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Original Research Article

Challenges and Prospects for the Conservation of Natural Resources in an Urban Forest in Mali: Case of the Koulouba Classified Forest, Bamako

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Abstract: The Koulouba Classified Forest is Bamako's main wooded reserve, Mali. It is exposed to anthropogenic pressure from the urban expansion of Bamako and Kati and to the effects of climate change. This study analyses the challenges of biodiversity conservation and identifies prospects for the sustainable management of the forest's natural resources. A mixed-methods approach combined a woody-species inventory in 18 sampling units with a survey of users of green spaces. At district scale, vegetation lost 58% of its area between 1995 and 2025, and built-up land now covers 75% of the territory. The inventory recorded 434 woody individuals belonging to 26 taxa; five species accounted for 79% of individuals, and 59% of individuals were 2 m tall or less. The Shannon index was 2.30 (95% confidence interval: 2.16–2.37), and Pielou's evenness was 0.71. The abundance-weighted mean circumference was 22 cm, and height increased strongly with circumference across species ($H = 0.61 \cdot C^{0.56}$; $R^2 = 0.77$). Abundant species had the thinnest stems and belonged mainly to the *Combretaceae*, whereas the *Sapotaceae* dominated basal area. About 45% of the forest has been encroached upon, although the law prohibits any occupation of a classified forest and provides for the summary eviction of occupants. The principal challenge is therefore the non-enforcement of existing legislation rather than its absence. Reforestation in Bamako remains limited, and seedlings are poorly monitored, leading to water stress; the effectiveness of surveillance has yet to be established, and citizen mobilisation is weak. Priority actions are to secure the forest boundary, to make any declassification conditional on compensation, to involve residents in surveillance, and to enrich the stand with native species.

Keywords: Urban Forest, Classified Forest, Conservation, Woody Biodiversity, Land Governance.

1. INTRODUCTION

Urban and peri-urban forests provide cities with essential ecosystem services, including microclimate regulation, air filtration, stormwater infiltration, biodiversity conservation, timber and non-timber products, and amenity and recreation (Salbitano *et al*., 2016). In West Africa, a cooling effect has been measured in urban green infrastructure, where temperatures are lower inside than at the periphery (Zoungrana *et al*., 2021). These services nevertheless depend on the integrity of the stands, which deteriorates as anthropogenic pressure increases and reduces the aboveground woody carbon potential (Konaté *et al*., 2024).

The population of the Malian capital is growing by approximately 3.3% per year, and urbanisation is accompanied by unplanned land occupation and the exhaustion of land reserves (Dagno *et al.,* 2025). A complementary study of land-cover dynamics in the district (Toulema *et al*., submitted) shows that vegetation lost 58% of its area between 1995 and 2025, while built-up land increased from 53.7% to 75.0% of the territory. Similar links between vegetation dynamics,

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rainfall variability, and population pressure have been reported elsewhere in Mali (Coulibaly and Traoré, 2026). The climatic context further increases the vulnerability of the stands: in Mali, annual rainfall decreased by 115 mm (−18.3%) between 1921 and 2000, and the isohyets shifted 135 km southwards (Diawara, 2019).

In this context, the classified forests close to the city are the last large wooded reserves. The Koulouba Classified Forest, established in 1935 and covering 2,010 ha, is the most emblematic of them: it occupies the Mandé plateau in the north of the district. Classified status nonetheless confers one of the strongest forms of protection in forestry law. Law No. 10-028 of 12 July 2010, which sets out the principles governing the management of the national forest domain, exempts the classified domain from any form of occupation (Art. 41) and provides for the summary eviction of occupants (Art. 113). A protection status, however, does not by itself guarantee the integrity of a site (Konaté *et al*., 2024).

Despite this issue, the woody stand shows chronic disturbance, with the dominance of a few species and a high proportion of regeneration-stage individuals. The main obstacle to conservation is the enforcement of existing law rather than a gap in the legal texts. The objective of the study is to analyse the challenges of conserving the natural resources of the Koulouba Classified Forest and to propose prospects for the sustainable management of urban biodiversity. Specifically, it aims to characterise the composition, diversity and structure of the woody stand and then to derive operational perspectives.

2. MATERIALS AND METHODS

2.1. Study Area

The Koulouba Classified Forest is located in the north of the Bamako District (centroid: 12.659° N, 8.008° W), on the Mandé plateau, whose elevation reaches 485 m at Koulouba. It is bounded to the east by the neighbourhoods of Sikoroni and Banconi, to the west by the villages of Lassa, Koulouniko and Sirakoro, to the north by the village of N'Gomi and the Kati road, and to the south by Missira, Darsalam and N'Tomikoroboungou. The forest was classified by Order No. 1438/SE/5 of 28 June 1935 and covers 2,010 ha; it is the second classified forest of Mali, after the Paparah forest in the Kayes region. Its classification was intended to prevent degradation caused by clearing and to protect the Dakar–Niger railway, laid in 1924, from runoff. The climate is Sudanian, with a dry season from November to April or May and a rainy season from May to October; July and August are the wettest months. The forest lies in valleys of the Mandé plateau.

