

RESEARCH ARTICLE

An integrated forest-to-market approach to promote lesser-known timber species (LKTS) in a domestic timber market in the Congo Basin

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Societal Impact Statement

In the Congo Basin, domestic timber markets account for ~40% of timber consumption, yet demand is concentrated on a few high-value species also sought after on international markets, raising concerns about their long-term availability. We combine market, wood, and forest data to assess the potential of lesser-known timber species (LKTS) to support a sustainable local timber supply. Although marginally used, some LKTS combine wood properties suited to local uses with greater forest availability or regeneration potential. This provides a practical basis for selecting LKTS based not only on wood properties but also on local knowledge of timber quality and forest availability.

Summary

- The continued reliance on a few high-value commercial species in the Congo Basin raises concerns about their long-term availability. This study adopts an integrated forest-to-market approach to assess the potential of lesser-known timber species (LKTS) to support sustainable timber supply in the domestic market of Kisangani, Democratic Republic of the Congo.
- Surveys and wood sampling were conducted in sawmills and joinery workshops to identify locally traded timber species and their uses. Local uses were then compared with measured wood properties and local craftworkers' perceptions of these

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properties. Forest inventory data for the identified species were also analysed to assess their availability and dynamics.

- Twenty-seven timber species were identified, nine of which were particularly widespread in the market. Of the remaining 18 species, 14 were LKTS and showed limited market integration. Local uses matched reference wood properties, which also aligned with craftworkers' perceptions, highlighting local knowledge of timber quality that may facilitate the market acceptance of species. The nine widespread species variously exhibited low standing stocks ($<1 \text{ m}^3 \text{ ha}^{-1}$), slow growth ($<0.5 \text{ cm yr}^{-1}$), or limited regeneration, raising concerns about their long-term capacity to sustain local timber supply. Beyond suitable wood properties, certain LKTS showed advantages in these ecological attributes, highlighting their potential as alternatives for local timber supply.
- This approach could be extended to other domestic timber markets, with LKTS selected based not only on wood properties but also on local knowledge of timber quality and forest resource availability and dynamics.

KEYWORDS

artisanal logging, forest availability, local knowledge, sustainable forest management, timber supply, tree population dynamics, wood properties

1 | INTRODUCTION

Wood is increasingly recognized as a promising material for sustainable construction, particularly because of its favourable carbon balance compared with non-bio-based materials (Churkina et al., 2020). Amid rapid urbanization and rising demand for building materials (UNEP, 2022), timber represents a strategic lever for developing a more sustainable built environment.

The forests of the Congo Basin are well positioned to contribute to this transition to a low-carbon economy. As the world's second largest contiguous block of tropical forest, they cover 89.3% of Africa's rainforests (Mayaux et al., 2013) and harbor more than 2000 tree species (Sosef et al., 2017). They also act as a major carbon sink, accumulating $\sim 0.66 \text{ tC ha}^{-1} \text{ yr}^{-1}$ (Hubau et al., 2020). Around 14.1 million m^3 of roundwood is harvested annually through both industrial (54%) and artisanal (46%) logging systems (BAD/FRMi, 2018). However, at the regional level, more than 80% of industrial timber production relies on just five commercially valuable species, despite substantial variation in species composition among countries (BAD/FRMi, 2018; Ruiz Pérez et al., 2005). Most of these harvested species are light-demanding, and their natural regeneration is constrained by the limited canopy opening generated under selective logging regimes (Bourland et al., 2012; Makana & Thomas, 2006). The long-term persistence of their populations may be further affected by ongoing deforestation and forest degradation, particularly in the Democratic Republic of the Congo, which recorded the second-highest average annual net loss of forest area worldwide between 2010 and 2020, at 1.1 million ha yr^{-1} , after Brazil at 1.5 million ha yr^{-1} (FAO, 2020).

To address these pressures, several silvicultural interventions have been developed to enhance post-harvest recovery and restore

degraded areas (Djiofack et al., 2025; Doucet et al., 2016; Gourlet-Fleury et al., 2013; Ilunga-Mulala, Ligot, et al., 2025). However, these approaches often require long-term investments and may not fully offset the demographic constraints affecting heavily harvested species (Ilunga-Mulala, Ligot, et al., 2025). Promoting lesser-known timber species (LKTS) therefore represents a complementary strategy to alleviate pressure on these species while increasing timber yields in managed forests (Karsenty & Gourlet-Fleury, 2006).

Although no single universally accepted definition exists, LKTS (also commonly referred to as 'lesser-used species,' 'underutilized species,' or 'secondary species') are consistently described as species present in forests but remaining marginal or absent in formal timber trade due to limited knowledge of their wood properties, low market recognition, and the absence of established commercial demand (ITTO, 2016; WWF/GFTN, 2013; Yeom, 1984). Although poorly documented in official statistics, domestic timber markets represent a major outlet for timber in the Congo Basin. They consume ~ 6 million m^3 of roundwood annually, equivalent to 40% of regional production (BAD/FRMi, 2018), and are mainly supplied by artisanal chainsaw milling (Cerutti & Lescuyer, 2011; Lescuyer et al., 2014, 2025). In the DRC, artisanal timber production accounts for $\sim 94\%$ of national timber output (BAD/FRMi, 2018) amounting to 3.4 million $\text{m}^3 \text{ yr}^{-1}$ in roundwood equivalents, $\sim 85\%$ of which supplies domestic demand (Lescuyer et al., 2014). Studies show that domestic markets across the Congo Basin largely rely on the same high-value species targeted by export markets (Cerutti & Lescuyer, 2011; Lescuyer et al., 2014, 2025). However, uncertainties in timber identification (Monnoye et al., 2025) suggest that the range of timber species circulating in local markets may extend beyond those currently recognized, including some LKTS.

Research on LKTS in Central Africa has often focused on characterizing their wood properties, which is crucial for assessing their suitability for different applications (Doucet, 2024; Doucet et al., 2022; Kana et al., 2024; Ndongmo Zebaze et al., 2023). However, promoting these species also requires assessing their capacity to support a sustainable timber supply (R. Doucet, 2024), as well as the factors that may influence their market acceptance. Studies of species population dynamics, essential for evaluating this capacity, remain largely focused on dominant commercial species and are primarily conducted in the context of industrial logging (Biwolé et al., 2019; Bourland et al., 2012; Gourlet-Fleury et al., 2013; Karsenty & Gourlet-Fleury, 2006; Ligot et al., 2022). Only a limited number of LKTS have been examined in detail, likewise mainly within industrial forest concessions. Their population dynamics and sustainable management under artisanal harvesting, and the implications for sustainable management, remain largely unexplored. Similarly, little is known about their acceptance in domestic timber markets. This may depend in part on local market actors' knowledge of these species, their uses and perceptions of their wood quality.

This study adopts an integrated forest-to-market approach to explore the potential for promoting LKTS in the domestic timber market of Kisangani, one of the largest in the DRC (Lescuyer et al., 2014). Rapid urban expansion ($\sim 8.2\% \text{ yr}^{-1}$) and population growth ($\sim 5.3\% \text{ yr}^{-1}$) (Balandi et al., 2023; INS, 2022) are associated with increasing demand for timber for construction and furniture, with sawnwood consumption rising from $\sim 58,207 \text{ m}^3$ in 2011 (Lescuyer et al., 2014) to $\sim 78,392 \text{ m}^3$ in 2024 (Tshimpanga et al., 2025). This growing demand is met almost entirely by timber harvested from surrounding natural forests. These forests are also under substantial pressure from woodfuel extraction, with urban demand estimated at ~ 2.74 million $\text{m}^3 \text{ yr}^{-1}$ (Imani & Moore-Delate, 2021).

By integrating timber market surveys, measured wood properties, local as measured and perceived by local craftspeople's perceptions of timber quality, and forest inventory data, this study aims to identify the timber species used locally, assess the extent to which LKTS are integrated into the domestic market and identify potential alternative species based on their suitability for local uses, knowledge of timber quality and forest availability and dynamics. Specifically, the following research questions are addressed:

- i. Which timber species are currently traded in the domestic timber market of Kisangani, and to what extent are lesser-known timber species integrated into this market?
- ii. Do the wood properties of locally traded species align with their reported local uses, and how is local knowledge related to the market acceptance of lesser-known timber species?
- iii. What do forest availability and population dynamics of the most frequently traded species indicate about their capacity to sustain long-term timber supply, and can lesser-known timber species help fill potential supply gaps based on these ecological attributes?

