R Core Team, 2025).

3. Results

3.1. Tree Density and Aboveground Biomass (AGB)

In the forest, there are approximately 372.2 $\pm$ 46.3 trees per hectare. This represents an aboveground biomass of 373.5 $\pm$ 41.9 Mg ha^{-1}. In the field, the density of TOFs is 7.7 $\pm$ 5.1 trees per hectare, representing an aboveground biomass of 66.8 $\pm$ 52.9 Mg ha^{-1}. In the medium class, the density of trees (DBH 40–60 cm) is 316 stems per hectare, and the aboveground biomass is 88.5 Mg ha^{-1} (Table 1) for forest trees. In forests, large-diameter trees (DBH $\geq$ 60 cm) account for 6.1% of the tree density (22.8 stems per hectare) and 55.9% of the aboveground biomass (208.7 Mg ha^{-1}). Small-diameter trees (DBH 10–40 cm), most abundant at 316 stems per hectare in forests, account for only 23.7% of the aboveground biomass, totalling 88.5 Mg ha^{-1}. In agricultural lands, the average tree density of TOFs is 7.7 stems per hectare. Large-diameter trees contribute to 78.3% of the total stem density, which amounts to 6.1 stems per hectare. These large-diameter trees account for 95.5% of the *AGB*, totalling 63.8 Mg ha^{-1}. Small-diameter trees comprise only 6.3% of the stems and contribute just 0.6% to the total *AGB* in agricultural lands.

Table 1. Trees' density and aboveground biomass stocks (Mg ha^{-1}) for trees outside forests (TOFs) and forest trees in the province of Mongala.

	TOF				Forest			
DBH Class (cm)	**Stem Density**	**% of Density**	***AGB* (Mg ha^{-1})**	**% of *AGB***	**Stem Density**	**% of Density**	***AGB* (Mg ha^{-1})**	**% of *AGB***
DBH 10–40	0.5 ± 1	6.3	0.4 ± 0.8	0.6	316.0 ± 45.4	84.9	88.5 ± 10.9	23.7
DBH 40–60	1.2 ± 1	15.4	2.6 ± 3.6	3.9	33.3 ± 6.4	9.0	76.3 ± 11.2	20.4
DBH $\geq$ 60	6.1 ± 4	78.3	63.8 ± 51.0	95.5	22.8 ± 4.3	6.1	208.7 ± 38.6	55.9
All	7.7 ± 5	100.0	66.8 ± 52.9	100.0	372.2 ± 46.3	100	373.5 ± 41.9	100

3.2. AGB Conservation Rate by Region

In the study area, the contribution of TOF-AL for the preservation of the initial forest *AGB* is 17.9% (66.8 Mg ha^{-1} out of 373.5 Mg ha^{-1}). However, as shown in Figure 2, the conservation rate of the initial forest *AGB* varies from territory to territory. The highest *AGB* conservation rate was observed in the territory of Lisala, where TOF-AL preserved approximately 22.1% of the initial forest *AGB*. This is followed by the territory of Bongandanga, with 20.5% of the *AGB* conservation rate. The lowest *AGB* conservation rate was registered in the territory of Bumba, where TOF-AL only preserved 11.2% of the initial forest *AGB*.