2.2. Floristic Inventory

Plant nomenclature follows the APG IV classification (Angiosperm Phylogeny Group, 2016), and taxa were identified with Arbonnier (2009). Names have been updated to currently accepted usage (*Senegalia macrostachya* for *Acacia macrostachya*; *Vachellia tortilis* subsp. *raddiana* for *Acacia raddiana*). The inventory covered woody individuals with a circumference at breast height (1.30 m above ground) of at least 10 cm. This threshold is widely used in studies of woody stand structure in tropical environments and allows a reliable characterisation of floristic composition and dendrometric parameters (Picard *et al*., 2012).

The woody inventory was carried out during the rainy season in 18 cartographic sampling units, each corresponding to a homogeneous vegetation grouping, distributed along transects of approximately 1 km. In each unit, woody individuals were identified and counted, and the mean height of each species was measured with a clinometer (Plate 1); positions were recorded with a Garmin 78 GPS receiver. Abundance–dominance was scored on the Braun-Blanquet scale (Braun-Blanquet, 1964), following the phytosociological protocol of Meddour (2011).



Plate 1: Suunto clinometer (left) and Garmin 78 GPS receiver (right) used in the inventory

A complementary data sheet records, for each species, the family, the number of individuals, the circumference (cm) and the height (m). Circumference and height were weighted by the number of individuals. Family names were harmonised according to APG IV (Angiosperm Phylogeny Group, 2016).

2.3. Diversity Indices

Diversity was measured with species richness (S), the Shannon index (H′, natural logarithm; Shannon, 1948), the Simpson index (D; Simpson, 1949) and Pielou's evenness (J; Pielou, 1966), which describes the evenness of abundances (Magurran, 2004). H′ and D were converted into Hill numbers, exp(H′) and 1/D (Hill, 1973), which are interpreted as effective numbers of equally abundant species. Total richness was estimated with the Chao1 estimator (Chao, 1984; $f_1 = 4$ singletons, $f_2 = 7$ doubletons). The 95% confidence intervals were obtained by bootstrap resampling of individuals (Efron and Tibshirani, 1993). With N the total number of individuals, n_i the number of individuals of species i and $p_i = n_i / N$ its proportion, the indices were computed as follows:

- Species richness: S = number of observed taxa.
- Shannon index: $H' = -\Sigma\, p_i \ln p_i$.
- Pielou's evenness: $J = H' / \ln S$.
- Simpson index: $D = \Sigma\, p_i^2$, the sum running over the S species.
- Hill number of order 2: ${}^2D = 1 / \Sigma\, p_i^2$, the number of equally abundant species that would give the same dominance.
- Hill number of order 1: ${}^1D = \exp(-\Sigma\, p_i \ln p_i)$, the number of equally abundant species that would give the same Shannon index.
- Chao1 richness estimator: $S_Chao1 = S + f_1^2 / (2 f_2)$, where f_1 and f_2 are the numbers of taxa represented by exactly one and exactly two individuals (singletons and doubletons), respectively.

Here H′ measures the uncertainty about the identity of a randomly drawn individual; it increases with the number of taxa and with the equality of their abundances, and reaches its maximum, ln S, when all taxa have the same abundance. J ranges from 0 (one taxon almost completely dominant) to 1 (perfectly equal abundances). D is the probability that two individuals drawn at random (with replacement) belong to the same taxon; it increases with dominance and thus decreases with diversity. Chao1 adds to the observed richness a correction for rare taxa probably missed by the inventory.

2.4. Stand Structure and Statistical Analysis

The equivalent diameter was derived from circumference ($d = C / \pi$), and individual basal area was computed as $g = C^2 / (4\pi)$. The relative basal area of a species or family is its share of the sum of the products $n_i \times g_i$, computed over species. Family means are weighted by the number of individuals. The relationship between height H (m) and circumference C (cm) was fitted by linear regression of the logarithms, $\ln H = \ln a + b \ln C$, i.e. $H = a \cdot C^b$, with the species as the unit of analysis. The uncertainty of the exponent b was quantified with a 95% confidence interval obtained by bootstrap resampling of species, and Spearman's rank correlation was used as a robust indicator of association. The fit was repeated without *Eucalyptus camaldulensis* and with weighting by number of individuals. The relationship between abundance and circumference was assessed with Spearman's correlation. Differences in height among families represented by at least two species were tested with a Kruskal–Wallis test, and differences in species abundance with a Mann–Whitney test. Calculations were performed in Python.

Individuals with a circumference below 10 cm (indicated by a dash in the data sheet), classed as regeneration, were analysed separately with respect to number of individuals, height, family and share of the sample. We also computed the ratio of regeneration individuals to individuals with a circumference of at least 10 cm, and compared the abundance of species represented only by regeneration with that of the other species.

3. RESULTS

3.1. Composition and Diversity of the Woody Stand

The inventory recorded 434 woody individuals belonging to 26 taxa. Five species dominate the stand and together account for 79.0% of individuals: *Vitellaria paradoxa* (100 individuals), *Combretum micranthum* (91), *Senegalia macrostachya* (67), *Combretum ghasalense* (44) and *Anogeissus leiocarpa* (41). The Combretaceae represent 46% of individuals. Conversely, four taxa are represented by a single individual (*Khaya senegalensis*, *Sclerocarya birrea*, *Prosopis africana* and *Vachellia tortilis* subsp. *raddiana*) and seven by two individuals.