Beyond Kisangani, this study provides a transferable framework for assessing the potential of LKTS in other domestic timber markets

by integrating wood properties, local knowledge of timber quality for est availability, and species population dynamics.

2 | MATERIALS AND METHODS

2.1 | Study area

Data were collected in the city of Kisangani ($0^{\circ}31'N$, $25^{\circ}11'E$) and three forest sites located in Tshopo Province, northeastern Democratic Republic of the Congo (DRC): the Yangambi Biosphere Reserve ($0^{\circ}48'N$, $24^{\circ}28'E$), the Yoko Forest Reserve ($0^{\circ}17'N$, $25^{\circ}18'E$) and Yanonge village ($0^{\circ}36'N$, $24^{\circ}43'E$) (Figure 1). These sites were selected because they lie within Kisangani's timber supply area and provide the most extensive forest inventory datasets available in the region. These include permanent and non-permanent plots established at Yoko and Yangambi, as well as the only pre-harvest inventories conducted in artisanal logging areas at Yanonge.

The region has an Af Köppen climate, with a mean annual temperature of $\sim 25.1^{\circ}\text{C}$ and mean annual rainfall of $\sim 1837 \text{ mm}$ (Kasongo Yakusu et al., 2023). Two rainy seasons (August–November and March–May) alternate with two relatively dry periods (December–February and June–July). Soils are predominantly Ferralsols (Van Ranst et al., 2010). Vegetation includes mixed and monodominant tropical forests, as well as disturbed ecosystems such as fallows and secondary forests associated with former industrial plantations (oil palm, rubber, coffee and cocoa) and shifting cultivation (Mangaza et al., 2022).

2.2 | Data collection

2.2.1 | Survey and inventory of locally used timber species

Surveys were conducted in sawmills and joinery workshops located in the main timber markets of Kisangani, as well as in additional facilities outside these markets. Facilities located within the same timber market generally processed similar species for comparable uses and were therefore grouped for frequency analyses and treated as a single analytical unit, whereas those located outside the main markets were considered individually. In total, 21 sawmills and 38 workshops were surveyed. Based on official records from the *Coordination Provinciale de l'Environnement et Développement Durable* (Tshopo, DRC), the surveyed sawmills represented all active sawmills in Kisangani during the 2022–2023 survey period. Workshop sampling continued until species accumulation reached saturation, with no additional timber species recorded during the final surveys.

At each facility, the manager or an experienced sawyer/joiner capable of providing technical information was selected as the respondent. Each respondent was first asked to identify the timber species currently used in their facility and specify their main uses. They then evaluated wood density, hardness, natural durability and workability (sawing, nailing and planing) based on practical experience using predefined ordinal

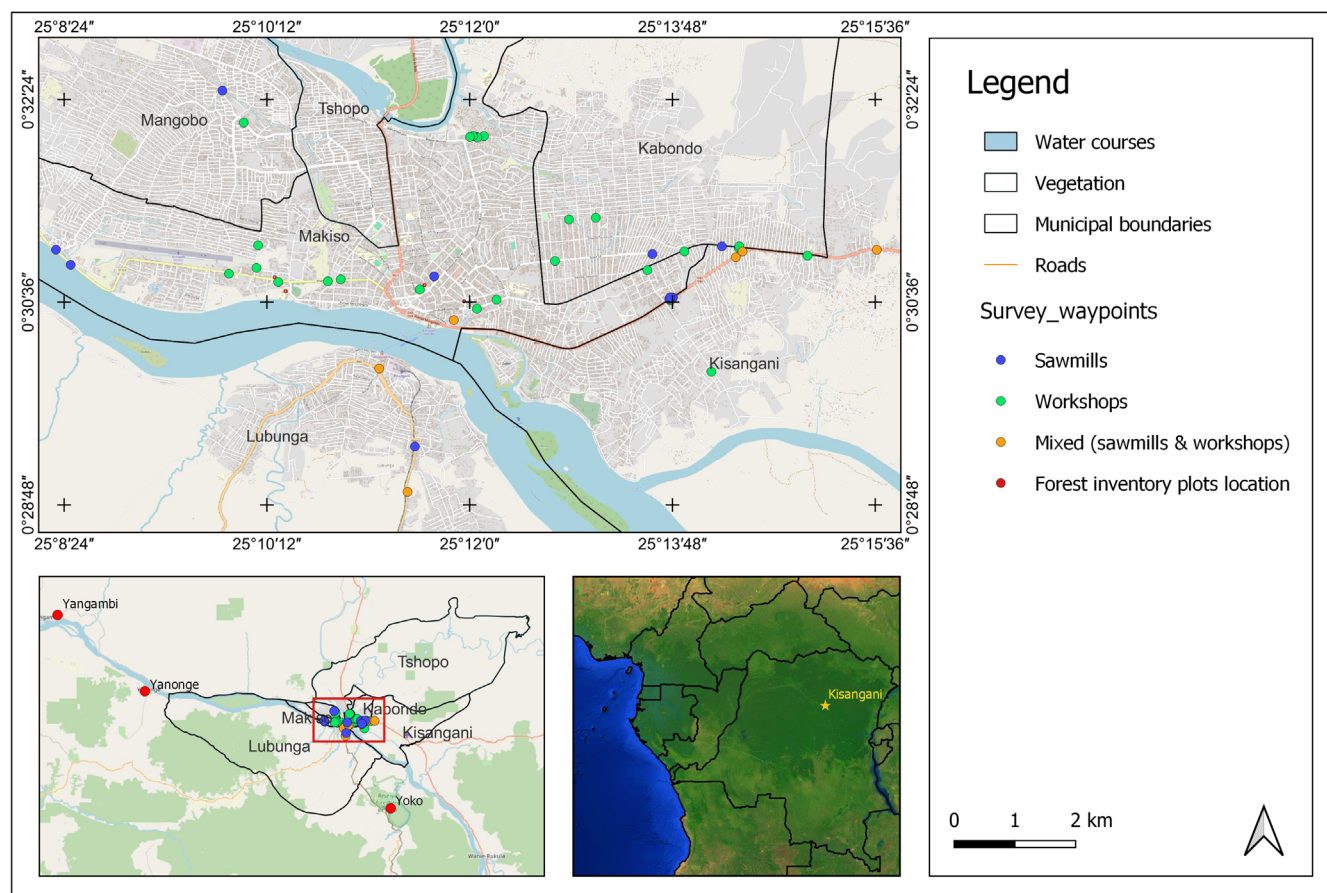


FIGURE 1 Location of surveyed sawmills ($n = 11$, blue), workshops ($n = 28$, green) and sites where a sawmill and a workshop were surveyed separately but share the same location ($n = 10$, orange), within Kisangani's major timber markets, as well as forest sites (red) containing forest inventory plots, in northeastern Democratic Republic of the Congo.

scales. These properties were selected because they are directly observable during timber processing and use, whereas properties such as shrinkage, drying and mechanical strength generally require standardized testing for accurate evaluation.

2.2.2 | Wood sample collection and identification

Species identification based on vernacular and trade names was first cross-checked against floristic references (DIAF, 2017; Lejoly et al., 2010; Tailfer, 1989) with support from botanists at the University of Kisangani and the *Institut National pour l'Étude et la Recherche Agronomiques* (INERA/Yangambi). These survey-based identifications were validated using a combination of wood anatomical analysis and direct analysis in real time—time-of-flight mass spectrometry (DART-TOFMS) performed on 110 wood samples collected from the surveyed facilities (Monnoye et al., 2025). Anatomical features observed in radial, tangential and transverse microsections were compared with those documented in the InsideWood database (Wheeler, 2011). DART-TOFMS identification combined multivariate analyses with spectral matching against the For-EST© database using the NIST search algorithm (Price et al., 2022). Identification was validated at either the genus or species level.

