

Article de recherche

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State of the demographic structure of *Mitragyna inermis* (willd.) k. schum. stands, in a context of high demand for wood energy in the southern zone of the Zio river watershed (TOGO)

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ملخص

تحتضن منطقة الجنوبية من حوض نهر زيو تنوعًا بيولوجيًا غنيًا، بما في ذلك نوع *Mitragyna inermis* ذو الأهمية البيئية والاجتماعية الاقتصادية في توغو. تقم هذه الدراسة حالة مجتمعاتها تحت الضغوط البشرية، بما في ذلك الطلب الكبير على حطب الوقود، من خلال تحليل هيكلهم السكاني وقدرتهم على التجدد. أظهر مسح نباتي وجود 120 نوعًا (112 جنسًا، 51 عائلة) في 36 مكنًا بمساحة 30 × 30 مترًا. أبرزت النماذج الاسترجاعية ترابطات بين قطر وارتفاع وغطاء مجتمعات *M. inermis*. كشفت الدراسات الاجتماعية والاقتصادية استخدامات متنوعة: الطب التقليدي (70.08%)، العلف (77.68%)، حطب الوقود (91.37%)، الخشب (84.52%)، والحرف اليدوية (57.64%). يُرجع تدهور النوع في المقام الأول إلى تدمير المواطن الحيوية (41%)، والاستغلال المفرط (26%)، والرعي المفرط (17%)، وتغيرات استخدام الأراضي (9%). على الرغم من أهميتها للسكان المحليين، إلا أن *M. inermis* تتطلب تدابير وقائية لضمان استدامتها واستدامة موطنها.

كلمات مفتاحية: حوض نهر، كتلة حيوية، حطب وقود، *Mitragyna inermis*، توغو.

Abstract

The southern watershed area of the Zio River basin harbors rich biodiversity, including *Mitragyna inermis*, a species of ecological and socio-economic importance in Togo. This study assesses the status of its populations under anthropogenic pressure, particularly high demand for fuelwood, by analyzing their demographic structure and regeneration capacity. A floristic inventory identified 120 species (112 genera, 51 families) in 36 plots of 30 × 30 m. Regression models highlighted correlations between diameter, height, and canopy of *M. inermis* populations. Socio-economic surveys revealed diverse uses: traditional medicine (70.08%), fodder (77.68%), fuelwood (91.37%), timber (84.52%), and handicrafts (57.64%). Species degradation is primarily attributed to habitat destruction (41%), overexploitation (26%), overgrazing (17%), and land use changes (9%). Despite its importance to local populations, *M. inermis* requires protective measures to ensure its sustainability and that of its habitat.

Keywords: watershed, biomass, fuelwood, *Mitragyna inermis*, Togo.

Résumé

La zone sud du bassin versant du fleuve Zio abrite une biodiversité riche, incluant *Mitragyna inermis*, une espèce d'importance écologique et socio-économique au Togo. Cette étude évalue l'état de ses peuplements face à la pression anthropique, notamment la forte demande en bois énergie, en analysant leur structure démographique et leur capacité de régénération. Un inventaire floristique a recensé 120 espèces (112 genres, 51 familles) dans 36 placettes de 30 × 30 m. Des modèles de régression ont mis en évidence des corrélations entre le diamètre, la hauteur et le houppier des peuplements de *M. inermis*. Les enquêtes socio-économiques révèlent ses usages variés : médecine traditionnelle (70,08 %), fourrage (77,68 %), bois de chauffe (91,37 %), bois d'œuvre (84,52 %) et artisanat (57,64 %). La dégradation de l'espèce est principalement due à la destruction des habitats (41 %), la surexploitation (26 %), le surpâturage (17 %) et les changements d'usage des terres (9 %). Malgré son importance pour les populations locales, *M. inermis* nécessite des mesures de protection pour assurer sa pérennité et celle de son habitat.