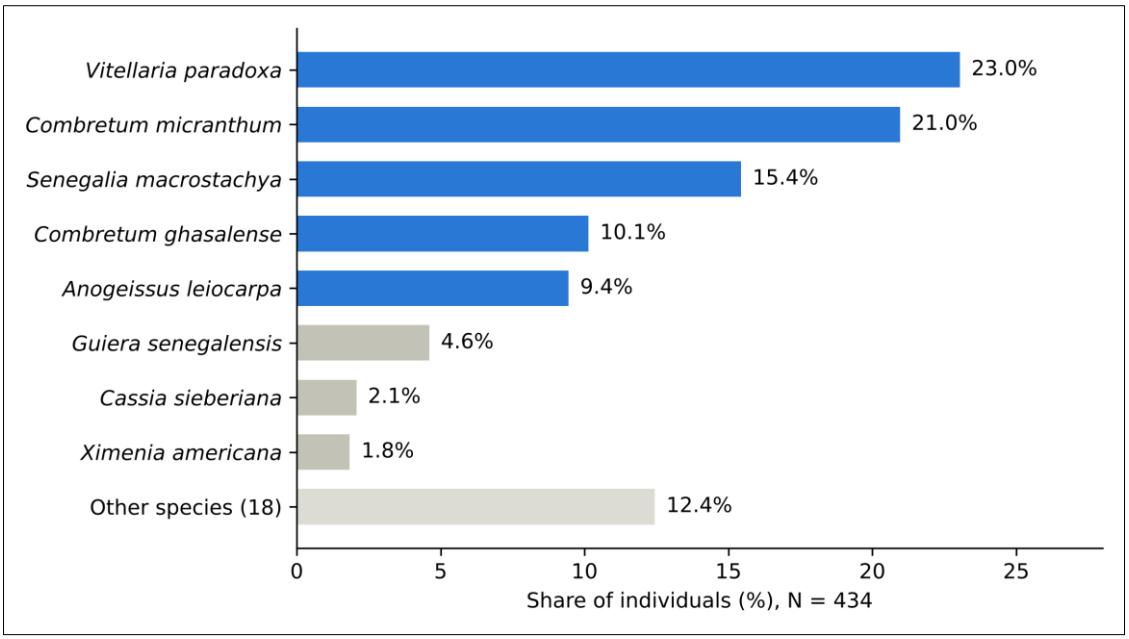


Figure 1: Abundance of woody species in the Koulouba Classified Forest. The five dominant species are shown in blue. Other species (each ≤ 1.4%): *Bombax costatum*, *Cordyla pinnata*, *Azadirachta indica* (1.4% each); *Ziziphus mauritiana*, *Pterocarpus lucens* (1.2%); *Eucalyptus camaldulensis*, *Terminalia macroptera* (0.9%); *Lannea microcarpa*, *L. acida*, *Annona senegalensis*, *Daniellia oliveri*, *Hexalobus monopetalus*, *Balanites aegyptiaca*, *Ficus vallis-choudae* (0.5%); *Khaya senegalensis*, *Sclerocarya birrea*, *Prosopis africana*, *Vachellia tortilis* subsp. *raddiana* (0.2%).

The stand is thus dominated by a small number of taxa. The five most abundant taxa account for 79% of individuals, whereas the remaining 21 taxa together account for 21%. Among these, 18 each represent 1.4% or less of individuals, and 11 do not exceed 0.5%. This distribution is unequal, with many rare species, low evenness and a banalised stand, as reflected by the diversity indices (Shannon = 2.30; Pielou = 0.71; Table 1). The dominant species are typical of Sudanian savannas subject to repeated disturbance (cutting and fire). The status of *Vitellaria paradoxa*, a protected species, is probably favoured by this management. Among the rare taxa are two introduced species, *Eucalyptus camaldulensis* and *Azadirachta indica* (2.3% combined).

Table 1: Diversity indices of the woody stand

Index	Value	95% CI
Observed species richness (S)	26	
Total number of individuals (N)	434	
Shannon index (H′, ln)	2.30	2.16–2.37
Pielou's evenness (J)	0.71	0.69–0.75
Simpson index (D)	0.144	
Hill number, 1/D	6.9	
Hill number, exp(H′)	10.0	
Estimated richness (Chao1)	27.1	

Source*: woody inventory, 2024. Legend: CI, confidence interval.*

The Shannon index (2.30) is lower than its theoretical maximum for 26 taxa (ln 26 = 3.26), and evenness (0.71) reveals an unequal distribution of abundances. The stand behaves as if it contained about ten equally abundant species (exp(H′) = 10.0) for 26 observed species. The Chao1 estimator (27.1) is close to the observed richness, indicating that the inventory captured most of the taxa present.

3.2. Stand Structure

Individuals of 2 m or less are the most numerous (59%), ahead of the 3–5 m class (28%) and the class of 6 m or more (13%). The mean height, computed from species means, is approximately 3.1 m. The stand is therefore low and dominated by small individuals, which is compatible with the hypothesis of chronic disturbance.

