Urban harvest pressures: Bark stripping of African Mahogany (*Khaya senegalensis*) trees for medicinal use in the Northern Region of Ghana

Hamza Issifu, Ibrahim Sita, Edmund Afful

Correspondence

Hamza Issifu[1*], Ibrahim Sita[1], Edmund Afful[1]

[1]Department of Forestry and Forest Resources Management, Faculty of Natural Resources and Environment, University for Development Studies. P.O. Box 1350, Tamale, Ghana.

*Corresponding Author: hamza.issifu@gmail.com

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Abstract

Background: *Khaya senegalensis* (Desr.) A.Juss. (African mahogany) is planted in urban landscapes as an amenity tree but also exploited for medicinal bark. However, little is known about bark stripping pressure and its link to urban tree health. This study was aimed at assessing the extent and intensity of bark-stripping among African mahogany trees in urban spaces and examining associations between bark-stripping, stem burl formation and stem decay.

Methods: Field survey was conducted in three districts (Tamale, Sagnarigu and Tolon) in the northern region of Ghana between 2017 and 2018. Multi-stage sampling together with tree inventory techniques were used to assess tree height, diameter at breast height (DBH), presence of bark stripping, stem burls, stem decay, and stripping intensity of bark-stripped trees. Data were analysed using descriptive statistics as well as logistic regression and chi-square tests to assess relationships among variables.

Results: A total of 509 African mahogany trees were assessed across the three districts. Bark-stripping was intensive and widespread (80% of trees). Prevalence was highest in Tolon district compared to the more urbanized Tamale Metropolis. Bark-stripping was a significant predictor of stem burl formation ($p < 0.001$), which in turn significantly predicted stem decay ($p = 0.039$). Bark-stripped trees were 26 times more likely to develop stem burls, and trees with stem burls were four times more likely to show stem decay.

Conclusions: Bark-stripping intensity is high among urban African mahogany trees in the Northern Region of Ghana and is associated with burl formation and increased risk of stem decay.

Keywords: Ethnobotany, stem decay, stem burls, tree health, amenity trees

Background

Trees are an integral and important component of urban landscapes (O'Brien *et al*. 2017, Wolf *et al*. 2020, Oliveira *et al*. 2026). Urban tree planting is undertaken with specific objectives such as shade provision, windbreaks and recreational or ornamental reasons, with enormous benefits to the environment and the general wellbeing of urban dwellers (Wolf *et al*. 2020, Pataki *et al*. 2021, Oliveira *et al*. 2026). Nevertheless, because many tree species have multiple uses, urban residents often exploit them for purposes beyond those for which they were originally planted (Hamilton 2004, Wolf *et al*. 2020, Pataki *et al*. 2021, Godonou *et al*. 2025). These other use values of trees are determined by the ethnobotanical knowledge of locals about various tree species as well as the accessibility to these trees (Senkoro *et al*. 2014, Asigbaase *et al*. 2024).

In many cities and towns across West Africa, *Khaya senegalensis* (Desr.) A. Juss. (Meliaceae) (African mahogany) is one of the tree species found along roads in amenity planting in government departments and agencies, educational institutions and religious establishments (Douny & Sawadogo 2025, Godonou *et al*. 2025). Across Sub-Saharan Africa, it is a multipurpose tree species of significant ecological, economic, and medicinal value (Amekpo *et al*. 2025). It is an excellent timber species and was reportedly one of the first timber species exported from Africa (Dalziel 1937). It is an important livestock feed and has been known to occupy an important place in traditional medicine for curing many ailments in both humans (Abbiw 1990, Gaoue & Ticktin 2007, Delvaux *et al*. 2009, Boafo *et al*. 2016, Gaoue *et al*. 2021, Asigbaase *et al*. 2024, Amekpo *et al*. 2025) and livestock (Atawodi *et al*. 2002).

In Ghana, local communities rely on the bark of African mahogany for treating ailments such as malaria, fever, and gastrointestinal disorders (van Andel *et al*. 2012, Boafo *et al*. 2016, Asigbaase *et al*. 2024), contributing to its widespread harvesting (Abbiw 1990, Boafo *et al*. 2016). There have been reports of shortage of bark material for commercial production of herbal medicines such that herbal practitioners have had to turn to other West African countries for supply (Asase 2023). The widespread use of the species in traditional medicine may derive its scientific validity from studies that have reported the presence of bioactive compounds with therapeutic properties in many plant parts of African mahogany, particularly the bark (Abbiw 1990, Abdelgaleil *et al*. 2001, Zhang *et al*. 2009).

However, unsustainable harvesting of bark from live trees poses significant threat to the survival of trees (Laird & Pierce 2002, Vermeulen 2006). The increased pressure on African mahogany is due to several reasons. One of the foremost reasons is inadequate afforestation targeting African mahogany, despite a low relative abundance of the species within its ranges in the northern Guinea Savanna where it has been heavily exploited for timber (Dalziel 1937, CITES 2002, Louppe *et al.* 2008). Therefore, for ease of access, locals tend to depend on urban populations of the species planted for other reasons other than for the harvest of medicinal plant parts. Secondly, urbanization and population growth tend to increase the demand for medicinal plant parts, especially in traditional societies where a significant percentage of the population still depends on herbal medicines (Wodah & Asase 2012). For example, the Greater Tamale area is reported as one of the fastest expanding cities in West Africa (Karg *et al*. 2022). The city has merged with almost all towns and villages that form part of Tamale Metropolis or Sagnarigu Municipality, blending modernity with traditional African lifestyles and a high dependence on both herbal and orthodox medicines (Ghana Statistical Service 2014, Ameade *et al*. 2018, Iddrisu *et al*. 2023). Thus, although the extent of dependence on herbal medicines differs between rural and urbanized communities (Wodah & Asase 2012, Boafo *et al*. 2016), the demand for medicinal plant resources could be high in the greater Tamale area, as reflected in the phenomenon of bark-stripped trees observed along major roads in the area.

The effects of very high pressures on medicinal tree bark of African mahogany may reflect in reduced tree growth rates and or increased susceptibility to pests and diseases (Delvaux *et al*. 2009, Gaoue & Ticktin 2010, Gaoue *et al*. 2021). The latter may manifest or result in stem decay and eventual mortality (Cunningham 2001, Ticktin 2004). The ecological consequences of unsustainable bark harvest may extend beyond individual tree health to broader impacts on other use values of the trees within urban landscapes. Yet the extent and intensity of bark harvesting and its impacts on tree health indicators remain undocumented for urban tree populations. Although there have been few studies that have mentioned bark-stripping as one of the anthropogenic pressures on urban trees including African mahogany (Godonou *et al*. 2025), most studies have targeted wild populations (Gaoue & Ticktin 2007, Delvaux *et al*. 2009, Gaoue & Ticktin 2010, Gaoue *et al*. 2021) within the West African subregion.