Mots clés : bassin versant, biomasse, bois énergie, *Mitragyna inermis*, Togo.

1. Introduction

Tropical forests, beyond being reservoirs of biodiversity, are now recognized as crucial carbon sinks in the fight against climate change (Moumouni et al., 2017). They provide essential ecosystem services, including biodiversity conservation, climate regulation, soil and water protection, air purification, and poverty alleviation (Hounkpèvi et al., 2011; Assogba et al., 2017). Globally, tropical forests supply 70% of wood energy and less than 20% of industrial timber (280 million cubic meters) (Mondiale, 2011; Padonou et al., 2023).

In sub-Saharan Africa, wood energy accounts for over 80% of domestic energy consumption, primarily for cooking, due to its affordability compared to other energy sources (Mallet, 2009). However, increasing demand has led to overexploitation of biodiversity and ecosystem services, contributing to ecological imbalances (Millennium Ecosystem Assessment, 2005). Africa's energy metabolism remains low, relying mainly on renewable sources such as wood. Nearly 90% of wood removals come from forests, plantations, agroforests, savannahs, and isolated trees (Peltier & Montagne, 1997; Bertrand & Montagne, 2009; Mallet, 2009). Despite its critical role, wood energy is often blamed for deforestation and forest degradation.

Mitragyna inermis, a woody species of the Rubiaceae family, is widespread in wetlands and gallery forests of West Africa. It plays a key ecological role and is widely used for firewood, construction, and traditional medicine (Mallet, 2009; Padonou et al., 2023). In Togo, it is known under various local names, including dikprigan (Lamba), yéluwum (Moba), leppati/lèti (Ewé), and linkpa/elin (Mina) (Akpagana et al., 1986; Millennium Ecosystem Assessment, 2005). Its ecological and pharmacological properties make it increasingly important, particularly in the southern Zio River watershed. As a primary source of fuelwood, demand for *M. inermis* is driven by traditional consumption practices (Mallet, 2009). Its ability to reach 16 meters in height and thrive in humid tropical biomes gives it significant ecological and economic value (Mondiale, 2011; Padonou et al., 2023).

The demographic structure of *M. inermis* populations is influenced by several factors, particularly

the high demand for fuelwood in the southern Zio River watershed. Studies indicate that this species accounts for approximately 88.39% of fuelwood sources in the region (Peltier & Montagne, 1997). Overexploitation, coupled with poor land management and climate change, threatens its sustainability (Peltier & Montagne, 1997; Cédessia et al., 2019). This raises concerns about biodiversity conservation and forest ecosystem stability, already under pressure from deforestation and human activities (Dossou et al., 2012; Cédessia et al., 2019).

A comprehensive assessment of the demographic structure of *M. inermis* is essential for sustainable forest resource management, balancing ecological preservation with the growing energy needs of local communities.

This study aims to evaluate the current status of *M. inermis* populations in light of increasing fuelwood demand, highlighting the ecological and societal implications of its exploitation.

2. Materials and methods

2.1. Environment of study

The Zio watershed drains a narrow area of approximately 3,400 km², oriented NNW-SSE between latitudes 6°5'N and 7°18'N and longitudes 0°15'E and 1°40'E (Figure 1). It extends across three ecological zones: ecological zone V, characterized by a wooded or shrubby savannah landscape in the south; ecological zone III, featuring a wooded savannah and gallery forest landscape in the central part, around Méssiobé and Kati; and ecological zone IV, covering a large portion of the northern area, which is dominated by forest landscapes and numerous tributaries (Tampo et al., 2015). The study was conducted in the southern part of Togo, specifically in the Maritime region. The physical and agroecological parameters are representative of this region, with altitudes ranging between 200 and 400 meters (Blivi, 1993).