2.2.3 | Wood density measurements

The same 110 wood samples were air-dried under ambient conditions at the Tervuren xylarium. Wood density (WD) was calculated as the ratio of air-dry mass to air-dry volume (Williamson & Wiemann, 2010). Air-dry mass was measured using a precision balance (VWR® LA1202E), while volume was determined by water displacement following Archimedes' principle. The resulting measurements were incorporated into the Tervuren xylarium Wood Density Database (TWDD; Verbiest et al., 2026). To improve species-level estimates, additional WD records from specimens collected in the Kisangani region and stored in the same database were combined with the measurements obtained in this study.

2.2.4 | Reference wood properties

Reference wood properties were obtained primarily from the TROPIC 7.0 software developed by CIRAD (*Centre de coopération internationale en recherche agronomique pour le développement*), including wood density, hardness, mechanical strength, natural durability and workability. Hardness, mechanical properties and natural durability were

determined according to French standards (Gérard et al., 2011). When species-level information was unavailable in TROPIC 7.0, complementary data were obtained from the International Tropical Timber Organization (ITTO, <http://www.tropicaltimber.info/fr/>) database, the Plant Resources of Tropical Africa (PROTA, <https://prota.prota4u.org/>) database and Fouarge and Gérard (1964).

2.2.5 | Forest inventory data collection

Forest inventory data were compiled from permanent and non-permanent plots located in Yangambi and Yoko, as well as from pre-harvest inventories conducted in artisanal logging areas in Yanonge. The plots cover a range of forest ecosystems, including mixed and monodominant mature forests, fallows and former oil palm and rubber plantations. Plot data from Yangambi and Yoko are available through the [ForestPlots.net](https://forestplots.net) platform (Lopez-Gonzalez et al., 2011).

Stem density (trees ha⁻¹) and standing volume (m³ ha⁻¹) of harvestable trees, defined as trees with a diameter at breast height (DBH) ≥ the species-specific minimum cutting diameter (MCD) established for the DRC by the *Direction des Inventaires et Aménagement Forestiers* (DIAF, 2017), were calculated for each species identified in the domestic timber market of Kisangani using inventory data covering 119.33 ha (60.33 ha at Yangambi, 9 ha at Yoko and 50 ha at Yanonge). Only the first censuses of permanent plots were considered for these estimates. Tree bole volume was estimated using species-specific allometric equations proposed by DIAF (2017).

Diameter distributions were analysed using the first census of permanent plots together with non-permanent plot data from Yangambi and Yoko (69.33 ha), as inventories in Yanonge were restricted to harvestable trees (DBH ≥ MCD). Forest dynamics parameters, including annual diameter increment (ADI), mortality and recruitment, were calculated exclusively from 21 ha of permanent plots monitored from 2009 to 2020 in Yoko (10 plots, 9 ha) and from 2012 to 2020 in Yangambi (11 plots, 12 ha).

Mean annual diameter increment (ADI, cm yr⁻¹) was calculated for each surviving tree as follows:

$$ADI = \frac{DBH_{t2} - DBH_{t1}}{t}$$

where DBH_{t1} and DBH_{t2} are tree diameters at breast height measured at the first and last censuses, respectively, and t is the time interval between these censuses (years). Species-level ADI was obtained by averaging individual ADI values across all surviving trees of each species.

Annual mortality and recruitment rates (m and r , % yr⁻¹) were calculated for each plot over the interval between the first and last censuses by linearly annualizing the proportions of deaths and recruits relative to the initial population size:

$$m_i = \frac{N_{deaths,i}}{N_{initial,i} \times \Delta t_i} \times 100; r_i = \frac{N_{recruits,i}}{N_{initial,i} \times \Delta t_i} \times 100$$

where $N_{initial,i}$ is the number of individuals of a given species initially recorded at the first census in plot i , $N_{deaths,i}$ is the number of

individuals that died by the last census, $N_{recruits,i}$ is the number of individuals that entered the monitored size class between the first and last censuses, and Δt_i is the time elapsed between these censuses (years). Species-level mortality and recruitment were estimated as weighted means of plot-level values using the initial number of individuals as weights.

2.3 | Data analysis

All analyses were conducted using R version 4.5.1 (R Core Team, 2026). Species occurrence frequencies were calculated as the proportion of analytical units in which each species was recorded, separately for sawmills and joinery workshops. Differences in measured WD among perception-based hardness categories were assessed using Kruskal–Wallis tests, followed by Dunn's post hoc pairwise comparisons with Bonferroni adjustment. The relationship between reference-based WD and wood hardness was analysed using a power-law regression model. Species were then classified according to natural durability and workability using two parallel datasets: local perceptions and reference wood property data. Hierarchical clustering was performed separately on each dataset using standardized variables, Euclidean distances and the unweighted pair group method with arithmetic mean (UPGMA). Concordance between the resulting classifications was assessed using tanglegrams and quantified with the entanglement coefficient implemented in the dendextend R package (Galili, 2015). Finally, relationships between binary species-use data (presence/absence of each reported use; response variables) and reference wood properties (constraining variables) were analysed using a constrained binary logistic biplot implemented in the MultBiplotR package (Vicente-Villardón, 2021; Vicente-Villardón & Vicente-Gonzalez, 2021).

3 | RESULTS

3.1 | Timber species list: Frequencies, economic importance and main uses

A total of 27 timber species, belonging to 12 botanical families and 21 genera, were identified across the sawmills and joinery workshops surveyed in Kisangani (Table 1). Fabaceae (eight species) and Meliaceae (five species) were the most represented families. Nine species (33.3%) were recorded in at least 70% of analytical units (Figure 2), including the four *Entandrophragma* species, *Milicia excelsa*, *Pericopsis elata*, *Prioria balsamifera*, *Khaya anthotheca* and *Alstonia boonei*. All recorded species are listed in the official forest species catalogue of the DRC (DIAF, 2017), including 12 commercially logged species (category I), two species with commercial potential (category II), nine species to be promoted (category III) and four species of unknown commercial status (category IV). In total, 15 species belonged to categories II–IV and were considered LKTS in this study. Regarding local uses, respondents reported seven main timber uses in

TABLE 1 Timber species identified in Kisangani: scientific names, trade names, local names, botanical families, uses and commercial importance categories as defined by the *Direction des Inventaires et Aménagement Forestiers* (DIAF, 2017).