Understanding the scale and effects of the practice of bark harvesting in urban tree populations is crucial for developing sustainable management strategies and conservation policies. This study was aimed at assessing the extent and intensity of bark-stripping among African mahogany trees in urban spaces and examine associations between bark-stripping, stem burl formation and stem decay with the broader goal of informing sustainable management and conservation strategies. The specific objectives of the study were to: 1) assess the abundance of African mahogany trees in urban areas in the northern region of Ghana, 2) examine the extent and intensity of African mahogany tree bark harvesting in the area, 3) assess the effects of bark harvesting on some tree health indicators (stem burls and stem decay) and, 4) examine the effects of bark harvesting on diameter at breast height (DBH) and the correlation between tree height and DBH.

Materials and Methods

Study area

The study was conducted in three districts of the northern region of Ghana: Tamale Metropolis, Sagnarigu Municipal and Tolon district (Fig. 1). Tamale and Sagnarigu together constitute the Greater Tamale area. Tolon, the capital town of the Tolon district, is about 25 km away from Tamale (Ghana Statistical Service 2022). The selected districts represent a continuum from low to high levels of urbanisation.

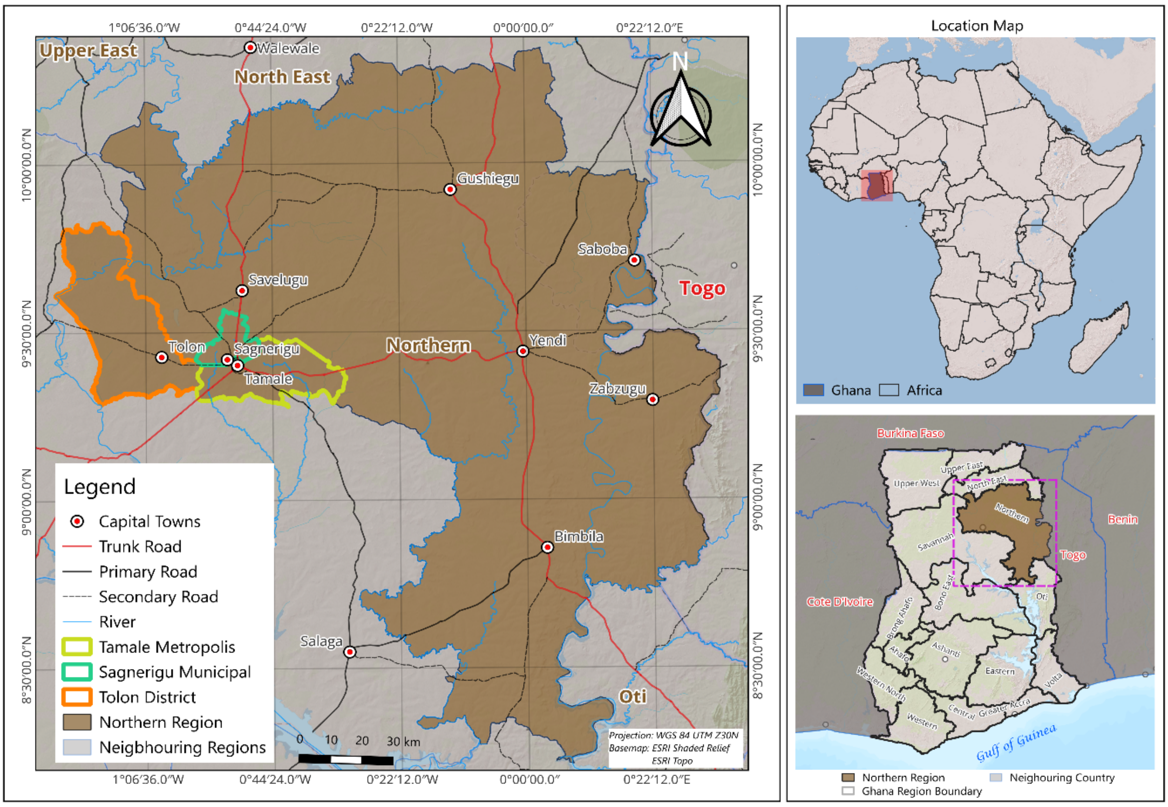

Figure 1. Map of the study region (Northern region of Ghana) showing the three selected districts (Tamale Metropolis, Sagnarigu Municipal and Tolon District).

Tamale Metropolis, located between latitude 9º 16'N and 9º 34'N and longitudes 0º 36'W and 0º 57'W, has an estimated land area of 647 km^2 (Ghana Statistical Service 2022). it is one of six Metropolitan areas in Ghana, the only Metropolis in Northern Ghana and the third largest urban centre with second highest annual population growth rates in Ghana (Fuseini *et al*. 2017). Tamale, the Metropolitan capital city and the regional capital of the northern region of Ghana, is one of the most rapidly expanding capital cities in West Africa (Karg *et al*. 2022). There are 115 communities in the Metropolis, but most have merged with Tamale, with a total population of 374,744 being entirely urban (Fuseini *et al*. 2017, Ghana Statistical Service 2022).

Sagnarigu Municipal lies between latitudes 9º 16'N and 9º 34'N and longitudes 0º 36'W and 0º 57'W. It has a total land area of 200.4 km^2, 79 communities (20 urban, six peri-urban and 53 rural), all of which have almost merged with the capital, Sagnarigu which is also a part of the greater Tamale area (Ghana Statistical Service 2022). The total population of the Municipality is 341,711, with 81.6% being urban and 18.4% being rural (Ghana Statistical Service 2022).

The Tolon district lies between latitudes 90 15'N and 100 02'N and Longitudes 00 53'W and 10 25'W. It also covers a total land area of 1353.7 km^2. The Tolon District is one of the poorest districts in the northern region of Ghana (Ghana Statistical Service 2022). The total population is 118,101, with rural population accounting for 78.2 % of the population while 21.8% is urban (Ghana Statistical Service 2022).