The basin is part of the vast southern Precambrian peneplains of the country. The region experiences a tropical Guinean subequatorial climate with

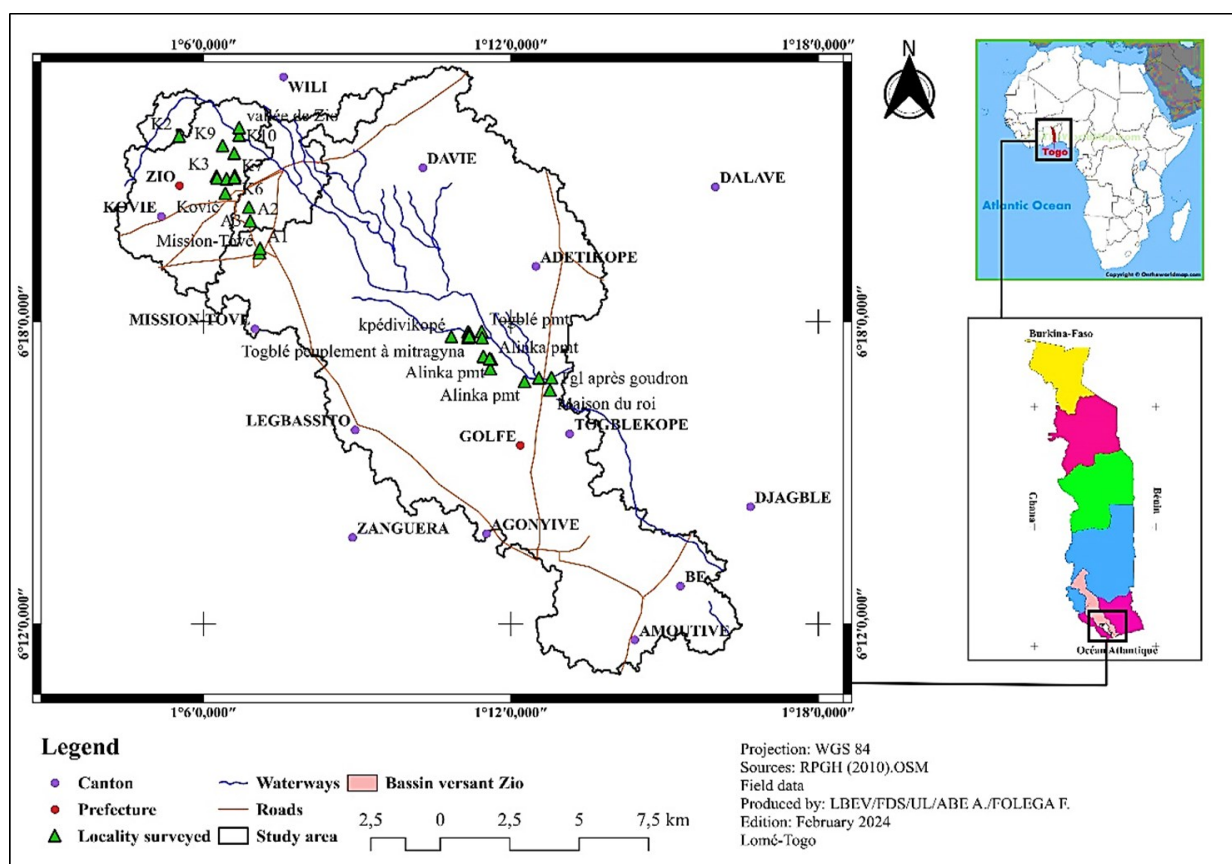


Figure 1. Location of the Zio micro-basin in southern Togo

four distinct seasons and two variants: the Guinean mountain type, which is the rainiest, with an annual precipitation of approximately 1,600 mm, and the Guinean plain type, which is less rainy, with annual precipitation ranging from 1,000 to 1,300 mm (Seou et al., 2022). The average temperature is 27 °C, with an annual precipitation of 900 mm. The vegetation is a mosaic of forests and savannahs, gradually transitioning from forested areas in the north of the basin to wooded and shrubby savannahs in the south.