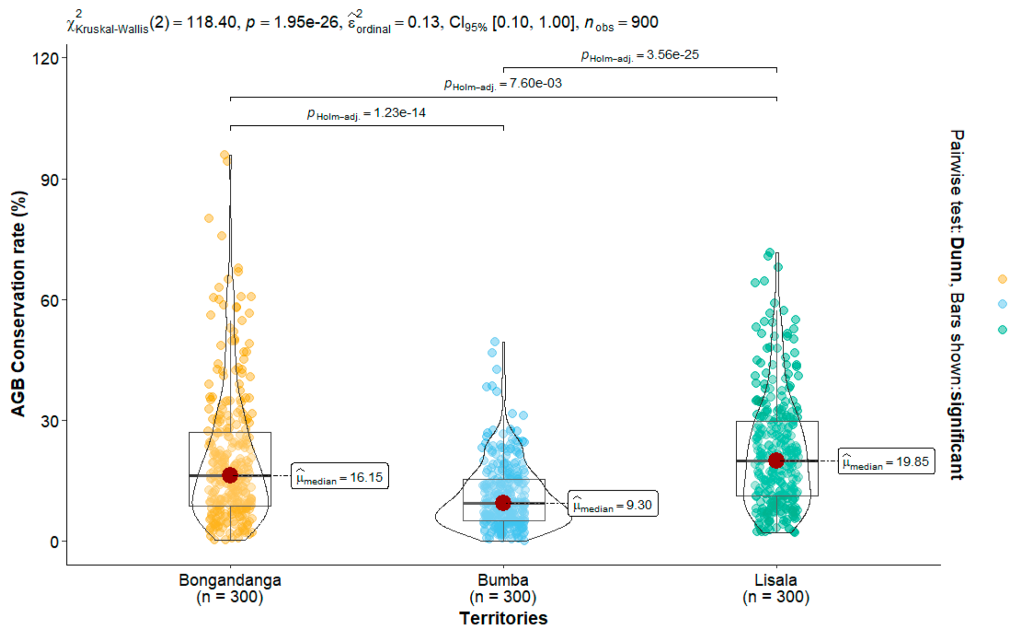

Figure 2. Variation in the conservation rates of aboveground biomass (*AGB*) across different territories of Mongala province.

The Kruskal–Wallis test confirms that the *AGB* conservation rate significantly differs in these tree territories (χ^2 = 118.4, df = 2, *p*-value = 1.1×10^{-26}). The Dunn test confirms that the *AGB* conservation rate in Lisala is significantly higher than that in Bongandanga ($P_{\text{Holm-adj.}} = 7.60 \times 10^{-3}$) and significantly higher than that in Bumba ($P_{\text{Holm-adj.}} = 3.56 \times 10^{-25}$). The Dunn test also confirms that the *AGB* conservation rate in Bongandanga is significantly higher than that in Bumba ($P_{\text{Holm-adj.}} = 1.23 \times 10^{-14}$).

3.3. The Impact of Artisanal Logging on the Conservation Rate of AGB

Overall, artisanal logging in the village significantly reduces the *AGB* conservation rate of TOF-AL in the three territories (Figure 3). In villages where artisanal logging is not practised, the average *AGB* conservation rate is 22.5%, equating to 83.97 Mg ha^{-1} of biomass preserved. However, where artisanal logging is practised, the average conservation rate of the initial *AGB* drops to 8.8% (32.81 Mg ha^{-1}). As confirmed by the Mann–Whitney test (WMann–Whitney = 31,146.00, $p = 1.10 \times 10^{-57}$), artisanal logging significantly negatively affects the conservation of *AGB* by TOF-AL in the province of Mongala.

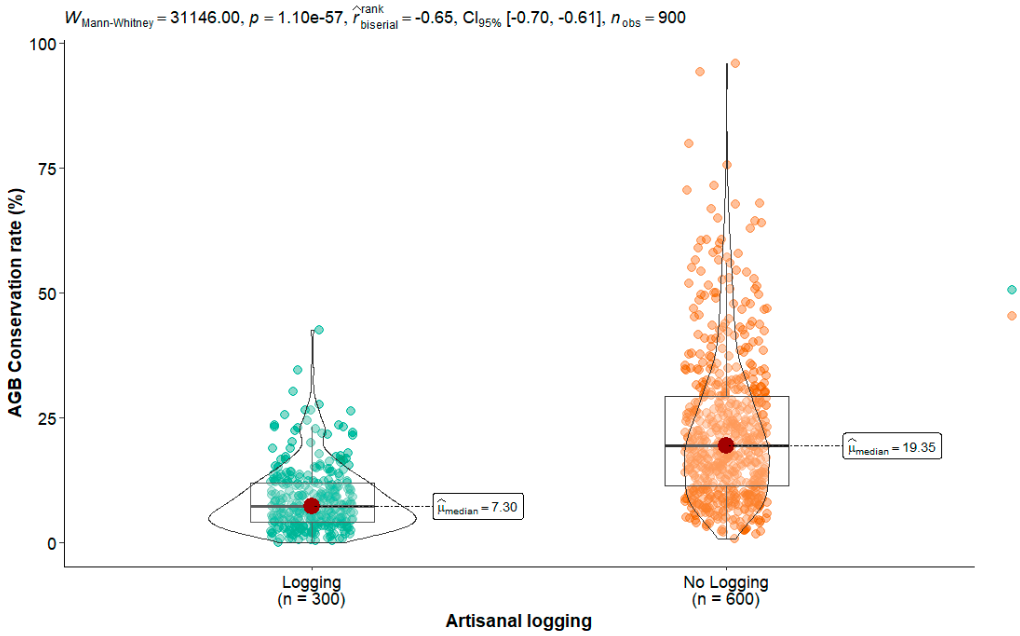

Figure 3. Influence of artisanal logging on aboveground biomass (*AGB*) conservation rate.