Sampling of urban African mahogany tree populations and data collection

African mahogany populations in urban areas result predominantly from deliberate planting rather than natural regeneration, as the species is widely used as an amenity tree in roadsides, parks, and public institutions (Darwesh *et al*. 2017). Therefore, a multi-stage sampling approach was used first to select three districts in the northern region of Ghana. For this, purposive sampling was used to select Tolon District, Sagnarigu Municipal and Tamale Metropolis as these were the most likely districts with public institutions with amenity planting involving African mahogany trees. Then, a reconnaissance survey was conducted to locate African mahogany tree zones in towns and cities (i.e. stratified sampling within each of the three selected districts). The reconnaissance survey revealed varying numbers of African mahogany tree zones: six in Tamale Metro, five in Sagnarigu Municipal and three in Tolon district (Table 1). These African mahogany trees were confined to certain suburbs in towns or cities as avenue trees, trees planted by roadsides in office premises or school (high schools, colleges of education and university) campuses and in a plantation forest managed by the Forest Services Division (FSD) of the Forestry Commission of Ghana.

In each zone, all African mahogany trees were counted, their height measured with a Hagar altimeter and diameter at breast height (DBH), at 1.3 m, measured using a diameter tape. To quantify the extent of bark stripping, binary data were recorded on bark-stripping status as “yes”, for bark-stripped individuals or “no” for individuals not bark-stripped. To quantify bark-stripping intensity, we assessed slash or wound depth using categorical descriptions as follows: “shallow” (i.e., when cambial sheet was still intact after stripping); “deep” (when cambial sheet has been removed in stripping) or “very deep” (when part of xylem tissues has been removed in stripping). For example, Fig. 2A shows “shallow slashing” while Fig. 2B shows “very deep slashing”. This assessment (wound depth) was done in Tamale Metropolis and Sagnarigu Municipal using a total of 294 trees sampled across tree zones in the two districts using simple random sampling. Using only trees in Tolon district, we measured wound/slash diameter for three random wounds for all bark-stripped trees for the determination of wound surface area. In all three districts, maximum bark stripping height (i.e., the highest point on tree trunk where bark has been harvested) was measured by means of tape measure, from base of tree to wound/scar on the highest part of the tree trunk (indicated by vertical arrow in Fig. 2B).

In all three districts, we assessed tree health status using presence of tree stem burls (Fig. 3A) and stem decay (Fig. 3B) as indicators. Stem burls were described as: "no burl" for trees with zero burls on stem, "moderate burls" for those with few burls (less than ten burls on tree trunk) and "severe burls" for those having many burls (ten or more burls on tree trunk, e.g., Fig. 3A). Binary data were recorded on stem decay as; “decay present” (e.g. Fig. 3B) versus “decay absent”. Data collection started in June 2017 and was completed in September 2018.

Figure 2. Bark-stripped African mahogany trees used in avenue planting in the northern region of Ghana. Figure 2A and 2B both show wound surface area, Figure 2A shows shallow slashing and Figure 2B shows “very deep slashing” as well as stripping height (indicated by vertical arrow).

Figure 3. Bark-stripped African mahogany trees used in avenue planting in the northern region of Ghana showing; (A) stem burls and (B) stem decay.

Table 1. African mahogany tree zones in three districts of the Northern Region of Ghana

District	Tree zone	Location	Description
Tamale Metropolis	Z1	Zogbeli	Trees in public roadside alley
	Z2	F.S.D Tamale	Trees within gated office premises
	Z3	NADMO	Trees within office premises
	Z4	ByFCS	Trees within gated private business premises
	Z5	CYC	Trees in roadside alley on office premises
	Z6	Gumani Forest	Trees in forest plantation
Sagnarigu Municipal	Z1	BTC	Trees in roadside alley on school premises
	Z2	BDBS	Trees in roadside alley on school premises
	Z3	TCoE	Trees within school premises
	Z4	TSHS	Trees in roadside alley on school premises
	Z5	TTU	Trees in roadside alley on school premises
Tolon District	Z1	Tolon township	Trees in public roadside alley
	Z2	SARI	Trees on office premises
	Z3	UDS-Nyankpala	Trees in roadside alley on school premises

Data Analysis

Population abundances were presented as counts of African mahogany trees and analysed for differences among districts with negative binomial test (due to overdispersion) using *glm.nb* function in package *MASS* with Tukey pairwise comparisons done in package *multcomp* in R. Extent of bark stripping was presented as percentage of stripped trees by zone and districts and analysed using binomial logistic regression (with logit link function) on bark stripping status as binary response variable

(stripped vs. unstripped) and district as the predictor. Tukey pairwise comparisons (for significant district effect) were performed in package *multcomp* in R. We used binomial logistic regression (with logit link function) in R to test if there was a preference for certain tree sizes for bark harvest.
Mean stripping height was analysed using one-way ANOVA with significant district effect separated using Tukey post hoc contrasts. Then each district was analysed separately, in one-way ANOVA with Tukey post hoc contrasts, for effect of African mahogany tree zone on bark stripping height.

Number of wounds per trunk was analysed using negative binomial test (also due to overdispersion) in R for differences among districts. Wound depth categories (i.e., shallow, deep and very deep) were quantified in terms of percentage of wounds that fell under each category. Wound surface area was calculated assuming the wounds are elliptical, whereby wound length and width (and hence diameter) are approximately the same, using the formular, $A = \frac{\pi d^2}{4}$ (where A = wound area and d = wound diameter). Total surface area was then analysed for differences among tree zones within Tolon district (i.e., the only district where this was assessed) in one-way ANOVA with Tukey post hoc contrasts (for significant tree zone effect).

Tree health indicators were analysed using Chi-square to test association between bark stripping and the development of stem burls and then between prevalence of stem burls and stem decay in a separate analysis. In each analysis, Odds ratio was computed based on Fisher's exact test in R. Severity of burls was assessed by quantifying the percentage of trees that fell within each of the severity categories (i.e. severe, moderate and no-burls). We assessed whether stem decay (binary response variable) was more common to certain tree sizes (DBH in continuous scale) using binomial logistic regression and tested the effect of bark stripping on tree DBH using one-way ANOVA. Then we examined diameter-height relationships for bark-stripped and unstripped trees using Pearson's correlation tests and visualized these associations in scatter plots in ggplot2 in R. A significance threshold of 0.05 was applied for all statistical analyses.

Results

Urban African mahogany tree populations in the three districts

A total of 509 African mahogany trees were found across all districts. Tree counts differed significantly (χ^2 (2) = 258.6, $p <$ 0.001) among districts. Tree abundance was highest in Sagnarigu Municipal (240 individuals), followed by Tamale Metropolis (145 individuals), while Tolon District recorded the lowest number of African mahogany (124 individuals). However, Multiple comparisons revealed differences between Sagnarigu Municipal and both Tamale Metro and Tolon district, but not between Tamale Metro and Tolon district ($z = 1.252$, $p = 0.421$).