2.2. Data collection

2.2.1. Forest sampling and inventory

The forest inventory was conducted in Kovie, within the Zio basin. A stratified random sampling approach was adopted, a statistical method designed to improve data representativeness by dividing the

population (or study area) into homogeneous sub-groups, known as strata. Within each stratum, samples were randomly selected. The study considered plots representative of different stand types of *M. inermis* (Figure 2).

The sampling units consisted of 30 m × 30 m plots (900 m²) to measure various dendrometric parameters for stands composed of woody plants with a diameter at breast height (DBH) ≥ 20 cm. In addition to DBH, the following parameters were assessed: tree diameter, height, total height, crown diameter (both NS and E-W), and wood health status. Diameter measurements were taken using a pi tape at DBH.

2.2.2. Phytosociological inventory

A floristic inventory was conducted to identify all woody species present in the plots and herbaceous

species in the subplots. Each species was assigned an abundance and dominance coefficient following Braun-Blanquet's methodology (Braun-Blanquet, 1932). These coefficients are widely used in vegetation studies across West Africa (Woegan et al., 2013; Fousseni, 2023). Species identification and nomenclature followed the analytical floras of Togo (Brunel et al., 1984) and Benin (Akoègninou et al., 2006).

2.2.3. Ecological inventories

The ecological inventory was conducted alongside the floristic inventory in each plot. Ecological indicators recorded included formation types, fire incidence, degree of canopy closure, proximity to watercourses, stand density, soil texture, signs of erosion, and human activities (e.g., presence of charcoal production sites, ox passages, wood cutting). Additionally, the presence of pyrophytic species and dominant species was noted (Folega et al., 2022; Fousseni, 2023).

2.2.4. Socio-economic surveys

Surveys on the exploitation practices of *M. inermis*

and the demand for wood energy were conducted among local populations. These surveys aimed to assess local knowledge regarding the management of this species. The survey methodology consisted of semi-structured interviews with woodcutters, farmers, community leaders, and users of wood energy. A total of 46 respondents, randomly selected within the Zio prefecture, participated in the study.

2.3. Data processing and analysis

2.3.1. Flora and forest inventory data

The collected data were entered into a Microsoft Excel spreadsheet and analyzed using SPSS statistical software (Table 1). The analysis focused on a structural assessment to examine both the floristic structure and the spatial structure of the stand, providing insights into species composition and exploitation potential (e.g., density, canopy coverage, carrying capacity) (Table 2).

The analysis involved listing the recorded species and classifying them by family and genus. The biological and phytogeographic types of these species were determined based on reference docu-