Scientific name	Trade name	Local name	Family	Timber uses	DIAF classes
<i>Alstonia boonei</i> De Wild.	Emien	Mutondo/Bokuka/Aguga	Apocynaceae	Frm, J, F, Fc	III
<i>Amphimas</i> sp.	Lati	Njeke	Fabaceae/ Papilionoideae	Rfr, J, F	III
<i>Autranella congolensis</i> (De Wild.) A. Chev.	Mukulungu	Pilipili/Mosembe/Mayasali	Sapotaceae	Rfr, J, F, Br	I
<i>Ceiba pentandra</i> (L.) Gaertn.	Fromager	Coton	Malvaceae	Frm, Fc	IV
<i>Coelocaryon preussii</i> Warb.	Ekoune		Myristicaceae	Frm, J, F, Fc	IV
<i>Entandrophragma angolense</i> (Welw.) C.DC.	Tiama	Liboyo	Meliaceae	Rfr, J, F, Tc	I
<i>Entandrophragma cylindricum</i> (Sprague) Sprague	Sapelli	Liboyo	Meliaceae	Rfr, J, F, Tc	I
<i>Entandrophragma candollei</i> Harms	Kosipo	Liboyo	Meliaceae	Rfr, J, F, Tc	I
<i>Entandrophragma utile</i> (Dawe & Sprague) Sprague	Sipo	Liboyo	Meliaceae	Rfr, J, F, Tc	I
<i>Erythrophleum suaveolens</i> (Guill. & Perr.) Brenan	Tali	Tali	Fabaceae/ Caesalpinoideae	Rfr, J, F, Br	I
<i>Gambeya lacourtiana</i> (De Wild.) Aubrév. & Pellegr.	Red Longhi	Malinda	Sapotaceae	Rfr	II
<i>Gambeya</i> sp.		Sabuni	Sapotaceae	Rfr	II
<i>Gilbertiodendron dewevrei</i> (De Wild.) J. Léonard	Limbali	Limbalu	Fabaceae/ Detarioideae	Rfr, J, F, Br	III
<i>Khaya anthotheca</i> (Welw.) C.DC.	African mahogany	Khaya	Meliaceae	Rfr, J, F	I
<i>Milicia excelsa</i> (Welw.) C.C. Berg	Iroko	Bolondo	Moraceae	Rfr, J, F	I
<i>Nauclea diderrichii</i> (De Wild. & T. Durand) Merr.	Bilinga	Bokese/Mamvuli/Moningo	Rubiaceae	Rfr, J, F, Br	I
<i>Ongokea gore</i> (Hua) Pierre	Angueuk	Boleke	Olacaceae	Rfr	III
<i>Pericopsis elata</i> (Harms) Meeuwen	Afromosia	Mogoya	Fabaceae/ Papilionoideae	J, F	I
<i>Petersianthus macrocarpus</i> (P. Beauv.) Liben	Essia	Foyo	Lecythidaceae	Rfr, J, F, Br	III
<i>Prioria balsamifera</i> (Vermoesen) Breteler	Tola	Tola blanc	Fabaceae/ Detarioideae	Rfr, J, F, Tc	I
<i>Prioria oxyphylla</i> (Harms) Breteler	Tchitola	Tola rouge	Fabaceae/ Detarioideae	Rfr, J, F, Tc	III
<i>Prioria</i> sp.			Fabaceae/ Detarioideae	Rfr, J, F, Tc	IV
<i>Pterocarpus soyauxii</i> Taub.	Padouk	Ngola	Fabaceae/ Papilionoideae	J, F	I
<i>Pycnanthus angolensis</i> (Welw.) Warb.	Ilomba	Angobe/Ngobe/Muvunja tembo/Bojange	Myristicaceae	Frm	III
<i>Ricinodendron heudelotii</i> (Baill.) Pierre ex Heckel	Essessang	Lisongo/Peke	Euphorbiaceae	Frm, Fc	III
<i>Uapaca guineensis</i> Müll.Arg.	Rikio	Mutakala/Bosenge	Euphorbiaceae	Rfr, J, F	IV
<i>Zanthoxylum gillettii</i> (De Wild.) P.G. Waterman	Olon gille/ Olonvogo	Fagara/Kipanga/Mofombo	Rutaceae	Rfr, Br	III

Abbreviations: Br, bridge; F, furniture; Fc, fishing canoe; Frm, formwork; J, joinery; Rf, roof framing; Tc, transport canoe.

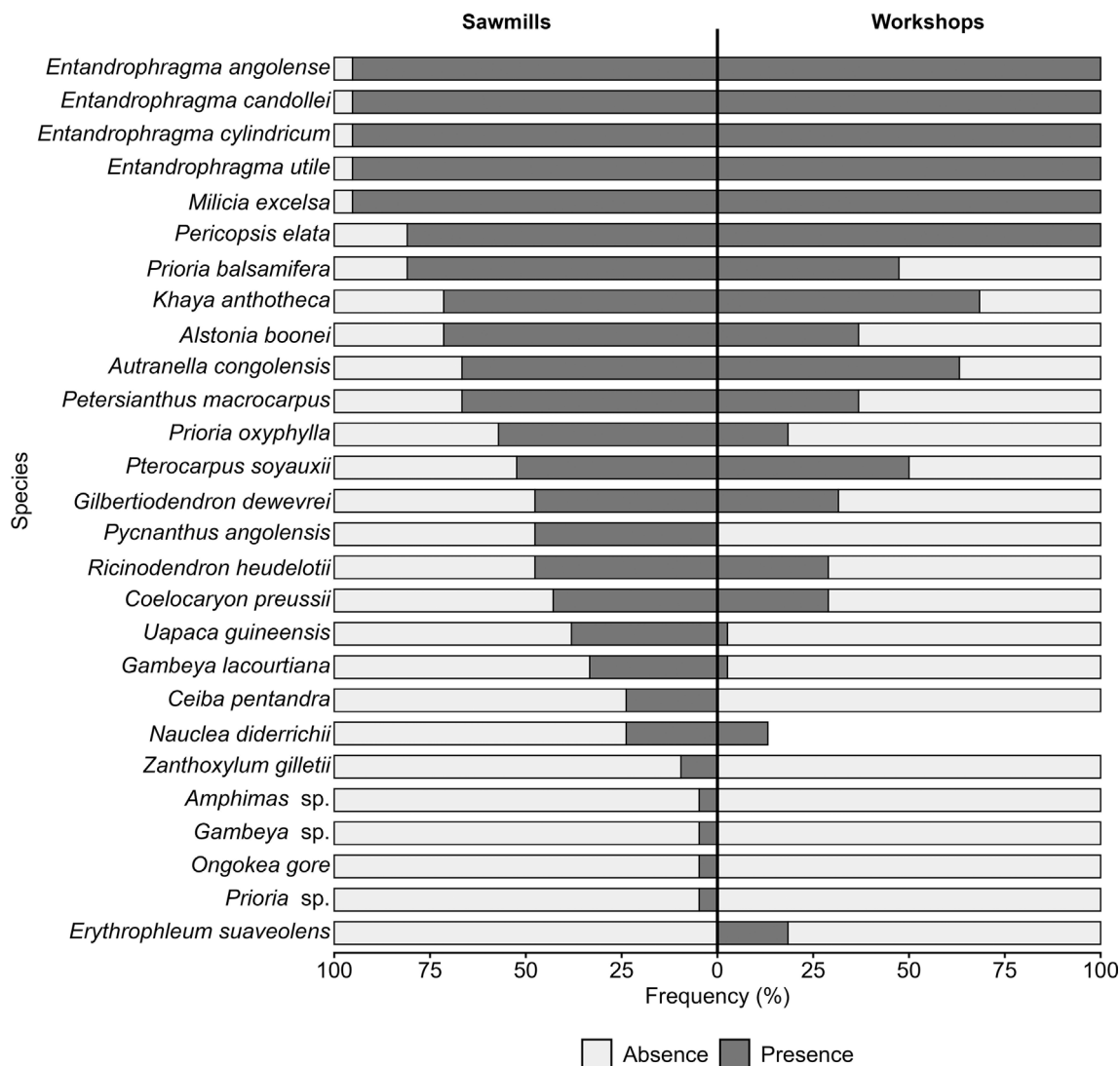


FIGURE 2 Frequency of presence and absence of timber species in sawmills ($n = 21$) and workshops ($n = 38$) in Kisangani.

Kisangani (Table 1). Most identified species were used for joinery, furniture making and roof framing, whereas fewer species were used for transport canoe construction, formwork, bridge construction and fishing canoe construction (Figure S1).

3.2 | Perceived wood quality versus measured wood properties

3.2.1 | Wood density and hardness

Sawyers and joiners consistently classified wood density and hardness into the same three qualitative categories (low, medium and high). Perceived hardness closely corresponded to measured WD (Table 2), with significant differences in WD among perceived hardness categories (Figure 3a). This pattern was consistent with the significant relationship between reference-based WD and hardness values for the identified species (Figure 3b).

3.2.2 | Natural durability and workability

Tanglegrams comparing perception-based and reference-based classifications revealed strong agreement for natural durability (entanglement coefficient, $E = 0.08$), with species showing consistent groupings across classifications (Figure 4). In contrast, workability showed weaker agreement ($E = 0.62$), as indicated by fewer shared subtrees and numerous crossings (Figure 4).

3.3 | Matching wood properties to local uses

The constrained binary logistic biplot identified three groups of species associated with distinct wood properties and local uses (Figure 5). The low wood density (LWD) group comprised five species combining low hardness, mechanical strength and natural durability with high workability, mainly used for formwork, fishing canoes, joinery and furniture. The medium wood density (MWD) group included eight species with

TABLE 2 Perceived wood density and hardness and measured wood density ($\pm$ standard deviation) by species and perceived density group. All wood density data were extracted from the *Tervuren xylarium Wood Density Database* (Verbiest et al., 2026). Sample sizes (N) used to calculate species-level means are also provided.