3.4. Effects of Charcoal Production on AGB Conservation Rate

Charcoal production, particularly in areas close to cities, diminishes the capacity of TOF-AL to maintain the aboveground biomass (*AGB*) of primary forests in agricultural lands (Figure 4). In villages where trees are not felled for charcoal production, the initial *AGB* conservation rate following slash-and-burn agriculture is 23.4%, roughly equivalent to 87.4 Mg ha^{-1}. However, in areas where local people are involved in charcoal production as a source of income, the *AGB* conservation rate is 8.9%, equating to 33.3 Mg ha^{-1}. The statistical analysis conducted confirms the negative impact of charcoal production on the ability of TOF-AL to sustain the initial forest *AGB* (WMann–Whitney = 29,525.00, $p = 1.40 \times 10^{-67}$).

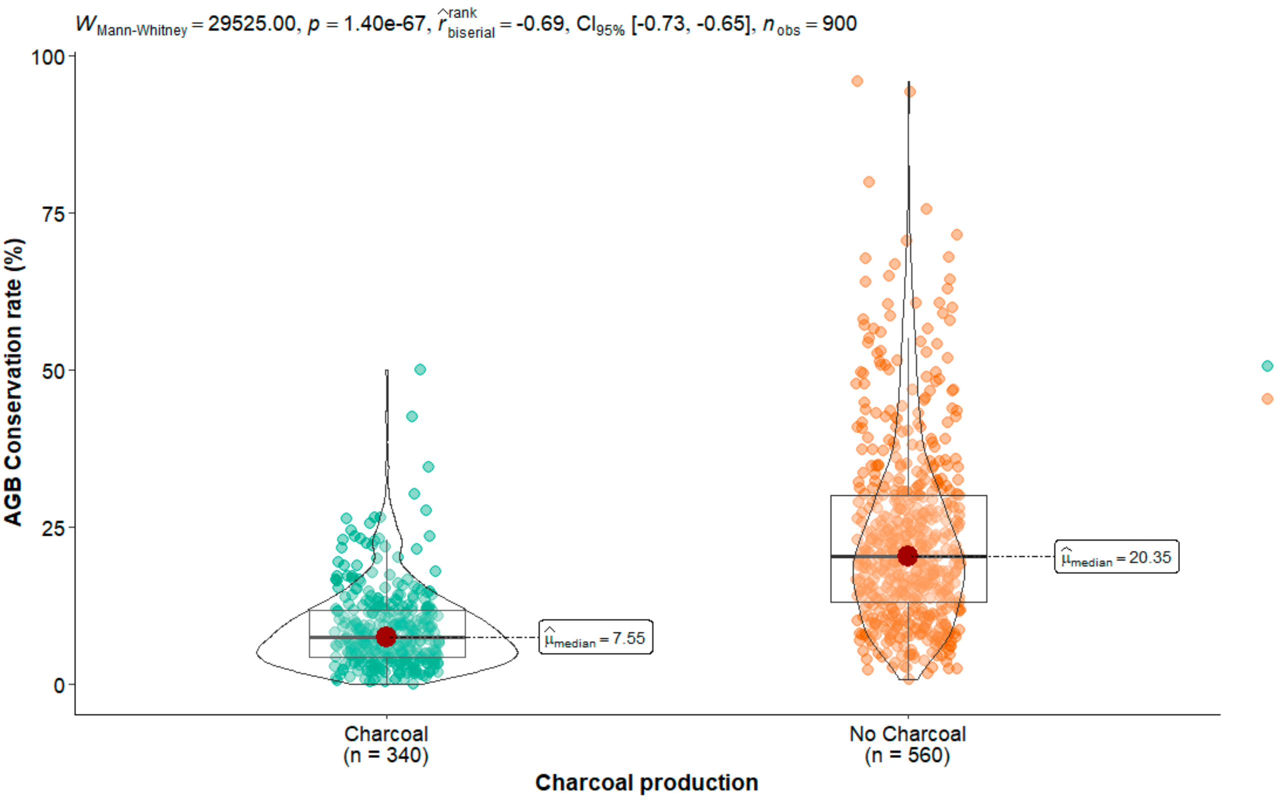

Figure 4. Influence of charcoal production activity on *AGB* conservation rate in Mongala province.