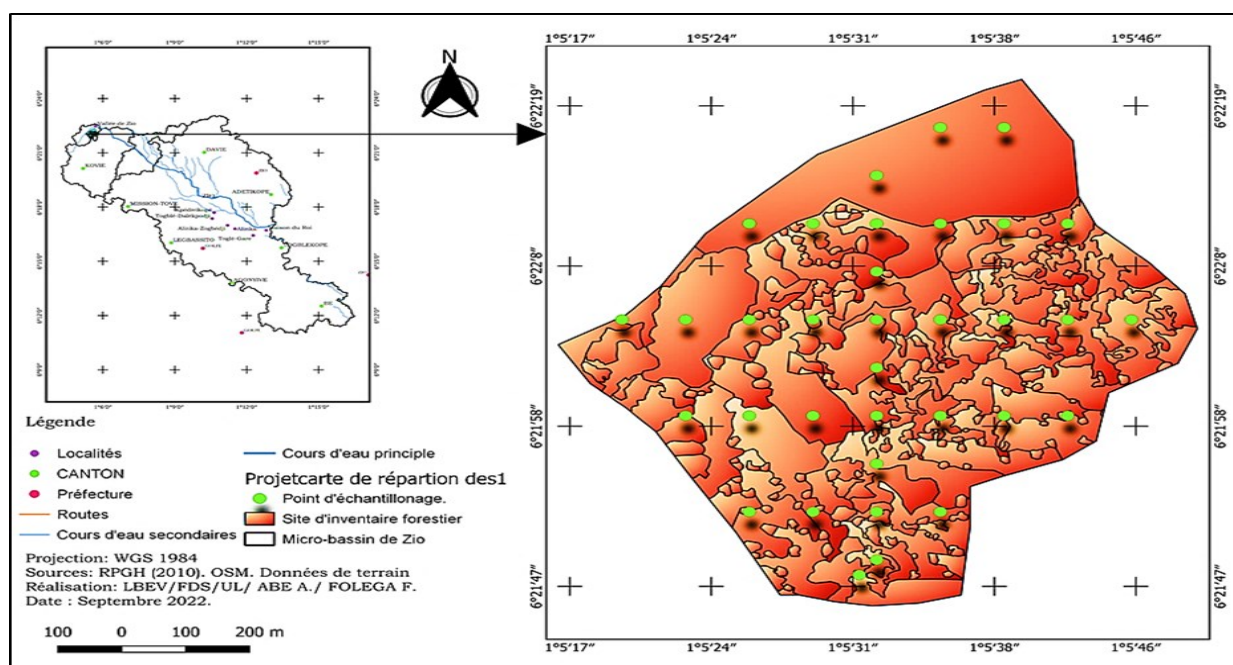


Figure 2. Sampling plan of the study area

Table 1. Statistical parameters

Parameters	Formulas	Sources
Diameter	$D_{1.30} = \frac{C_{1.30m}}{\pi}$	Folega et al., 2022; Karimi et al., 2004
Average Diameter	$Dm = \frac{1}{n} \sum_{i=1}^n Di$	Karimi et al., 2004; Rajoelison et al., 2008
Average Height	$Hm = \frac{1}{n} \sum_{i=1}^n hi$	Karimi et al., 2004; Rajoelison et al., 2008

$D_{1.30}$: diameter at 1.30 meters from the ground (cm), $C_{1.30}$: circumference at 1.30 meters from the ground (cm), Dm : average diameter (cm), n : number of individuals counted by statement, Di : individual diameter at 1.30m from the ground (cm), Hm : average height of individuals (m), hi : individual height (m).

Table 2. Statistical parameters according to the spatial structure

Parameters	Formulas	Sources
Basal area	$G = \frac{\sum_{i=1}^n gi}{S} = \frac{\pi}{4S} \sum_{i=1}^n 0.0001 di^2$	Karimi et al., 2004
Coefficient of slenderness	$CE = \frac{H_{total}}{D_{1.30m}}$	Rajoelison et al., 2008
Density	$D = \frac{n}{S} \times 0.0001$	Melesse & Jordan, 2002
Shannon-Weaver Diversity Index	$H = - \sum_{i=1}^n Pi \cdot \log_2 Pi$	Souley et al., 2018
Pielou Equity Index	$E(\text{bit}) = \frac{H}{H_{max}}, \text{ and } H_{max} = H' = \log_2 S$	Souley et al., 2018
Regeneration rate (Tx)	$T(x) = \left[\frac{n}{(N+n)} \right] 100$	Bawa et al., 2022
Crown (hp)	$\frac{[Crown(N-S) + Crown(E-O)]}{2}$	Bawa et al., 2022

G : basal area (m²/ha), n : total number of individuals per survey, gi : individual basal area (m²), S : the survey area in hectares, di : individual diameter at 1.30m from the ground (cm), CE : slenderness coefficient, H_{total} : total height of individuals (m), $D_{1.30}$: diameter at 1.30 m from the ground (cm), D : diameter (cm), H : height (m), Pi : relative proportion of species i ($pi = ni/N$), $E(\text{bit})$: shannon fairness index expressed in bits, H_{max} : maximum diversity possible for a sample ($H_{max} = \log_2 S$, S being the total specific richness), N : total number of species recorded, $Crown(N-S)$: diameter of the crown measured in the North-South axis (m), $Crown(E-O)$: diameter of the crown measured in the East-West axis (m).