Species	Perceived wood density	Perceived wood hardness	N	Means wood density per species	Mean wood density per group
<i>Alstonia boonei</i>	Low	Low	12	0.43 ($\pm$ 0.07)	0.48 ($\pm$ 0.14)
<i>Ceiba pentandra</i>	Low	Low	3	0.50 ($\pm$ 0.11)	
<i>Coelocaryon preussii</i>	Low	Low	11	0.53 ($\pm$ 0.02)	
<i>Pycnanthus angolensis</i>	Low	Low	10	0.64 ($\pm$ 0.13)	
<i>Riciodendron heudelotii</i>	Low	Low	14	0.36 ($\pm$ 0.13)	
<i>Entandrophragma angolense</i>	Medium	Medium	8	0.62 ($\pm$ 0.08)	0.71 ($\pm$ 0.11)
<i>Entandrophragma candollei</i>	Medium	Medium	13	0.69 ($\pm$ 0.07)	
<i>Entandrophragma cylindricum</i>	Medium	Medium	12	0.73 ($\pm$ 0.08)	
<i>Entandrophragma utile</i>	Medium	Medium	8	0.63 ($\pm$ 0.06)	
<i>Gambeya lacourtiana</i>	Medium	Medium	15	0.71 ($\pm$ 0.08)	
<i>Gambeya</i> sp.	Medium	Medium	1	0.63	
<i>Khaya anthotheca</i>	Medium	Medium	7	0.59 ($\pm$ 0.05)	
<i>Milicia excelsa</i>	Medium	Medium	16	0.67 ($\pm$ 0.08)	
<i>Petersianthus macrocarpus</i>	Medium	Medium	30	0.85 ($\pm$ 0.09)	
<i>Prioria balsamifera</i>	Medium	Medium	12	0.63 ($\pm$ 0.10)	
<i>Prioria oxyphylla</i>	Medium	Medium	20	0.65 ($\pm$ 0.09)	
<i>Prioria</i> sp.	Medium	Medium	1	0.60	
<i>Pterocarpus soyauxii</i>	Medium	Medium	19	0.71 ($\pm$ 0.09)	
<i>Uapaca guineensis</i>	Medium	Medium	6	0.78 ($\pm$ 0.08)	
<i>Amphimas</i> sp.	High	High	3	0.80 ($\pm$ 0.10)	0.81 ($\pm$ 0.13)
<i>Autranella congolensis</i>	High	High	7	0.85 ($\pm$ 0.07)	
<i>Erythrophleum suaveolens</i>	High	High	10	0.94 ($\pm$ 0.10)	
<i>Gilbertiodendron dewevrei</i>	High	High	19	0.84 ($\pm$ 0.06)	
<i>Nauclea diderrichii</i>	High	High	11	0.76 ($\pm$ 0.06)	
<i>Ongokea gore</i>	High	High	4	0.85 ($\pm$ 0.04)	
<i>Pericopsis elata</i>	High	High	20	0.81 ($\pm$ 0.09)	
<i>Zanthoxylum gillettii</i>	High	High	15	0.68 ($\pm$ 0.19)	

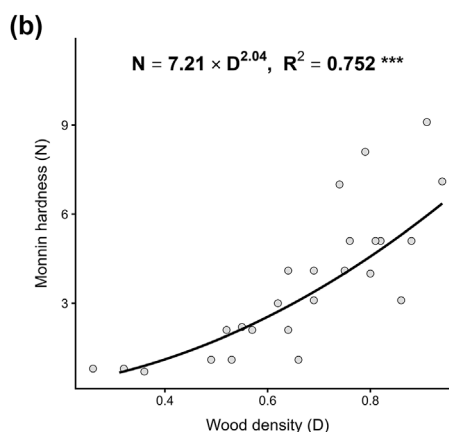
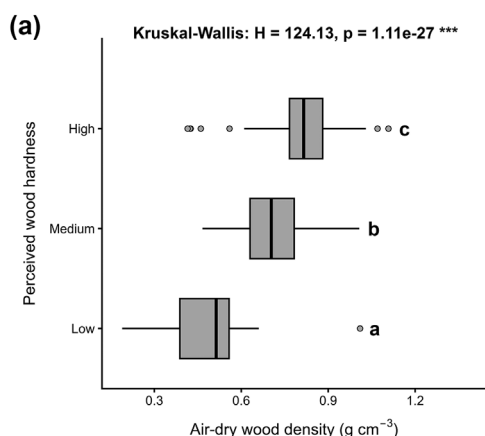


FIGURE 3 Relationships between perceived wood hardness and measured wood density in Kisangani (a), and between wood hardness and wood density from reference databases (b).

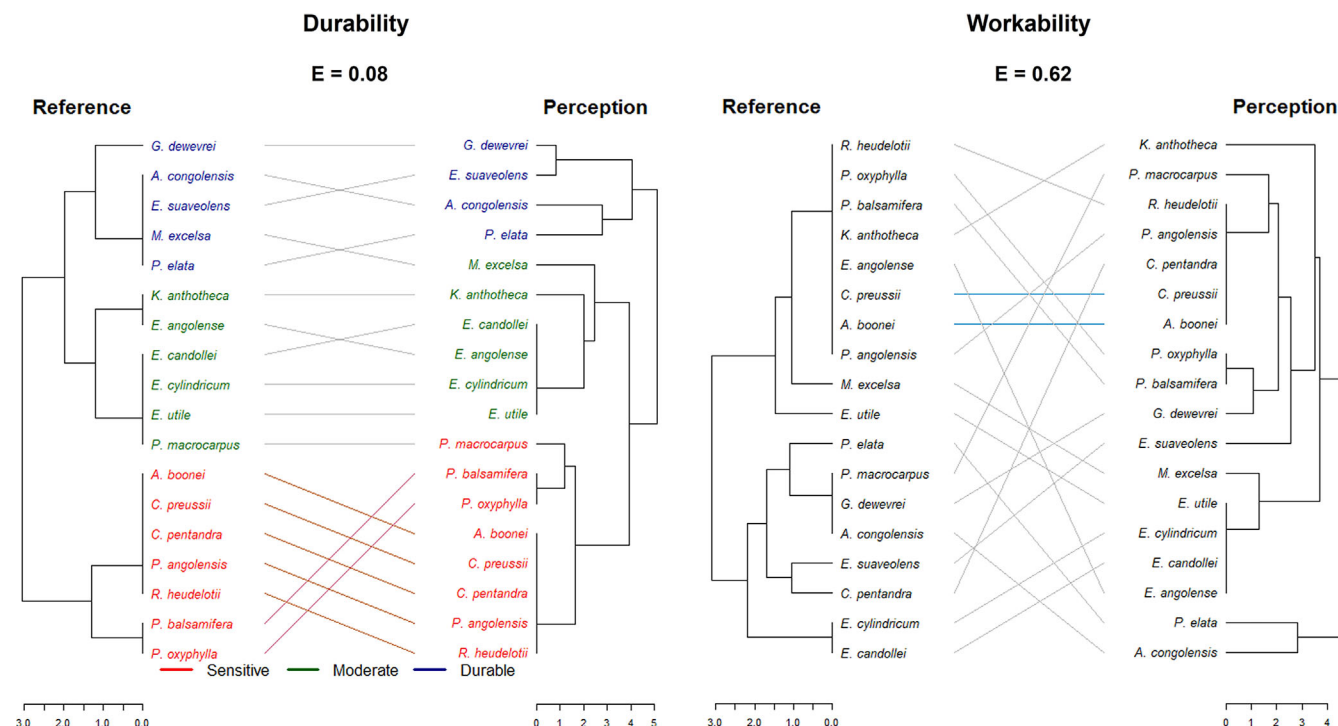


FIGURE 4 Tanglegrams comparing species groupings based on reference wood property data and local perceptions of natural durability and workability of timber species used in Kisangani.

intermediate hardness, mechanical strength and natural durability, together with good workability, primarily used for joinery, furniture, roof framing and transport canoes. The high wood density (HWD) group comprised 12 species combining high hardness, mechanical strength and natural durability with limited workability, mainly associated with roof framing, bridge construction, joinery and furniture.