The number of trees also varied among zones within each district (Table 2). In Tamale Metropolis, most trees were found in the Gumani Plantation Forest, which had more trees than all other zones in the Metropolis combined. In Sagnarigu Municipal, there was no clear dominance of zone in terms of African mahogany tree abundance. Nevertheless, more trees were found in Tamale College of Education and Tamale SHS than in other zones within the municipality. In Tolon, CSIR-SARI Campus (with 74 individuals) recorded the highest number of individuals followed by Nyankpala Campus of the University for Development Studies (with 47 individuals) and Tolon township itself recording the least number of African mahogany trees (at five individuals).

The population structure of African mahogany exhibited a Gaussian distribution, with medium- to large-sized individuals dominating (Fig. 4A). In Tolon District, the size-class distribution displayed a smaller peak and extended tails on both sides, resulting in a slightly flattened curve compared to Sagnarigu, where trees were confined to a diameter range of 30–149 cm DBH (Fig. 4A). Tamale Metropolis showed a distribution pattern similar to Sagnarigu, but with the presence of larger individuals (DBH range 140 to >159 cm).

Bark stripping extent and intensity in the three districts

Percentage of bark-stripped trees

Across all three districts, 80% of African mahogany trees were found to have been bark-stripped. The extent of bark stripping differed significantly among districts ($\chi^2(2) = 510.4$, $p = 0.002$). The highest proportion of bark-stripped trees occurred in Tolon District (87%), followed by Sagnarigu Municipal (82%), while Tamale Metropolis recorded the lowest proportion (70%). Post hoc multiple comparisons indicated significant differences between Tamale Metropolis and both Tolon District and Sagnarigu Municipal, but no significant difference between Tolon District and Sagnarigu Municipal ($z = 0.962$, $p = 0.597$).

Within districts, the intensity of bark stripping varied considerably across zones (Table 2). In some zones, stripping reached 100%, whereas in others it was markedly lower, with two zones in Tamale Metropolis (the FSD office premises and ByFCS premises) showing no stripping (0%). In Sagnarigu Municipal and Tolon District, the lowest stripping percentages were recorded on institutional campuses, 46% at a senior high school (Tamale SHS) and 66% at the University for Development Studies, Nyankpala campus (UDS-Nyankpala). By contrast, the highest stripping levels occurred in township areas and along roadsides, where trees were planted as avenues trees (Tables 1 and 2).

Table 2. Percentage of trees bark-stripped in African mahogany tree zones in the three study districts of the Northern Region of Ghana. The *Total* for number of trees and number bark-stripped are the sum of values across tree zones. The *Total* for bark-stripped percentage is calculated as a percentage of total number of trees bark-stripped and not as average across tree zones.

District	Tree zone	Zone Description	Number of trees	Number bark-stripped	Percent bark-stripped
Tamale metropolitan	1	Zogbeli	27	27	100
	2	F.S.D Tamale	7	0	0
	3	NADMO	12	4	33
	4	ByFCS	7	0	0
	5	CYC	8	8	100
	6	Gumani Forest	84	62	74
Total			145	101	69.7
Sagnarigu Municipal	1	BTC	43	43	100
	2	BDPS	48	48	100
	3	TCoE	56	47	84
	4	TSHS	57	26	46
	5	TTU	36	32	89
Total			240	196	81.7
Tolon	1	Tolon township	5	5	100
	2	SARI	74	72	97
	3	UDS-Nyankpala	47	31	66
Total			124	108	87.1

Bark stripping and tree sizes

Analysis of stripping percentages by diameter class showed that there was a higher tendency to strip larger trees in Tamale Metropolis and Tolon District, whereas in Sagnarigu Municipal an opposite trend was observed (Fig. 4B). Logistic regression of tree size (DBH) against bark stripping status indicated that overall, larger trees were significantly more likely (ΔDeviance = 6.76, df = 1, $p = 0.009$) to be stripped than smaller ones. The odds of a tree being stripped increased by a factor of 2.83 (95% CI: 1.29–6.40) for each centimetre increase in diameter (Fig. 5A). Thus, mean DBH was significantly ($F = 6.66$, df =1, $p = 0.010$) larger for bark-stripped trees (at 0.91 m ± 0.27 m) than non- bark-stripped trees (at 0.83 ± 0.30). This difference in DBH also affected the DBH-height correlations among these urban African mahogany tree populations (Fig. 5B). Although there were significant correlations between tree height and diameter for both stripped and unstripped trees, the correlations were weaker for bark-stripped ($r = 0.35$, $t = 7.45$, df = 404, $p < 0.001$) than unstripped trees ($r = 0.50$, $t = 5.95$, df = 104, $p < 0.005$). Also, the difference in strength of association (r) decreased with tree size.

Maximum height of bark stripping

Maximum bark stripping height was defined as the highest point on the tree trunk where bark had been removed (Fig. 2B). Across districts, the mean stripping height was 2.7 ± 0.9 m. By district, mean values were 3.0 ± 1.0 m (N = 196) in Sagnarigu, 2.8 ± 0.9 m (N = 101) in Tamale Metropolis, and 2.2 ± 0.9 m (N = 108) in Tolon. Differences among districts were significant ($F = 28.4$, df = 2, $p < 0.0001$), with pairwise contrasts indicating that variation was primarily due to differences between Sagnarigu and Tolon, and between Tolon and Tamale Metropolis.

In Tolon District, bark stripping height was greatest in the SARI zone, which differed significantly from only the UDS-Nyankpala (UDS-NYC) zone according to pairwise contrasts (t ratio = 4.7, df = 105, $p < 0.0001$; Fig. 6A). In Sagnarigu Municipal, the highest stripping heights were observed in the Bagabaga Demonstration School (BDPS), Bagabaga College of Education (BTC), and Tamale Technical University (TATU) zones, which did not differ significantly from each other but were all significantly higher than found for the Tamale Senior High School (TSHS) zone, where stripping height was lowest. In Tamale

Metropolis, two zones had no evidence of stripping, while Zone 5 (NADMO office premises) showed the lowest stripping height, which differed significantly from the Catholic Youth Centre, Gumani Forest, and Zogbeli zones, where stripping heights were uniformly high (Fig. 6A).