The mean circumference of species ranges from 7 cm (*Combretum ghasalense*) to 80 cm (*Prosopis africana*) (Table 3). It is not recorded for nine species (10% of individuals), which belong to the regeneration stratum, whose mean height does not exceed 1.30 m. The abundance-weighted mean circumference is 21.9 cm, equivalent to a diameter of 7.0

cm. Four species (53% of measured individuals) have a mean circumference below 20 cm, eight species (44%) between 20 and 49 cm, and only four species (3%) reach 50 cm or more (*Pterocarpus lucens*, *Eucalyptus camaldulensis*, *Sclerocarya birrea* and *Prosopis africana*). The latter represent 21% of relative basal area, against 8% for the species below 20 cm and 72% for those of 20–49 cm. The woody species recorded are listed in Table 2 by family and order according to APG IV, together with their Braun-Blanquet abundance–dominance coefficients.

Table 2: Woody species recorded, by order and family (APG IV), with Braun-Blanquet abundance–dominance coefficients

Order	Family	Species	Abundance–dominance
Ericales	*Sapotaceae*	*Vitellaria paradoxa*	2
Fabales	*Fabaceae*	*Senegalia macrostachya*	2
		Cassia sieberiana	1
		Cordyla pinnata	1
		Pterocarpus lucens	1
		Daniellia oliveri	+
		Prosopis africana	r
		Vachellia tortilis subsp. raddiana	r
Magnoliales	*Annonaceae*	*Annona senegalensis*	+
		Hexalobus monopetalus	+
Malvales	*Malvaceae*	*Bombax costatum*	1
Myrtales	*Combretaceae*	*Combretum micranthum*	2
		Combretum ghasalense	2
		Anogeissus leiocarpa	2
		Guiera senegalensis	1
		Terminalia macroptera	+
	Myrtaceae	*Eucalyptus camaldulensis*	+
Rosales	*Rhamnaceae*	*Ziziphus mauritiana*	1
Santalales	*Ximeniaceae*	*Ximenia americana*	1
Sapindales	*Meliaceae*	*Azadirachta indica*	1
		Khaya senegalensis	r
	Anacardiaceae	*Lannea microcarpa*	+
		Lannea acida	+
		Sclerocarya birrea	r
Zygophyllales	*Zygophyllaceae*	*Balanites aegyptiaca*	+

Source*: woody inventory, 2024. Legend: Coefficients: 2 = abundant; 1 = abundant with low cover; + = sparse; r = rare. Tables 2 and 3 and the structural analyses are based on the 25 taxa (432 individuals) of the structure data sheet;* Ficus vallis-choudae *(2 individuals, Moraceae) was recorded only in the abundance inventory (Figure 1).*

The Combretaceae (46% of individuals) dominate numerically, but with a mean circumference of 15.5 cm, a mean height of 3.0 m and only 23% of relative basal area (Table 3; Figure 2). The Sapotaceae, represented by a single species (*Vitellaria paradoxa*), conversely concentrate 45% of relative basal area, for 23% of all individuals (26% of individuals with a measured circumference), a mean circumference of 35 cm and a height of 4 m. The Fabaceae (21%) are the lowest of the three main families (2.3 m) and account for 15% of relative basal area. Families with few individuals have thicker stems: the Myrtaceae (*Eucalyptus camaldulensis*) account for 8% of relative basal area with 1% of individuals, and the Anacardiaceae and Malvaceae account for 3% and 4%, respectively.

Table 3: Structure of the woody stand by family

Family	Species	Individuals	Share of individuals (%)	Mean circumference (cm)	Mean height (m)	Relative basal area (%)
Combretaceae	5	200	46.3	15.5	3.0	22.8
Sapotaceae	1	100	23.1	35.0	4.0	45.5
Fabaceae	7	91	21.1	15.7	2.3	15.4
Ximeniaceae	1	8	1.9	—	1.0	—
Meliaceae	2	7	1.6	20.0	5.3	0.9
Malvaceae	1	6	1.4	40.0	5.0	3.6
Rhamnaceae	1	5	1.2	10.0	2.0	0.2
Anacardiaceae	3	5	1.2	42.0	4.2	3.3
Myrtaceae	1	4	0.9	75.0	6.0	8.4
Annonaceae	2	4	0.9	—	1.5	—

Family	Species	Individuals	Share of individuals (%)	Mean circumference (cm)	Mean height (m)	Relative basal area (%)
Zygophyllaceae	1	2	0.5	—	2.0	—
Total	**25**	**432**	**100.0**	**21.9**	**3.1**	**100.0**

Source: woody inventory, 2024. Shares of individuals are computed on the 432 individuals of the data sheet; mean circumference and relative basal area refer to the 388 individuals with a recorded circumference. A dash indicates regeneration-stage individuals.