3.5. The AGB Conservation Rate and the Distance to Cities

The conservation rates of aboveground biomass (*AGB*) increase with the distance from major cities (Figure 5). This suggests that farmers situated further from Bumba, Bongandanga, and Lisala are more likely to leave additional trees standing in their fields, leading to a higher conservation rate of the *AGB*.

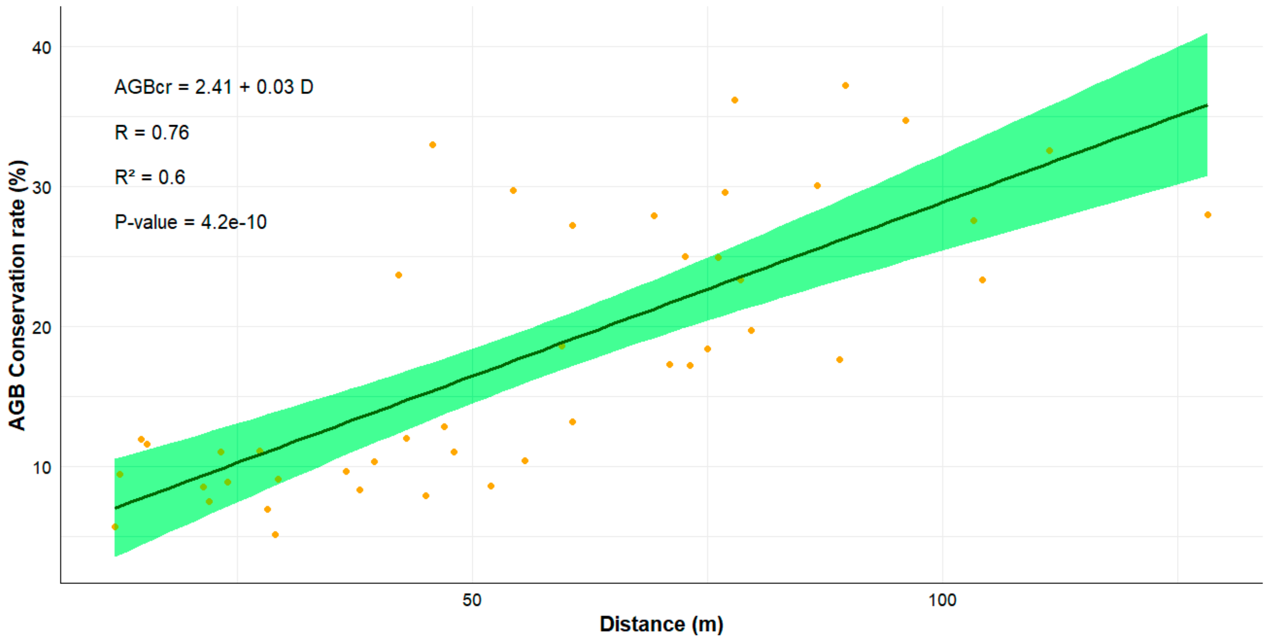

Figure 5. Relationship between distance to major cities and initial aboveground biomass (*AGB*) conservation rates in Mongala.

The correlation index indicates that the *AGB* conservation rate is correlated with the distance from major cities (Cor: 0.76, R^2: 0.6, *p*-value: 4.2×10^{-10}) in Mongala province.

4. Discussion

4.1. Tree Density and Aboveground Biomass

In Mongala province, the average density of trees in the forest is 372 trees ha^{-1}, representing 373.5 Mg ha^{-1} of *AGB*. Bradford and Murphy [3] found similar results in Australian forests, where the *AGB* stock ranges from 307 to 909 Mg ha^{-1}. In the eastern Amazon, Sist et al. [61] found that the average density of trees (DBH $\geq$ 20 cm) is about 219 trees ha^{-1}, which represents 378 Mg ha^{-1} of *AGB*. The average *AGB* observed in Mongala province is close to that found by Slik et al. [60], who showed that the average *AGB* in the tropics is about 418.3 Mg ha^{-1}. In Mongala forests, large-diameter trees (DBH $\geq$ 60 cm) represent about 6.1% of the tree density and 55.9% of the forest's *AGB*. Slik et al. [60] and Sist et al. [61] found similar results for tropical forests. They showed that, in tropical forests, large-diameter trees account for 69.8 and 49% of *AGB*, respectively. This study also showed that, in Mongala province, farmers tend to keep large-diameter trees in their fields. This may be explained by the difficulty of cutting these trees since farmers use rudimentary tools such as axes or machetes to cut trees. In addition, most of the trees kept belong to species of large trees of African forests, such as *Erythrophleum suaveolens*, *Petersianthus macrocarpus*, *Ricinodendron heudelotii*, *Pycnanthus angolense*, *Piptadeniastrum africanum*, *Entandrophragma* sp., etc. Thus, given the role of large-diameter trees in tropical forest biomass, conserving TOF-AL offers a great opportunity to reduce greenhouse gas emissions in Mongala province despite slash-and-burn agriculture. To achieve this, future research must explore the long-term carbon storage potential of TOF-AL in other provinces of the DRC. It is also important to compare *AGB* conservation rates in different TOF-AL systems (e.g., varying tree densities, species compositions, and management practices). To understand the dynamics of the *AGB* conservation rate in the agricultural landscape of Mongala province, future research should monitor the growth and mortality rates of large-diameter TOF-AL.