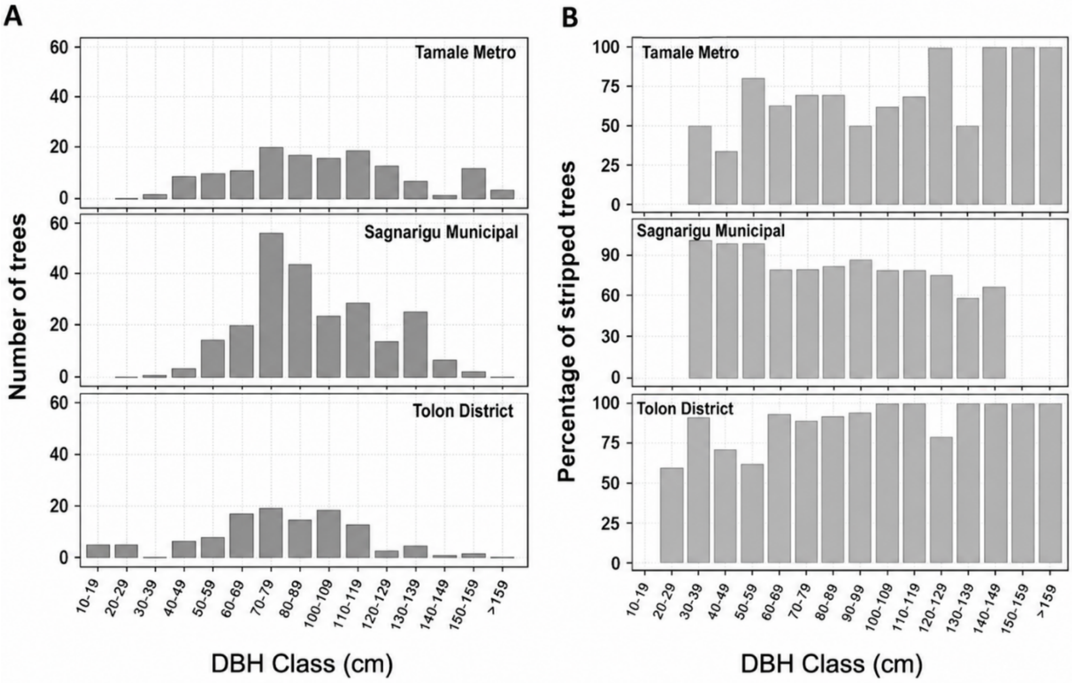

Figure 4. (A) Population structure and (B) percentage of stripped trees per diameter class of urban *Khaya senegalensis* (African mahogany) trees in three districts in the Northern Region of Ghana.

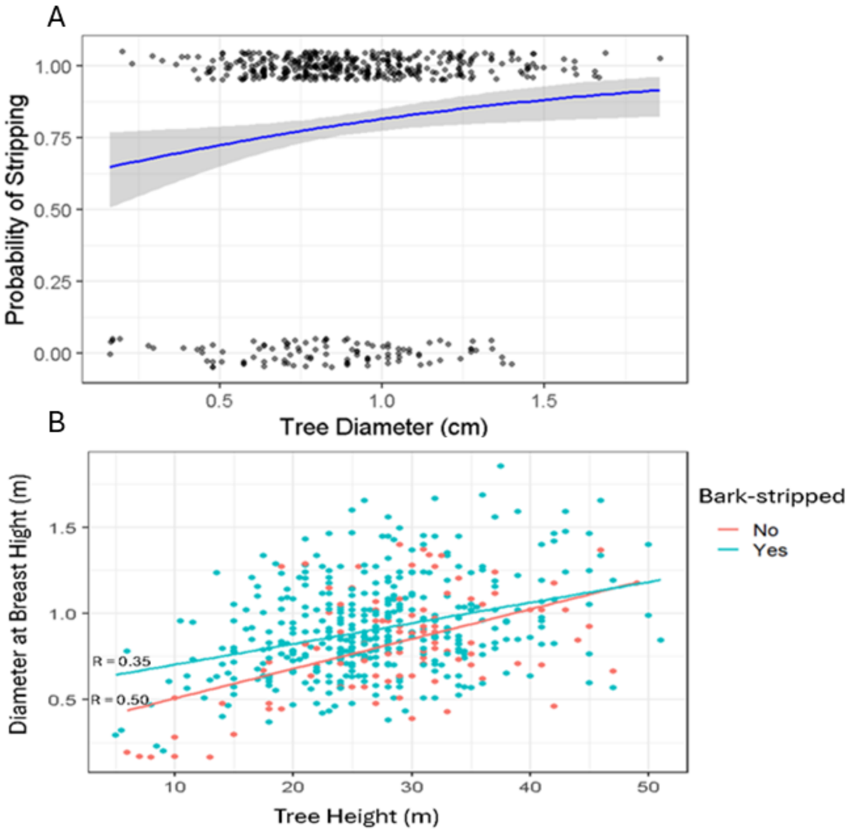

Figure 5. (A) Probability of bark stripping in African mahogany trees as a function of tree diameter (DBH, cm). The solid line shows the logistic regression fit, and the shaded area represents the 95% confidence interval. (B) Correlation of DBH to tree height among bark-stripped and unstripped African mahogany tree populations in three districts of the Northern Region of Ghana.

Number of wounds and scars per tree trunk

This assessment was conducted across all three districts. The mean number of slashes, wounds, or scars per tree trunk (Fig. 1 and 2) was 23, with no significant differences among districts ($\chi^2(2) = 423.41$, $p = 0.357$). On average, trees bore 24 wounds in Tamale Metropolis and Sagnarigu Municipal, and 21 in Tolon District. However, variation was evident among zones within districts (Fig. 6B). In Tamale Metropolis, trees in Zogbeli recorded the highest number of wounds (29), followed by Gumani Forest (24), whereas trees in the Catholic Youth Centre (CYC) and NADMO premises had substantially fewer scars (12 and 11, respectively). In Sagnarigu Municipal, the Bagabaga College of Education (BTC) zone had the highest mean number of wounds (31), followed by the Bagabaga Demonstration School (BDPS; 24), while Tamale College of Education (TCOE) recorded the lowest (18). In Tolon District, trees on the University for Development Studies (UDS) campus had the fewest wounds, whereas those in the SARI zone exhibited the most (24).

Wound depth and surface area

Wound depth (Fig. 2) was assessed in Tamale Metropolis and Sagnarigu Municipal. Across both districts, most wounds were classified as ‘deep’ (defined as removal of the cambial layer along with the bark tissue) representing 63% of all recorded wounds (N = 882) from 294 trees. ‘Shallow’ and ‘very deep’ slashing accounted for 20% and 17% of wounds, respectively.

Wound surface area was assessed in bark-stripped trees from Tolon District only. Across African mahogany tree zones in this district, mean wound area was 94.8 ± 117 cm² with no significant differences among tree zones ($F = 0.76$, $df = 2$, $p = 0.470$). Mean wound area values were 83.5 ± 103.5 cm² for trees in Tolon township, 104.7 ± 97.5 cm² on SARI campus, and 96.15 ± 149.9 cm² on UDS–Nyankpala campus.