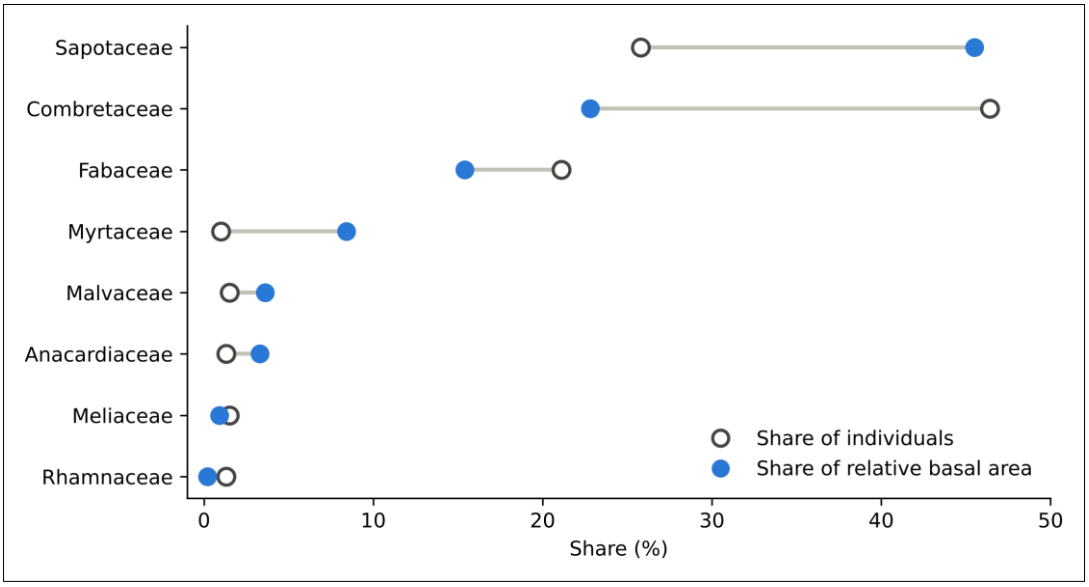


Figure 2: Share of individuals and share of relative basal area by family (388 individuals with a recorded circumference)

3.2.1. Height and Circumference

Across species, mean height increases with mean circumference (Figure 3): the log–log fit gives $H = 0.61 \cdot C^{0.56}$ ($R^2 = 0.77$; $p < 0.001$; 16 species), the bootstrap 95% confidence interval of the exponent ranges from 0.44 to 0.66, and Spearman's rank correlation is 0.78 ($p < 0.001$). The exponent is 0.58 without *Eucalyptus camaldulensis* and 0.62 when species are weighted by their number of individuals, which limits the risk that the relationship is driven by a single species or by the abundant species. Two species are clearly taller than expected for their circumference: *Azadirachta indica* (1.8 times) and *Anogeissus leiocarpa* (1.6 times); *Cassia sieberiana* and the two *Lannea* species are, conversely, lower than predicted (by 17–23%).

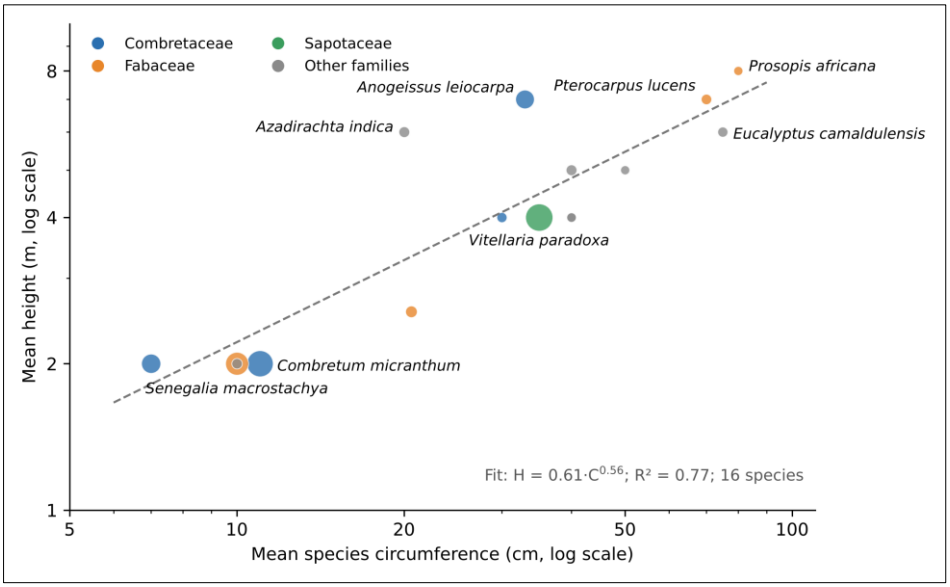


Figure 3: Relationship between mean height and mean circumference of species (log–log scale; symbol size proportional to abundance). The dashed line is the fitted allometric relationship.

3.2.2. Abundance, Size and Family

Abundant species are those with the thinnest stems: Spearman's correlation between abundance and mean circumference is −0.67 (p = 0.005; bootstrap 95% CI: −0.87 to −0.28; 16 species), whereas abundance is unrelated to height across all 25 species (ρ = 0.03; p = 0.89). At the family level, the mean height of species does not differ significantly among the five families represented by at least two species (Kruskal–Wallis: $\chi^2 = 2.46$; 4 d.f.; p = 0.65), nor between Fabaceae and Combretaceae (Mann–Whitney: height, U = 16, p = 0.87; circumference, U = 11, p = 0.49). These tests rest on small samples (two to seven species per family) and have low power: the absence of a significant difference does not demonstrate the absence of a family effect. The relationship between abundance and mean circumference is shown in Figure 4.