4.2. Aboveground Biomass Conservation Rate by Territory

The *AGB* conservation rate in Mongala province is 17.9%. This is very relevant information in the context of reducing emissions from deforestation and forest degradation. However, this study also showed that the role of trees outside forests in conserving the initial *AGB* of forests varies from territory to territory. In the three territories of Mongala province, the aboveground biomass conservation rate is higher in Lisala (22.1%), followed by Bongandanga (20.5%), and Bumba has the lowest *AGB* conservation rate (11.2%). Their intrinsic characteristics can explain this variation in the initial *AGB* conservation rate between the three territories. Indeed, the low aboveground biomass conservation rate in Bumba is consistent with information on deforestation and forest degradation in this territory. In a report, OSFAC [47] showed that Bumba is the territory with the highest deforestation rate in Mongala province. Enabel [54] explains the causes of this high deforestation rate, showing that agricultural activities are more intense in Bumba than in the other two territories. Furthermore, Bumba has the highest population density, resulting in a significant demand for agricultural products and wood energy [47,54]. The other two territories, although primarily agricultural, are less densely populated. The Bongandanga territory is even more landlocked than the others, which reduces pressure on forests and trees. In Bongandanga and Lisala, economic activities are less intense than in Bumba. Artisanal logging and charcoal production are also less developed in Lisala and Bongandanga than in Bumba [54], explaining why the *AGB* conservation rates are higher in these territories. A detailed and spatially explicit analysis of land-use change should be conducted in each territory (Bumba, Bongandanga, Lisala), using remote sensing and ground-truthing for a better understanding of land-use change's impact on the *AGB* conservation rates per territory. Market-oriented research should consider the dynamics of agricultural products and wood energy in each territory to understand the economic incentives for deforestation and forest degradation.

4.3. The Impact of Artisanal Logging on the AGB Conservation Rate

In Mongala province, the *AGB* conservation rate is three times higher in areas where artisanal logging is not practised than in areas where it is practised. Where trees are not cut for timber, the *AGB* conservation rate is about 22%. However, the *AGB* conservation rate drops to 8% where artisanal logging is practised. This result confirms, in general, the negative effects of artisanal logging on forest resources, as demonstrated by Kranz et al. [46] and Shapiro et al. [66]. Indeed, artisanal sawyers, who do not have the means to organise large-scale prospecting campaigns in the forest, take advantage of the accessibility of agricultural lands to identify interesting timber tree species. These trees preserved by farmers when opening their fields are then logged to supply the urban markets of Bumba, Lisala, and even Kinshasa [67]. Given that, in the DRC, most of the wood production of the industrial sector is intended for export [17], artisanal logging, primarily conducted on agricultural land, serves as the primary source of timber for Congolese cities like Bumba and Lisala. This unsupplied local demand for timber explains the low *AGB* conservation rates in areas where artisanal logging is practised. To ensure the success of *AGB* conservation on agricultural landscapes, it is important to assess the impacts of artisanal logging on local communities' livelihoods and investigate the potential for alternative livelihood opportunities that can reduce reliance on artisanal logging.

4.4. The Impact of Charcoal Production on the AGB Conservation Rate

It was observed in this study that in Mongala province, the aboveground biomass conservation rate is low in villages where slash-and-burn agriculture is practised simultaneously with charcoal production. Indeed, several studies have shown that in tropical regions, firewood and charcoal supply about 90% of household energy needs [23,68,69]. While in other regions, people cut down forest trees to make charcoal [22,24], in Mongala province, charcoal is generally produced from TOF-AL. After sowing the crops, farmers cut down the remaining trees in their fields to make charcoal [70]. Thus, charcoal production decreases the *AGB* conservation rate of TOF-AL when practised in an area. This research underlines the necessity to conduct longitudinal studies to track the temporal dynamics of TOF-AL use, from initial clearing to charcoal production and subsequent agricultural activities. Other research should analyse the profitability of charcoal production and its contribution to household income. Investigating the potential for alternative energy sources (e.g., biomass briquettes) to reduce reliance on charcoal is also important. On the other hand, it is crucial to analyse the feasibility and acceptability of these alternatives to local communities.