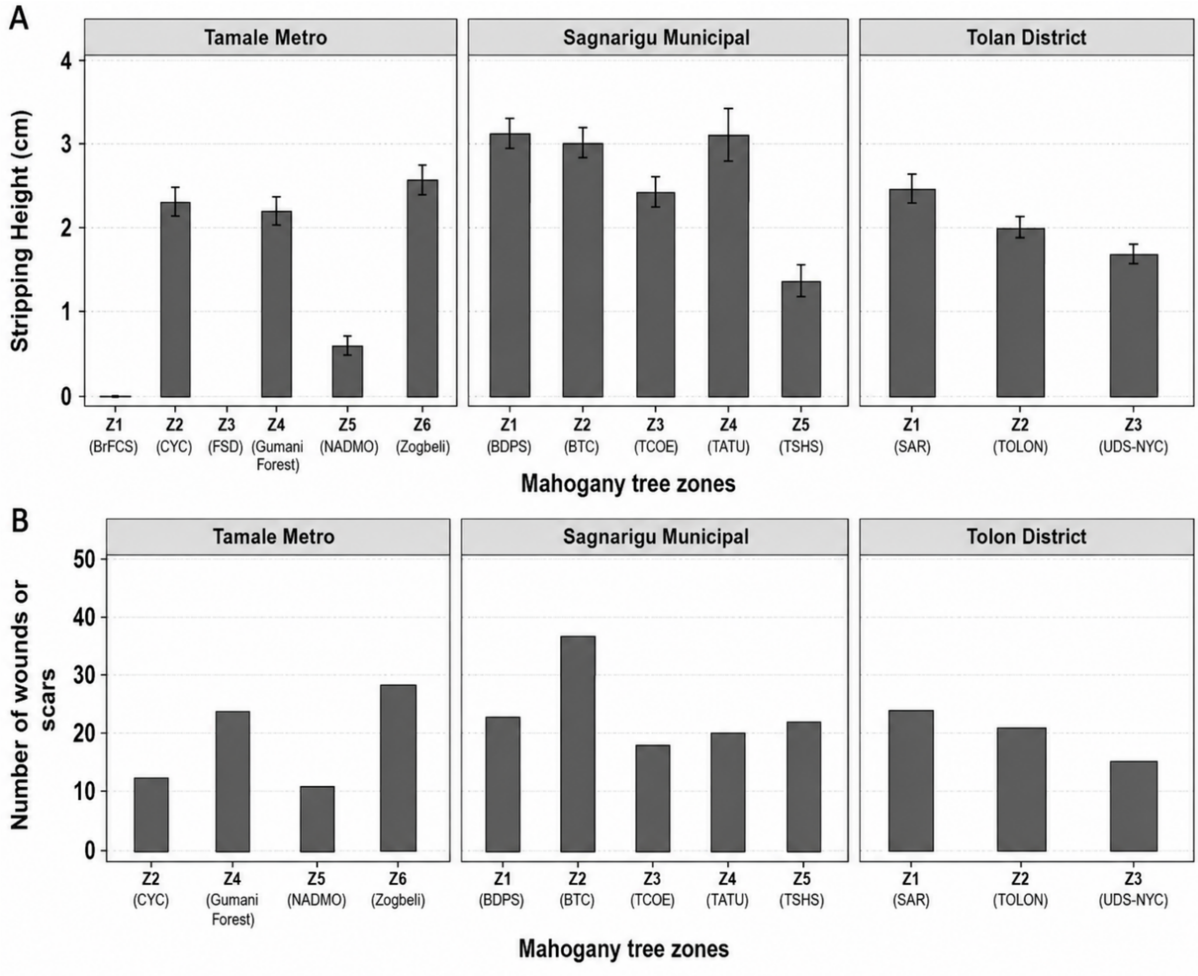

Figure 6. (A) Stripping height (distance between scar/wound on highest point on tree trunk to the base) for different tree zones in three districts of the northern region of Ghana. (B) Number of cutlass slashes/wounds/scars per tree trunk for different African mahogany tree zones in three districts of the northern region of Ghana.

Bark stripping effect on tree health indicators

Tree health indicators assessed in this study included the prevalence of stem burls and stem decay. Across all districts, bark stripping was significantly associated with stem burls (N = 509, $\chi^2(1) = 193.1$, $p < 0.001$). Among bark-stripped trees, 93% showed stem burls compared to only 7% without burls, whereas among unstripped trees, 32% showed burls and 68% did not. The odds of a tree developing stem burls were 26.2 times higher if bark-stripped than if unstripped (Fisher's exact test, $p < 0.001$). Regarding burl severity, 77% of bark-stripped trees were classified as having 'severe' burl, while 23% were categorized as 'moderate' burls.

In Sagnarigu Municipal, none of the unstripped trees showed stem burls. In contrast, a few unstripped trees in both Tamale Metropolis and Tolon District showed moderate or severe burls, although these were fewer than the number of unstripped trees without burls (Fig. 7A). Among stripped trees, the extent of stem burls differed significantly across districts ($\chi^2(4) = 176.8$, $p < 0.001$). In Tolon District, most stripped trees showed moderate burls (47 trees), followed by severe burls (31) and no burls (30). In Sagnarigu and Tamale, however, all stripped trees showed burls, with severe burls strongly dominating the populations (Sagnarigu: 184 severe vs. 13 moderate; Tamale: 86 severe vs. 15 moderate) (Fig. 7A).
Across districts, bark stripping was significantly associated with stem decay (N = 509, $\chi^2(1) = 9.21$, $p = 0.002$). Stem decay occurred in 8.1% of bark-stripped trees but was absent in all unstripped trees in Sagnarigu Municipal and very low prevalence in Tamale and Tolon (Fig. 7B).

Also, there was no association between tree size and proportion of stems with burls and there was no significant ($X^2 = 227.5$, df = 1, $p = 0.242$) association between DBH and stem decay. However, stem decay appeared to be more abundant among individuals in the highest diameter classes (i.e. > 150 cm) (Fig. 8). Additionally, there was a significant (N = 509, $X^2 = 4.25$, df = 1, $p = 0.039$) association between stem burls and stem decay. Trees were 4.1 times more likely (Fisher's exact test, $p = 0.041$) to have stem decay if they also had stem burls than if they did not.