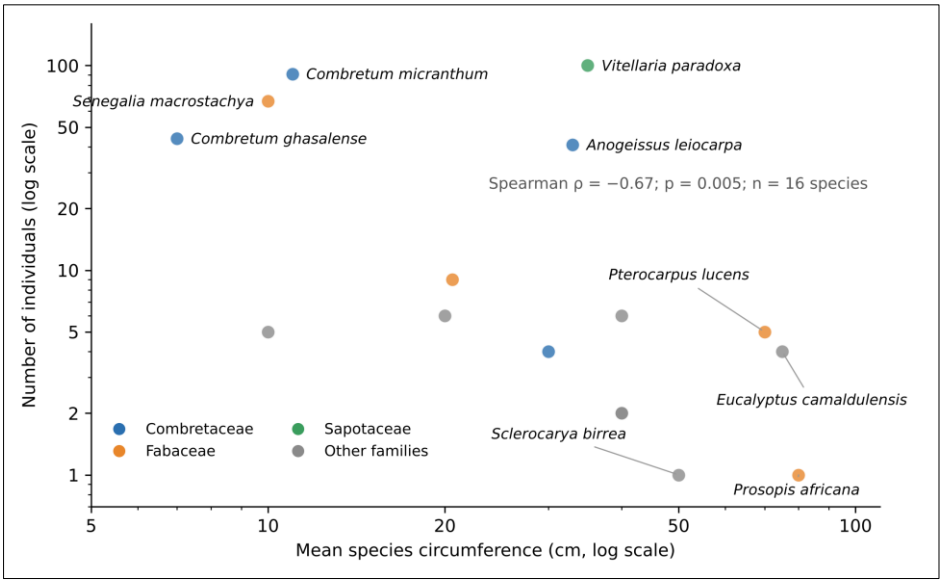


Figure 4: Scatter plot of abundance against mean circumference of species (log–log scale)

3.3. Regeneration

Regeneration-stage individuals total 44, i.e. 10% of individuals, or 11 regeneration individuals per 100 individuals with a measured circumference. Nine of the 25 species (36%) are represented only by this stage: *Guiera senegalensis* (20 individuals), *Ximenia americana* (8), *Cordyla pinnata* (6), *Annona senegalensis*, *Daniellia oliveri*, *Hexalobus monopetalus* and *Balanites aegyptiaca* (2 each), and *Khaya senegalensis* and *Vachellia tortilis* subsp. *raddiana* (1 each) (Figure 5). They belong to six families (Combretaceae, Fabaceae, Ximeniaceae, Annonaceae, Zygophyllaceae and Meliaceae); three of these (Ximeniaceae, Annonaceae and Zygophyllaceae) are represented in the sample only by regeneration. These species are less abundant than the others (median of 2 versus 5.5 individuals), but the difference is not significant (Mann–Whitney: U = 44; p = 0.12). Only one species shows both stages, *Cassia sieberiana*, of which 4 of the 9 individuals have a circumference of 5 cm and a height of 2 m, against 5 individuals of 33 cm and 3 m. For the other species, the mean circumference may include young individuals.

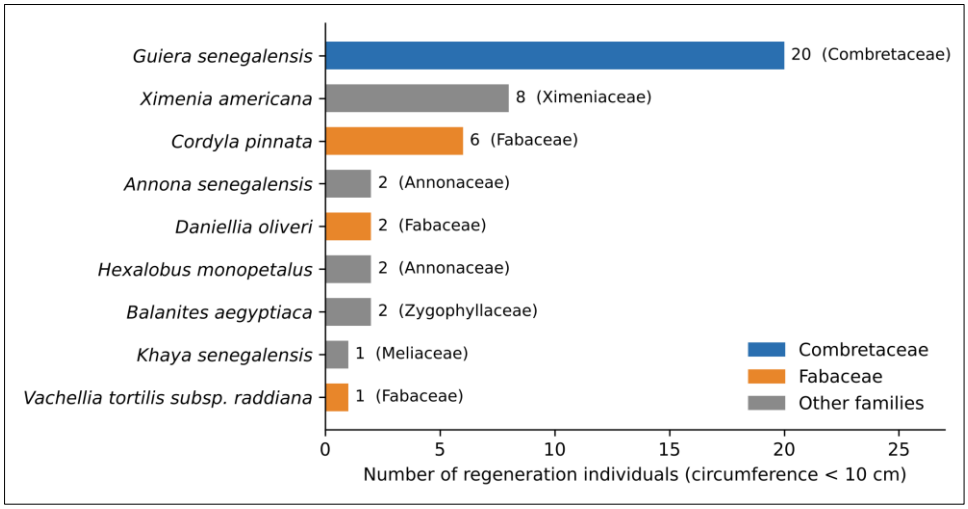


Figure 5: Species represented only by regeneration-stage individuals

The stand thus combines numerous thin, low stems (small Combretaceae and Fabaceae) with a small number of larger, taller species, among which *Vitellaria paradoxa* and *Anogeissus leiocarpa* together carry 62% of relative basal area. Family says more about how a species occupies the stand structure than about its size.