3.4 | Timber stocks and forest dynamics of the identified species

Stem density, standing volume and forest dynamics parameters varied substantially among the species recorded in the domestic timber market of Kisangani (Table 3). Stem density of harvestable trees ranged from 0 trees ha⁻¹ in *Pycnanthus angolensis* to 2.24 trees ha⁻¹ in *Gilbertiodendron dewevrei*, while standing volume ranged from 0 m³ ha⁻¹ in *P. angolensis* to 14.59 m³ ha⁻¹ in *G. dewevrei*. For most species, stem density and standing volume were below 0.5 trees ha⁻¹ and 1 m³ ha⁻¹, respectively. Mean annual diameter increment ranged from 0.14 cm yr⁻¹ (*Amphimas* sp.) to 1.64 cm yr⁻¹ (*K. anthotheca*), with most species showing values below 0.5 cm yr⁻¹. Annual mortality and recruitment rates reached 2.72% yr⁻¹ (*Zanthoxylum gillettii*) and 8.94% yr⁻¹ (*Coelocaryon preussii*), respectively, although several species exhibited no observed events or low annual rates (<1.5% yr⁻¹) for one or both parameters. However, substantial intraspecific variability was observed for all three forest dynamics parameters, with standard deviations often close to or exceeding the corresponding mean values. Furthermore, certain species exhibited inverted J-shaped or hump-

shaped diameter distributions, whereas others displayed irregular structures with empty intermediate classes. Some species also showed peaks in the smallest diameter classes followed by a sharp decline towards larger diameters (Figure S2).

4 | DISCUSSION

4.1 | A poorly diversified market dominated by high-value commercial species

The domestic timber market in Kisangani is characterized by limited species diversity. Although forest inventories in the surrounding region have recorded several hundred tree species, with reported richness exceeding 400 (Kompanyi et al., 2025), only 27 were identified across the surveyed sawmills and workshops, nine of which were particularly widespread. These were the same nine species reported by Lescuyer et al. (2014) a decade earlier, when they accounted for ~85% of urban sawnwood consumption. Most belong to category I of the DRC forest species catalogue (DIAF, 2017) and are also targeted by export-oriented logging companies (BAD/FRMi, 2018; Ruiz Pérez et al., 2005), suggesting that species selection in the domestic market partly reflects patterns observed in the international timber market rather than serving as an outlet for underutilized timber resources. Similar patterns have been reported in other urban timber markets in Central Africa, although the dominant species vary with local forest composition (Cerutti & Lescuyer, 2011; Lescuyer, 2011; Lescuyer et al., 2014).

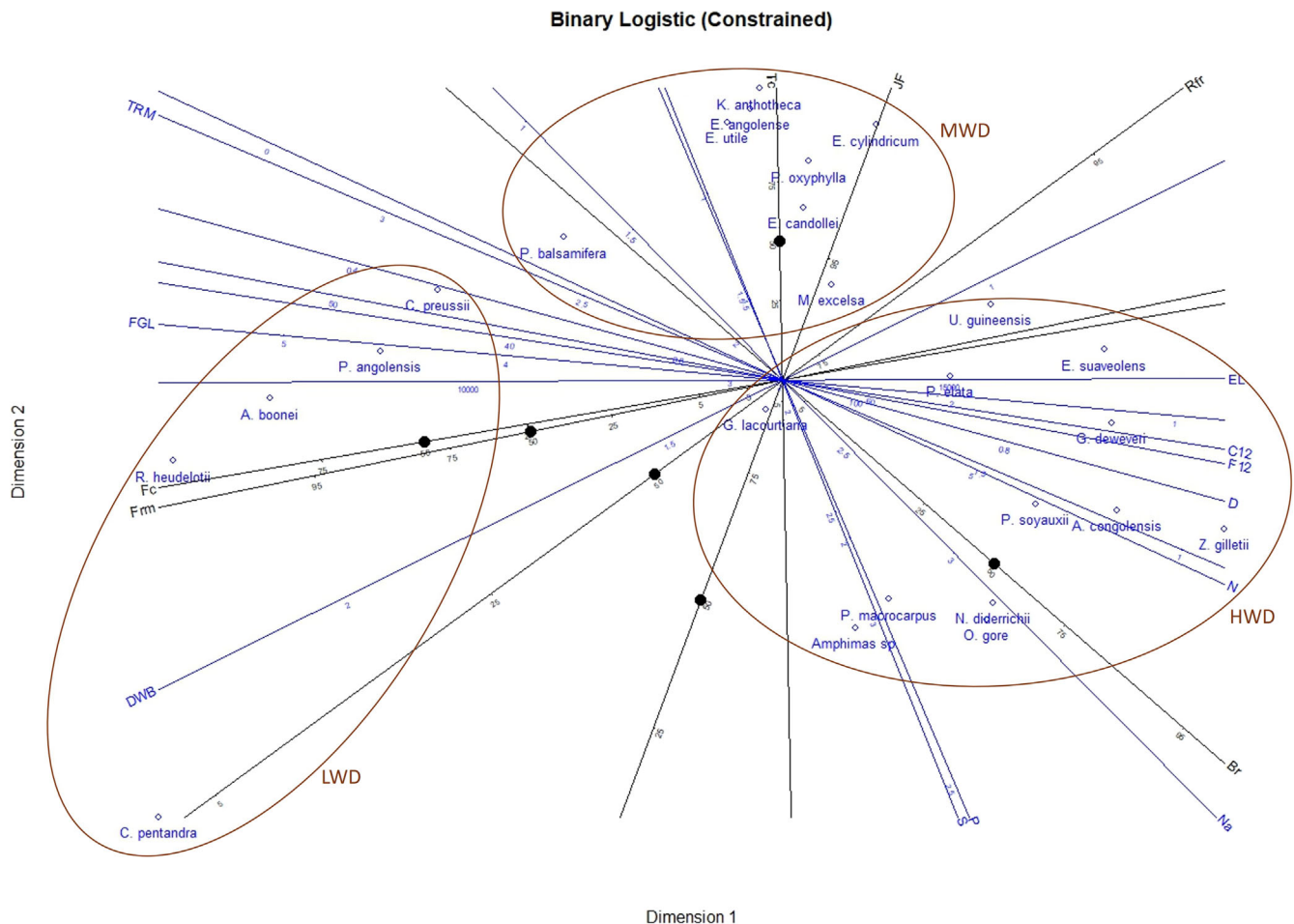


FIGURE 5 Constrained logistic biplot linking wood properties derived from reference databases to local uses of timber species in Kisangani. Species were classified into three wood density categories: low wood density (LWD), medium wood density (MWD) and high wood density (HWD). Wood properties (blue axes) include D (wood density), N (Monnin hardness), C12 (crushing strength), F12 (static bending strength), EL (modulus of elasticity), FGL (fungal resistance), DWB (resistance to dry-wood borers), TRM (termite resistance), S (sawing performance), Na (nailing performance) and P (planing performance). Local timber uses (black axes) include JF (joinery and furniture), Rfr (roof framing), Tc (transport canoe), Frm (formwork), Fc (fishing canoe) and Br (bridge construction). *Gambeya* sp. and *Prioria* sp. were excluded because their identification could not be confirmed at the species level, preventing reliable assignment of reference wood property data.

Despite accounting for more than half of the species identified, LKTS remain only marginally integrated into the domestic timber market of Kisangani. The strong market presence of *A. boonei* (category III), however, may reflect its ability to fulfil locally the functional role played elsewhere in Central Africa by commercially established light-weight timber species, such as *Triplochiton scleroxylon* (Ayous), *Aucoumea klaineana* (Okoumé) and *Terminalia superba* (Limba), which are absent from the natural forests surrounding Kisangani or occur locally only in plantations. Another shift has been reported for *Piptadeniastrum africanum* (Dabema) in Cameroon, where this species, previously marginal in urban markets, has become increasingly important to artisanal loggers as traditional commercial species have become scarcer and more distant from evacuation routes (Lescuyer et al., 2025). *P. africanum* has also shown relatively high diameter increments ($>0.5 \text{ cm yr}^{-1}$) in both logged and unlogged forests in Cameroon and the Republic of Congo (Ligot et al., 2022). In the DRC, this species has further demonstrated strong performance in an experimental plantation at Yangambi (Djiofack et al., 2025), where it also occurs naturally

(Lopez-Gonzalez et al., 2011), suggesting its potential as a timber resource for the domestic timber market in Kisangani. Together, these cases suggest that the integration of LKTS into domestic markets is feasible and has already begun, albeit modestly, either by fulfilling functions otherwise provided by commercial species absent from local forests or by replacing commercial species that have become increasingly scarce.