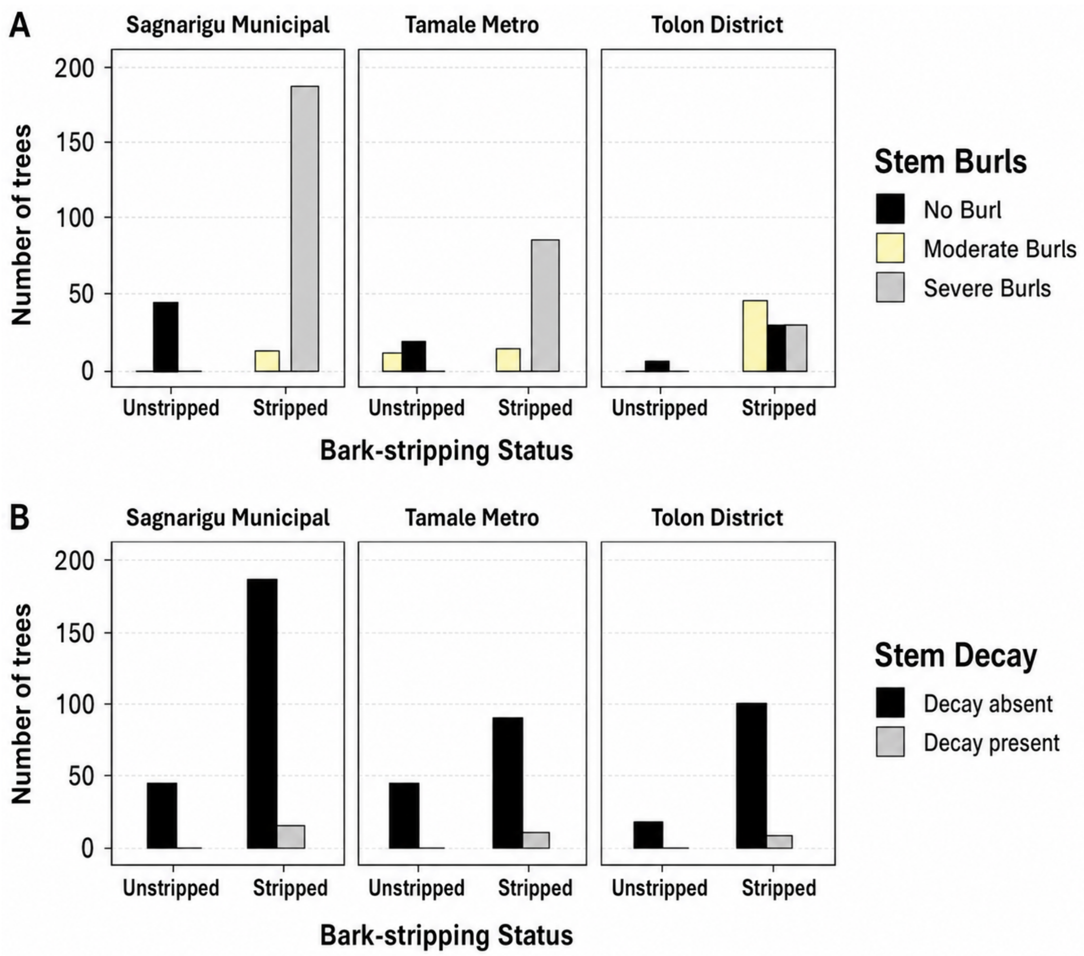

Figure 7. (A) Number of trees with various categories of stem burl and (B) Number of trees with various categories of stem decay for bark-stripped and non-bark-stripped trees in three districts of the Northern region of Ghana.

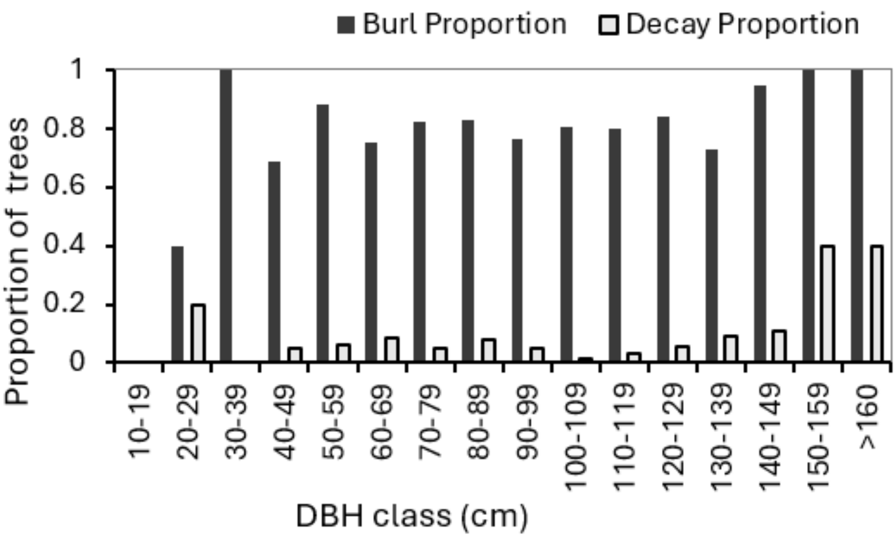

Figure 8. Proportion of trees with stem burls and stem decay by diameter class across all tree zones in three districts of the northern region of Ghana

Discussion

Abundance of African mahogany trees within urban centres

African mahogany trees were found to be unevenly distributed across the study districts, with higher abundance in Sagnarigu Municipality, where some of the oldest educational institutions and religious establishments in northern region of Ghana are located. In the other districts, African mahogany trees were also found within institutional landscapes. This pattern likely reflects historical planting practices associated with educational, religious, and government or colonial establishments, where tree planting and maintenance are more structured as urban amenity trees (Darwesh *et al.* 2017, Douny & Sawadogo 2025, Godonou *et al*. 2025) than in the general urban spaces observed within towns and cities.

The size-class structures of African mahogany trees in the study districts were Gaussian or near-Gaussian, characterized by an absence of juveniles, a predominance of medium-sized trees, and a decline in the number of much larger individuals (Bin *et al*. 2012, Yusup *et al*. 2022). This pattern reflects the artificial nature of the tree populations, with no evidence of natural regeneration, as the trees were primarily planted as avenue trees, windbreaks, and shade trees. Any juvenile African mahogany trees currently present would likely have originated from the Green Ghana initiative, a multi-species afforestation programme launched in March 2021 by the Government of Ghana (Ministry of Lands and Natural Resources 2021). Future research that evaluates the number of African mahogany seedlings planted through this initiative and their survival rates in the study areas is therefore strongly recommended to inform the long-term status of the species in the districts.

In Tolon District, the size-class distribution exhibited a smaller central hump with extended tails on both sides, reflecting a more uniform representation of tree sizes, including both smaller and larger individuals but with fewer trees in each DBH class. In contrast, in Sagnarigu Municipal and Tamale Metropolis, smaller trees (and, in Sagnarigu, larger trees as well) were much less abundant than middle-sized individuals. This pattern in Tolon may suggest that some African mahogany trees were planted more recently in the district.