3.4. Legal Framework and Observed Pressures

Malian forestry law provides explicit instruments for protecting a classified forest, set out in Articles 12, 23, 31, 32–33, 34, 41, 52, 66–67, 84, 112, 113 and 149 of Law No. 10-028 of 12 July 2010, which was amended and strengthened by Ordinance No. 2025-017/PT-RM of 1 April 2025.

Reforestation in Bamako is limited, and seedlings are poorly monitored, which leads to water stress. The effectiveness of surveillance remains to be established, and citizen mobilisation is weak.

4. DISCUSSION

A Low Stand Dominated by Disturbance-Tolerant Species

The Shannon index (H′ = 2.30) places diversity at a moderate level, and evenness (J = 0.71) shows that abundances are unbalanced in favour of a few taxa. The decreasing profile of the Hill numbers (10.0 for exp(H′) and 6.9 for 1/D) indicates that richness rests on many rare taxa, while abundance is concentrated in a few (Hill, 1973). Shannon indices of 2.14 in tree savanna and 1.92 in shrub savanna have been measured in the Tiogo Classified Forest (Konaté et al., 2024); in the Patako Classified Forest (Senegal), the index ranges from 1.24 in shrub savanna to 2.81 in gallery forest, and Pielou's evenness from 0.41 to 0.65 (Sambou, 2017). With H′ = 2.30 and J = 0.71, Koulouba lies in the middle of this range for the Shannon index and above it for evenness: the dominance of a few taxa is therefore less marked than in the Patako savannas, where low diversity is attributed to felling, fuelwood harvesting and overgrazing (Sambou, 2017). These comparisons remain indicative because vegetation types, protocols and sampled areas differ. They also remind us that a diversity index alone says little about the condition of a stand, and that indicators integrating abundance, such as basal area, complement richness (Gosselin, 2012).

The dominance of the Combretaceae, combined with heights of 2 m or less for 59% of individuals, suggests a stand regrowing after repeated disturbance rather than a mature stand. The scarcity of valuable species such as *Khaya senegalensis*, *Prosopis africana* and *Daniellia oliveri* (one to two individuals each) is consistent with selective removal. The inventory recovers only 83.33% of the sampling points, yet it brings together species from several ecological zones (wetland, mountainous and desert zones). The Chao1 estimator (27.1) indicates that the sample captured most of the taxa present in the 15 units, without prejudging the flora of unsampled parts of the forest.

Introduced species represent only 2.3% of individuals, which is favourable. This contrasts with the managed green spaces of Bobo-Dioulasso, where 36 of the 65 recorded species are exotic (Zoungrana *et al*., 2021). The Koulouba forest retains an essentially native woody flora worth preserving. This agrees with the situation in Patako, where the intrusion of exotic species is limited, essentially to *Azadirachta indica* and *Anacardium occidentale* (Sambou, 2017). In Bobo-Dioulasso, the neem, which spreads very easily and spontaneously, is found as much on sacred sites as among roadside trees (Deronzier, 2017); its presence in the Koulouba Classified Forest is therefore likely due to spontaneous dissemination as much as to plantation.

Thin Stems and Basal Area Carried by Few Species

The weighted mean circumference (21.9 cm, i.e. 7 cm equivalent diameter) and the rarity of large stems (3% reach 50 cm or more) confirm, through a second variable, the young or regrowth character of the stand suggested by height. More than half of the individuals belong to species whose mean circumference is below 20 cm, whereas 62% of relative basal area rests on two species, *Vitellaria paradoxa* and *Anogeissus leiocarpa*. This concentration ties a large share of the stand's functions (shade, wood production, carbon storage) to the fate of a very small number of species. The shape of the size distribution, which informs population dynamics and notably the presence of a reverse-J structure (Condit *et al.,* 1998), can however be established only with individual measurements. In the Banco National Park, an urban forest of Abidjan, the most represented stems are also the youngest, and the degraded formation is distinguished by affected basal area, richness and diversity and by a higher proportion of pioneer species (Gnahoré, 2021).

Height–Circumference Allometry Close to Theory

The exponent of 0.56 (95% CI 0.44–0.66) is close to, without reaching, the value of 2/3 predicted by the elastic similarity model of trees (McMahon and Kronauer, 1976) and by the vascular network model (West *et al*., 1999). The discrepancy is moderate; it remains compatible with height growth limited by seasonal drought and fire in the largest species, a hypothesis that only individual measurements can test. It must above all be stressed that this allometry is interspecific: it compares species means and does not describe the growth of an individual. Height–diameter relationships also vary with climate (rainfall variability, length of the dry season) and with stand basal area (Feldpausch *et al.,* 2011); an equation established elsewhere therefore cannot be transferred to Koulouba without caution, and a local equation will be

needed to estimate biomass (Chave *et al*., 2014). Among the species deviating from the relationship, *Azadirachta indica*, an introduced species, is 1.8 times taller than expected for its circumference: rapid growth of planted, closely spaced individuals would be compatible with this slender profile, although the data do not allow this to be verified.