4.2 | A functional alignment between wood properties and local uses

Timber use in the domestic market of Kisangani shows a clear functional alignment with wood properties, reflecting well-established relationships between wood density, hardness, mechanical strength, natural durability and workability. Wood density acts as a key integrative property strongly associated with other physical and mechanical characteristics (Niklas & Spatz, 2012).

TABLE 3 Minimum cutting diameter (MCD), stem density, standing volume, annual diameter increment, mortality and recruitment of timber species identified in Kisangani, based on inventory data from surrounding areas.

Species	MCD	Stem density (trees ha ⁻¹)	Standing volume (m ³ ha ⁻¹)	Diameter increment (cm yr ⁻¹)	Mortality (% yr ⁻¹)	Recruitment (% yr ⁻¹)
<i>Gilbertiodendron dewevrei</i>	60	2.24	14.59	0.16 (± 0.15)	0.54 (± 3.47)	0.18 (± 0.46)
<i>Petersianthus macrocarpus</i>	60	1.15	5.37	0.42 (± 0.36)	0.82 (± 0.76)	1.49 (± 1.10)
<i>Pericopsis elata</i>	60	0.55	4.61	0.31 (± 0.21)	0.53 (± 1.07)	0
<i>Pterocarpus soyauxii</i>	60	0.43	2.25	0.45 (± 0.59)	1.42 (± 2.92)	1.09 (± 2.92)
<i>Erythrophleum suaveolens</i>	60	0.24	1.51	0.25 (± 0.31)	1.25 (± 2.55)	0
<i>Gambeya lacourtiana</i>	60	0.33	1.40	0.40 (± 0.36)	0.90 (± 3.13)	0.83 (± 2.92)
<i>Prioria oxyphylla</i>	80	0.16	1.39	0.28 (± 0.26)	0	0
<i>Ricnodendron heudelotii</i>	60	0.17	1.36	1.03 (± 0.70)	1.51 (± 1.62)	3.79 (± 4.18)
<i>Alstonia boonei</i>	80	0.16	1.24	0.45 (± 0.70)	1.48 (± 3.46)	0
<i>Prioria balsamifera</i>	80	0.12	0.84	0.30 (± 0.24)	1.25 (± 1.29)	2.50 (± 2.26)
<i>Zanthoxylum gillettii</i>	60	0.13	0.79	0.50 (± 0.84)	2.72 (± 3.21)	0
<i>Uapaca guineensis</i>	60	0.15	0.74	0.69 (± 0.56)	0.53 (± 0.95)	1.60 (± 3.79)
<i>Entandrophragma angolense</i>	80	0.07	0.59	0.29 (± 0.30)	2.27 (± 2.62)	0
<i>Ongokea gore</i>	60	0.10	0.54	0.33 (± 0.22)	0	1.25 (± 4.72)
<i>Milicia excelsa</i>	80	0.05	0.49	0.32 (± 0.28)	0	0
<i>Austranella congolensis</i>	80	0.04	0.49	0.86 (± 0.09)	0	0
<i>Amphimas</i> sp.	60	0.05	0.32	0.14 (± 0.22)	1.51 (± 4.54)	1.51 (± 4.54)
<i>Entandrophragma utile</i>	80	0.01	0.32	0.79 (± 0.71)	0	0
<i>Entandrophragma cylindricum</i>	80	0.03	0.39	0.73 (± 0.44)	0	0
<i>Entandrophragma candollei</i>	80	0.02	0.27	0.24 (± 0.23)	0	0.82 (± 3.21)
<i>Nauclea diderrichii</i>	60	0.01	0.13	0.19	0	0
<i>Coelocaryon preussii</i>	60	0.01	0.10	0.43 (± 0.34)	1.07 (± 1.47)	8.94 (± 17.23)
<i>Khaya anthotheca</i>	80	0.01	0.07	1.64 (± 2.16)	0	3.03 (± 3.21)
<i>Pycnanthus angolensis</i>	80	0	0	0.35 (± 0.37)	0.58 (± 3.28)	6.69 (± 8.77)

Note: *Ceiba pentandra* was not represented because no individuals of this species were recorded in the inventoried plots, despite its documented presence in the region (Lejoly et al., 2010; Tailfer, 1989), while *Prioria* sp. and *Gambeya* sp. were excluded because their species-level identification could not be confirmed.

LWD species are generally less suited to load-bearing structural applications because of their lower mechanical resistance, but their flexibility and buoyancy make them well suited to arched formwork and fishing canoe construction, respectively. Their low natural durability limits service life under exposed conditions, although moisture control in joinery and furniture can mitigate this constraint. All species in this group are LKTS. *A. boonei*, however, is now among the most widespread species in the domestic timber market of Kisangani and has wood properties broadly comparable to those of *T. scleroxylon*, which is widely used for similar purposes in Cameroon (Gérard et al., 2011; Lescuyer et al., 2016), suggesting a convergence in empirical species selection across regional timber markets.

MWD species encompass most of the widespread species in Kisangani. Their popularity reflects local users' preference for timber

that is easy to work and transport, consistent with their moderate stiffness, hardness and density. In addition, their moderate mechanical strength and natural durability make them suitable for a broad range of local uses, such as roof framing, transport canoes, joinery and furniture (Gérard et al., 2011). Their aesthetic qualities are also valued in joinery and furniture. However, their moderate durability remains a limitation in exposed conditions, where waste engine oil is commonly applied as a preservative treatment despite associated environmental and health concerns (Vazquez-Duhalt, 1989).

HWD species are associated with structurally demanding applications such as roof framing and bridge construction, consistent with their high mechanical strength and natural durability (Gérard et al., 2011). However, their hardness and stiffness make them difficult to process with the manual and portable equipment typical of

artisanal operations, which may limit their adoption by local craftworkers. *P. elata* is an exception: it is the most expensive timber species on the Kisangani market (Tshimpanga et al., 2025) and is highly valued for premium joinery and furniture owing to its fine texture and decorative appeal. Local craftworkers commonly process it green, as higher moisture content reduces cell wall stiffness and the cutting energy required for machining (Guedes et al., 2020), though this practice may increase the risk of shrinkage and dimensional instability during subsequent drying (Glass & Zelinka, 2010).

Overall, the observed relationships between wood properties and uses reflect a coherent empirical knowledge system, supported by the close correspondence between local perceptions and reference data for density, hardness and natural durability. Such local knowledge of timber quality may facilitate the market acceptance of alternative species by enabling users to assess their suitability for specific uses. Divergences in workability assessments may reflect differences in tools and processing conditions between artisanal contexts and standardized reference assessments rather than shortcomings in local expertise.

4.3 | Abundant in the local market but scarce in the surrounding forests

Despite their widespread occurrence in the market, the most frequently used timber species in Kisangani exhibited low stem densities and standing volumes in surrounding forests. For instance, Lescuyer et al. (2014) estimated that *Entandrophragma utile* and *Entandrophragma candollei* together account for ~33% of locally consumed timber, yet their harvestable stem densities were remarkably low, at only 0.01 and 0.02 stems ha⁻¹, respectively. These low commercial stocks coincided with indications of regeneration or recruitment deficits in *P. elata* and *A. boonei*, as suggested by their hump-shaped diameter distributions, and with discontinuous population structures in the seven other widespread species, which displayed irregular distributions with empty classes. This latter pattern is consistent with episodic recruitment, whereby cohorts may establish following canopy-opening events that transiently increase light availability (Vlam et al., 2014). In this study, the absence or low rates of recruitment observed for these species during the monitoring period are consistent with this hypothesis, although longer monitoring periods would be required to confirm episodic recruitment. Indeed, despite the absence or rarity of observed mortality events, consistent with the generally low mortality rates reported for tropical tree species (Ligot et al., 2022), these recruitment patterns suggest that existing individuals may persist over the short term while population renewal remains limited or discontinuous. The limited number of individuals recorded in the monitored plots (Tables S1 and S2), reflecting their low abundance in these forests, likely reduced the probability of detecting both demographic events. Over time, such demographic imbalances may constrain the replenishment of harvestable size classes (Schulze et al., 2008). This process may be further limited by the generally slow diameter growth reported for these species, with rates typically below 0.5 cm yr⁻¹ (Détienne et al., 1998; Durrieu De Madron et al., 2000;

Ligot et al., 2022). The relatively high increments observed in this study for *E. utile* (0.79 cm yr⁻¹), *E. cylindricum* (0.73 cm yr⁻¹), *K. anthotheca* (1.64 cm yr⁻¹) and *Austranella congolensis* (0.86 cm yr⁻¹) should, however, be interpreted cautiously, as they were based on very small samples (≤4 individuals; Table S3). Ligot et al. (2022) similarly reported elevated values for these and other light-demanding species under specific site and logging conditions, while multisite averages based on larger samples remained below 0.5 cm yr⁻¹.