Extent and intensity of the bark stripping phenomenon

The high prevalence of bark stripping (approximately 80% of trees) indicates substantial harvesting pressure on African mahogany populations. The relatively lower incidence in Tamale Metropolis compared to Tolon District suggests that levels of urbanization and access to alternative healthcare options may influence harvesting intensity. In more rural areas, reliance on traditional medicinal resources likely drives increased bark extraction. This pattern aligns with previous reports identifying African mahogany as a heavily exploited species due to its medicinal value (Gaoue & Ticktin 2010, van Andel *et al*. 2012, Asase 2023, Godonou *et al*. 2025). The finding further reflects strong reliance on herbal medicine (Abbiw 1990, van Andel *et al*. 2012, Boafo *et al*. 2016, Asigbaase *et al*. 2024) and aligns specifically with studies that have reported high dependence on herbal medicine in Tamale Metropolis (Ameade *et al*. 2018, Iddrisu *et al*. 2023).

The small differences observed among districts may reflect varying levels of dependence on herbal medicines between urban and rural populations (Wodah & Asase, 2012, Boafo *et al*. 2016). Although Tolon is a district capital, it retains a largely rural population compared with Tamale Metropolis and Sagnarigu Municipality, which together form Ghana's third largest urban centre (Ghana Statistical Service 2022). Furthermore, variation in the extent of bark stripping among African mahogany tree zones within these urban areas may be influenced by differences in accessibility. For example, trees located within the premises of the Forest Services Division (FSD), the National Disaster Management Organization (NADMO), and By Faith Catering Services (ByFCS) (all of which are gated public or private compounds) are likely less accessible to potential bark harvesters.

We found a pattern of greater bark stripping among larger trees, consistent with previous reports that larger individuals are often preferred for bark harvest (Geldenhuys 2004, Shackleton *et al*. 2005, Gaoue & Ticktin 2007). However, some studies have also shown that smaller trees may be harvested more heavily under conditions of overexploitation (Cunningham & Mbenkum 1993). In our study, bark-stripped individuals may appear larger due to the presence of stem burls, which extend above the DBH measurement point (Fig. 3). This suggests the possibility of reverse causation, where bark stripping inflates DBH measurements rather than larger trees being preferentially targeted. Thus, the association between tree size and bark stripping should be interpreted with caution. Although stem burl formation occurred on all stripped trees, the pattern of larger trees being more heavily bark-stripped was absent in Sagnarigu Municipal suggesting that burl formation alone cannot explain the pattern of bark-stripping. A genuine preference for larger trees may also be at play, possibly because larger trees yield thicker bark and greater quantities of material (Fasola *et al*. 2014).

In this study, burls caused disproportionately high DBH values relative to tree height, particularly in individuals below 30 cm DBH (Fig. 3; Fig. 5B). Consequently, the diameter-height relationship was weaker in stripped than in unstripped trees, although this disparity became less pronounced among larger trees. This discrepancy does not reflect reduced height growth in bark-stripped trees but rather disproportionately increased diameters due to burl formation. These findings have important implications for forest inventories involving bark-stripped trees. Standard DBH measurements at 1.3 m may overestimate size in such cases; instead, measurements should be taken above the burls, as done for buttressed trees. On average, bark was harvested up to 2.7 m along the trunk, well above breast height. Such elevated stripping heights suggest greater effort by harvesters, likely reflecting higher demand or stripping pressure, as collectors may climb higher when bark from lower portions is depleted. This pressure appeared strongest in Sagnarigu Municipal and least in Tolon District, possibly due to greater tree accessibility in Tolon, as reflected by the higher proportion of bark-stripped trees observed there. Findings of many wounds, each with a large surface area, majority of which were categorized as "deep slashing" (i.e., the removal of cambial sheet along with the bark tissues), provide further evidence of high harvesting pressure. Although the technique of "deep slashing" yields maximum bark material, it also prolongs wound occlusion and increases tree vulnerability to insect attack (Delvaux *et al*. 2009) and possible infection by pathogens.

Bark stripping and tree health status

We found that bark stripping was strongly associated with burl formation (Fig. 3A), with a very high odds ratio. Burls arise from abnormal xylem proliferation (hyperplaxia), often attributed to infection by biotic agents such as bacteria, fungi, or viruses. Bark stripping creates entry points for these pathogens or their insect vectors (Delvaux *et al*. 2009, Orlović *et al*. 2024). Slow wound occlusion following severe bark removal can further increase susceptibility to insect attack (Geldenhuys *et al*. 2007, Delvaux *et al*. 2009), thereby facilitating infection and abnormal xylem growth. Although *Khaya senegalensis* is considered relatively resistant to insect damage (Delvaux *et al*. 2009), the high intensity of bark stripping observed in the study areas likely elevated infection risk. Stem decay (Fig. 3B) was observed exclusively among stripped trees, although most stripped individuals remained unaffected. Among bark-stripped trees, both small and large individuals were equally prone to burl formation; however, decay was more common in larger and presumably older trees. This suggests that stem burls may act as precursors to decay, with sufficient time required for decay to develop after burl formation. This interpretation is supported by the significant association observed between stem burls and stem decay in this study.

Conclusion

This study assessed African mahogany tree populations in three urban districts of northern Ghana, focusing on bark-harvesting pressure and its implications for tree health. Populations were dominated by medium-sized individuals, with no juveniles and few large, old trees. Across all districts, African mahogany trees were subjected to intense bark stripping, driven largely by ease of access. Bark-stripped trees were several times more likely than unstripped individuals to develop stem burls, which in turn predisposed them to stem decay. The heavy harvesting pressure observed in urban centres may also reflect declining wild populations of the species. To meet the high demand for medicinal bark and ensure the sustainability of African mahogany in northern Ghana, we recommend expanding planting programs, particularly in urban areas where reliance on the species is greatest. Integrating *Khaya senegalensis* into urban forestry planning and scaling up its inclusion in national initiatives such as the Green Ghana or Tree for Life afforestation programmes by government of Ghana would help secure future supplies of medicinal bark, reduce pressure on existing trees, and preserve the ecological and cultural value of the species in urban centres.

Declarations

List of abbreviations: DBH– Diameter at Breast Height

Ethics approval and consent to participate: This research was conducted with the approval of the Department of Forestry and Forest Resources Management of the University for Development Studies, Tamale, Ghana.

Consent for publication: All authors have reviewed and approved the final manuscript and agreed to its publication.

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Author contributions: H. I. designed the study, monitored data collection, analysed the data and wrote the final manuscript. I. S. and E. A. collected the data and wrote the first draft.

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