The Role of Family

The numerical dominance of the Combretaceae (46%) rests on small, shrubby species (*Combretum micranthum*, *C. ghasalense*, *Guiera senegalensis*; Arbonnier, 2009), whereas *Anogeissus leiocarpa*, of the same family, reaches 7 m and 33 cm in circumference. Likewise, the Fabaceae combine a very abundant shrub (*Senegalia macrostachya*) with some of the thickest stems inventoried (*Prosopis africana*, *Pterocarpus lucens*). Family therefore does not predict species size by itself, as confirmed by the absence of a significant height difference among families, subject to the low power of the tests. Its role is mainly structural: the Combretaceae dominate by number, the Sapotaceae by basal area. The dominance of the Combretaceae is a feature of the Sudano-Sahelian woody flora. In Patako, the family comprises 11 species, of which *Combretum glutinosum* is by far the most abundant, and this dominance largely explains the high importance-value indices in savanna (Sambou, 2017). The Koulouba Classified Forest thus fits a regional pattern, with the particularity of a basal area carried by shea (*Vitellaria paradoxa*). The distinction has practical relevance because wood density, which directly enters biomass and carbon estimation (Chave *et al.,* 2009, 2014), varies strongly among species.

The negative correlation between abundance and circumference ($\rho = -0.67$) means that abundant species are thin-stemmed, whereas large-stemmed species are rare (*Prosopis africana*, *Pterocarpus lucens*). Two readings are possible: a natural structure in which regrowth shrubs outnumber large trees, or selective removal of large individuals of species with valuable wood.

Stump sprouting is an important mode of stand reconstitution in Sudanian woodlands, and its vigour depends on fire and grazing (Dayamba *et al*., 2011); regeneration of the Combretaceae combines seedlings, sprouts and root suckers in proportions that vary with species and latitude (Bognounou *et al*., 2010). In the Banco National Park, the diameter structure is likewise dominated by regeneration stems (Gnahoré, 2021), and natural regeneration density ranges from 784 individuals per hectare in shrub savanna to 3,870 in gallery forest (Sambou, 2017).

The two introduced species, *Eucalyptus camaldulensis* and *Azadirachta indica* (2.3% of individuals), account for about 9% of relative basal area, of which 8% for *Eucalyptus* alone. Combined with species wood densities, these measurements would make it possible to estimate aboveground biomass with the equations of Chave *et al*., (2014) and to compare Koulouba with the Tiogo Classified Forest (Burkina Faso), where aboveground woody carbon potential decreased by 41% in thirty years (Konaté *et al*., 2024). Carbon stock depends on stand age and on the species retained: carbon in woody biomass rises from 80.25 tC/ha in 4–8-year-old fallows to 256.5 tC/ha in 14–24-year-old fallows, but remains far below that of forests (449.5 tC/ha in gallery forest; 1,335.25 tC/ha in forest on ferralitic soil) (Adingra and Kassi, 2016).

Management Prospects

The prospects below respond to the challenges identified. Urban forestry approaches recommend integrating the forest into urban planning and involving local stakeholders in its management (Salbitano *et al*., 2016). Accordingly, we propose to:

1. Secure the forest footprint in cooperation with the Water and Forests Service, the Land and Cadastre Services and the District City Hall;
2. Adopt a concerted management approach through the implementation of a management plan involving the Regional Directorate of Water and Forests, municipalities and civil society;
3. Value forest resources and services by measuring stored carbon and the cooling effect observed elsewhere in green infrastructure (Zoungrana *et al*., 2021); and
4. Promote educational and sporting uses.

5. CONCLUSION

The Koulouba Classified Forest, the second classified forest of the country, is under pressure from a city whose built-up area rose from 54% to 75% of the territory in thirty years, at the cost of a 58% loss of the district's vegetation cover. Its woody stratum, composed of 434 individuals and 26 taxa, is poorly balanced ($J = 0.71$), 79% dominated by five species and made up mostly of small, thin-stemmed individuals (weighted mean circumference of 22 cm; only 3% of individuals at 50 cm or more), with relative basal area resting for 62% on two species, *Vitellaria paradoxa* and *Anogeissus leiocarpa*. Nine of 25 species, including *Khaya senegalensis* and *Daniellia oliveri*, are represented only by regeneration individuals (10% of individuals), which calls for monitoring of their survival and of the presence of seed trees. The 1935 classification has not prevented encroachment on 45% of the forest's footprint, although Law No. 10-028 prohibits occupation and organises eviction. This indicates that the main obstacle to conservation lies in the enforcement of the law rather than its absence, although enforcement could not be monitored directly; citizen mobilisation is, moreover, weak at district scale. Securing land tenure through enforcement of existing law, effective surveillance, enrichment with valuable

native species, and shared management with local authorities, nurseries, and residents are the priority levers. Four lines of work are needed to consolidate these results: a precise survey of the current boundaries, permanent plots for dendrometric monitoring and regeneration, monitoring of law enforcement (reports, evictions, declassifications), and a survey focused on the users and managers of the Koulouba Classified Forest.

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