4.5. AGB Conservation Rate and Distance to Cities

It was observed in this study that in Mongala province, there is a positive correlation between the distance from major cities and the *AGB* conservation rate of TOF-AL. This means that in villages located further from cities, farmers keep more trees in their fields, which leads to a high *AGB* conservation rate. These results are consistent with those found by Xiong et al. [71], who showed that the deforestation rate in Zhejiang province (China) was very high within a 3 km radius of major cities. However, it gradually decreased as people moved away from cities. They argue that communication routes, whether roads or rivers, have a positive effect on deforestation. Consequently, the rate of deforestation decreases as the distance from these communication routes increases.

Several mechanisms can explain this. First, several studies have shown that in tropical regions, the deforestation rate is higher around large cities [68,71]. Indeed, proximity to cities has two effects: for rural populations, it improves market access [72,73], and for urban populations, it increases forest access [73], consequently increasing deforestation. On the other hand, increasing population density around large cities shortens the fallow period, compromising forest recovery [68]. So, if pressures on forests are higher near cities, it is logical that the *AGB* conservation rate is lower near cities, as observed in this study.

In Mongala province, the quality of road infrastructure can explain the low *AGB* conservation rate near major cities, the high population density near cities, and the presence of artisanal sawmilling and charcoal production in villages near cities. Indeed, as discussed above, artisanal logging and charcoal production attacks trees preserved in farmers' fields. Artisanal loggers trade these trees with farmers to make timber; some are cut down to produce charcoal. Given that these two activities are concentrated within a 40 km radius of the city, this partly explains the low *AGB* conservation rate near cities. In more remote areas, the roads are often poor-quality, restricting access to forests and trees. This is consistent with the results found by Li et al. [73] and Mena et al. [74], who showed that the quality of roads indirectly affects forest resources. Thus, the difficulty of evacuating products prevents artisanal logging and charcoal production in these areas, thus sparing trees outside forests on agricultural land. Regarding these results, future research must investigate the specific impacts of different types of infrastructure (roads, rivers, etc.) on *AGB* conservation and analyse the interaction between road quality, transportation costs, and resource exploitation. Other studies should analyse the specific commodity chains that drive resource exploitation near cities (e.g., timber, charcoal, agricultural products). Future research must also analyse how urban demand for resources (timber, charcoal, food) influences land-use practices and *AGB* conservation in surrounding rural areas. This research enhances the importance of conducting economic analyses to understand the incentives and disincentives for farmers to conserve trees on their land.

5. Conclusions

This study analysed the contribution of trees outside forests on agricultural lands (TOF-AL) to conserving the initial forest *AGB* following slash-and-burn agriculture in Mongala province of the Democratic Republic of Congo. Observations were carried out in 45 villages spread across three territories in Mongala province. Most trees preserved in farmers' fields have a DBH $\geq$ 60 cm. On agricultural lands, the average *AGB* is 66.8 ± 52.9 Mg ha^{-1}, representing 17.9% of the pre-existing forests' *AGB*. The *AGB* conservation rate varies from one territory to another. The territory of Lisala has the highest *AGB* conservation rate (22.1%), followed by Bongandanga (20.5%) and Bumba (11.2%). Artisanal logging and charcoal production negatively impact the biomass conservation rate of TOF-AL. Without charcoal production, the *AGB* conservation rate is 23.4%. However, if charcoal production is practised, the *AGB* conservation rate is 8.9%. Similarly, the *AGB* conservation rate is 22.5% if artisanal logging is practised and 8.8% when artisanal logging is not practised. A positive correlation exists between distance from major cities and the *AGB* conservation rate, which is higher when farther away from cities. These results demonstrate the importance of encouraging and supporting the conservation of TOF-AL. This conservation may be seen as a viable option for implementing the REDD+ mechanism in this province. However, it is also evident that to guarantee its success, alternative activities to charcoal production and artisanal logging must be developed to provide local populations with other sources of income.

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Abbreviations

The following abbreviations are used in this manuscript:

TOF-AL	Trees outside forests on agricultural land.
DRC	Democratic Republic of Congo.
AGB	Aboveground biomass.

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