Previous studies in managed tropical forests have similarly shown that such demographic constraints can substantially limit the recovery of harvestable stocks of light-demanding commercial species (Bourland et al., 2012; Gourlet-Fleury et al., 2013; Karsenty & Gourlet-Fleury, 2006; Schulze et al., 2008). As a result, these species may persist in the forest while becoming increasingly scarce in harvestable size classes (Karsenty, 2018). This situation may be particularly concerning in the context of forests supplying Kisangani, where artisanal logging frequently occurs outside legal frameworks and where ongoing deforestation and forest degradation (Lescuyer et al., 2025; Mangaza et al., 2026) may further affect populations of these high-value timber species. These management challenges coincide with broader international trade and conservation concerns surrounding many of these species. *P. elata*, for instance, has been listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since 1992, while *K. anthotheca* and *Pterocarpus soyauxii* were added to the same Appendix in 2022 (Groves & Rutherford, 2023). *P. elata* and *P. balsamifera* are classified as Endangered on the International Union for Conservation of Nature (IUCN) Red List, whereas *K. anthotheca*, *Entandrophragma cylindricum*, *E. candollei* and *E. utile* are Vulnerable (IUCN, 2026). Although these CITES listings primarily concern international trade rather than domestic use, they nonetheless highlight broader concerns surrounding the sustainable use of these timber species, including in the context of artisanal logging. Continued reliance on this narrow group of frequently used species therefore raises concerns about the capacity of surrounding forests to sustain Kisangani's timber supply over the long term.

4.4 | Balancing wood properties, market acceptance and forest availability for sustainable domestic timber supply

The LKTS identified as alternatives to widely used commercial species share similar wood properties within the three wood density groups. However, assessing their potential for integration into the domestic timber supply should consider not only wood properties but also local knowledge of timber quality and the ecological capacity of their populations to sustain long-term timber supply.

In the LWD group, the average growth rates observed (1.03 cm yr⁻¹ for *Ricinodendron heudelotii* and <0.5 cm yr⁻¹ for *A. boonei*, *P. angolensis* and *C. preussii*) may not fully capture the growth potential of these fast-growing pioneer species. Their maximum growth rates exceeded 1.5 cm yr⁻¹ (Table S3) and may

correspond to individuals experiencing more favorable light conditions. This pattern is consistent with substantially higher growth under more open environments, such as canopy gaps, plantations and other disturbed stands (Ilunga-Mulala, Doucet, et al., 2025; Ligot et al., 2022). The relatively slow growth of *P. angolensis* and *C. preussii* may limit the rate at which stems progress toward harvestable size classes; however, their recruitment rates, the highest recorded in this study, together with their inverted J-shaped diameter distributions, suggest ongoing population renewal and favourable regeneration patterns. This group could also be expanded to include other LWD species, including short-lived taxa such as *Musanga cecropioides* and *Macaranga* spp., which rapidly colonize canopy gaps and disturbed environments. However, additional studies are needed to determine whether their high abundance and rapid growth can compensate for their relatively small stem dimensions, short lifespan and the frequent defects observed in their stems under short rotation cycles.

In the MWD group, *Prioria oxyphylla* was the only underutilized species identified. It displayed higher standing volumes than most widespread commercial species ($>1 \text{ m}^3 \text{ ha}^{-1}$) and showed regeneration potential, given its inverted J-shaped diameter distribution. However, the absence of recruitment during the monitoring period should be interpreted cautiously, as recruitment in some long-lived tropical tree species may occur episodically over decadal timescales (Vlam et al., 2014). Slow growth and processing constraints potentially associated with wood exudates, as reported by local craftworkers, may further limit its market adoption. This group should therefore be further explored for additional underutilized species with suitable technological and demographic characteristics.

Among HWD species, *G. dewevrei* and *Petersianthus macrocarpus* exhibited the highest standing stocks of all identified species yet remain among the least used locally. Their adoption may be constrained by limited workability under artisanal processing conditions and, in the case of *P. macrocarpus*, by the unpleasant odour of freshly sawn wood reported by local craftworkers. Improved access to appropriate processing equipment could facilitate their integration into local markets. Furthermore, despite slow growth rates, their inverse J-shaped diameter distributions and high densities of individuals below the minimum cutting diameter suggest favourable population structures for the replenishment of harvestable stocks over time (Schulze et al., 2008). Diversification within this group should also consider other high-wood-density species that are currently absent from the local market but abundant in certain surrounding forests, such as *Scorodophloeus zenkeri* (Lopez-Gonzalez et al., 2011; Vanden Abeele et al., 2021), *Staudtia kamerunensis* (Lopez-Gonzalez et al., 2011) and *Julbernardia seretii* (Katembo et al., 2020), as well as species that combine HWD with strong growth performance in plantations, including *Pachyelasma tessmannii* and *P. africanum* (Djiofack et al., 2025; Ilunga-Mulala, Doucet, et al., 2025).

5 | CONCLUSION

This study provides one of the first integrated forest-to-market assessments of LKTS for a domestic timber market in the Congo

Basin. The results highlight strong functional relationships between wood properties and local uses, the concentration of timber use on a narrow group of commercial species despite high forest diversity and the ecological constraints limiting the ability of these widely used species to sustain long-term timber supply. Local perceptions of wood properties closely matched reference data, revealing a robust body of local knowledge that may facilitate the acceptance of alternative species in the domestic timber market. Although certain LKTS combine suitable wood properties with favorable forest availability or regeneration potential, their current integration into the domestic market remains limited. While these findings reflect the Kisangani context, regional variations in forest composition and market dynamics call for similar integrated assessments in other cities of the DRC and across the broader Congo Basin to enable regional comparisons. The selection of LKTS for promotion should therefore be based not only on suitable wood properties but also on local knowledge of timber quality and forest resource availability and dynamics. Future assessments should further consider their economic competitiveness relative to traditionally harvested species, including market prices as well as harvesting and processing costs. Expanding wood property databases and developing locally adapted engineering solutions to valorize timber with non-conventional dimensions and morphological characteristics would also help address current technical barriers to their use. At the same time, strengthening long-term ecological monitoring of LKTS and evaluating appropriate silvicultural interventions for these species, while improving governance of the domestic timber sector, will be essential to support sustainable forest management and secure the future urban timber supply.

AUTHOR CONTRIBUTIONS

Mbusa Wasukundi, Tom De Mil, Chadrack Kafuti, Nils Bourland, Hans Beeckman, Joris Van Acker, Benoît Jourez, Jean-Pierre Mate Mweru, Jan Van den Bulcke and Marie Caroline Momo Solefack planned and designed the research. Mbusa Wasukundi, Tom De Mil, Michael Monnoye, Nils Bourland, Hans Beeckman, Félix Laurent, Kévin Liévens, Silvia Ferrari, Wannes Hubau, Jean Gérard and Nestor Luambua conducted the experiments and collected the data. Mbusa Wasukundi, Tom De Mil, Michael Monnoye, Félix Laurent, Falonne Osiveri, Paul Katembo Vikanza and Robin Doucet analysed the data. Mbusa Wasukundi, Marie Caroline Momo Solefack and Tom De Mil wrote the initial draft of the manuscript. All authors reviewed and edited the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets and R scripts supporting this study are available in Figshare at: [10.6084/m9.figshare.32400630](https://figshare.com/10.6084/m9.figshare.32400630).

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