Table 3. Calculation of usage indices

Calculated Values	Formulas	Sources
Citation frequency of plant species (F)	$F = \frac{n}{N} \times 100$	(Gomez-Beloz, 2002; Zabouh et al., 2018)
Reported Use (NUsp)	$NU_{sp} = \sum_{i=1}^n NU_{organe}$	(Gomez-Beloz, 2002; Zabouh et al., 2018)

F : frequency of citation of a species (%), *n* : number of respondents who cited the species, *N* : total number of respondents , *NUsp* : number number of species usage , *NUorgane* :number of citations for a specific plant organ.

ments (White, 1986; Fousseni, 2023). A "Records × Species" matrix was then established based on abundance and dominance using the Braun-Blanquet scale (Braun-Blanquet, 1932). This matrix was subjected to hierarchical clustering following Ward's method using Community Analysis Package (CAP, 2015) software (Martin & Blackburn, 2012).

2.3.2. Survey data

All data collected during the study, including information from surveys, were compiled to produce a synthesized analysis. Microsoft Excel® (2016) was used for descriptive data processing.

The survey data enabled an evaluation of the different usage categories of *M. inermis* and helped determine its utilization value (Table 3). The processing of the collected data involved calculating various indices of plant usage.

3. Results

3.1. Characteristics of the structural diversity of *M. inermis* populations

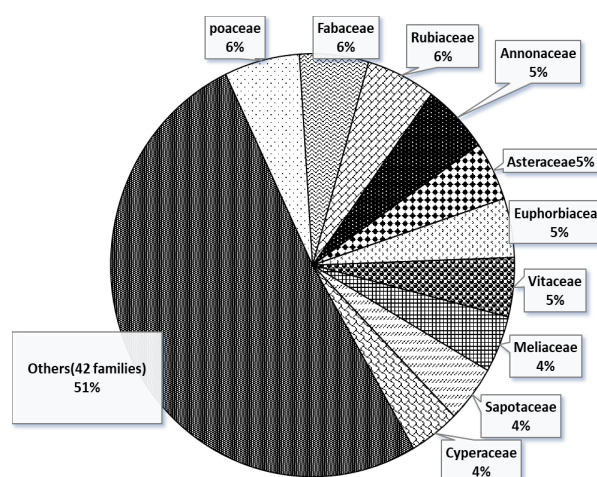
3.1.1. Floristic balance sheet

At the end of the floristic inventory, a total of 120 species were identified, divided into 112 genera and 51 families. The families with high specific richness (Figure 3) are: Poaceae (6%), followed by Fabaceae (6%), Rubiaceae (6%), Annonaceae (5%), Asteraceae (5%), Euphorbiaceae (5%), Vitaceae (5%), Meliaceae (4%), Sapotaceae (4%), and Cyperaceae (4.81%) (4 species).

Figure 4 shows the rank-frequency curve, and

its analysis reveals that the distribution of species according to their frequencies follows a logarithmic regression of the equation $y = -0.941 \ln(x) + 4.4227$, with a very high correlation coefficient ($R^2 = 0.9493$).

The biological spectrum of the floristic potential in Figure 5 shows a dominance of hemicryptophytes (14.93%), followed by meso-phanerophytes (14.93%), nano-phanerophytes (14.10%), nano-phanerophyte vines (13.69%), geophytes (12.44%), therophytes (12.03%), chamaephytes, meso-phanerophyte vines, mega-phanerophytes, epiphytes, and meso-phanerophyte vines, which are relatively underrepresented with rates of 8.29%, 3.73%, 3.31%, 1.24%, and 1.24%, respectively, in this gallery zone.

**Figure 3.** Specific spectrum of families

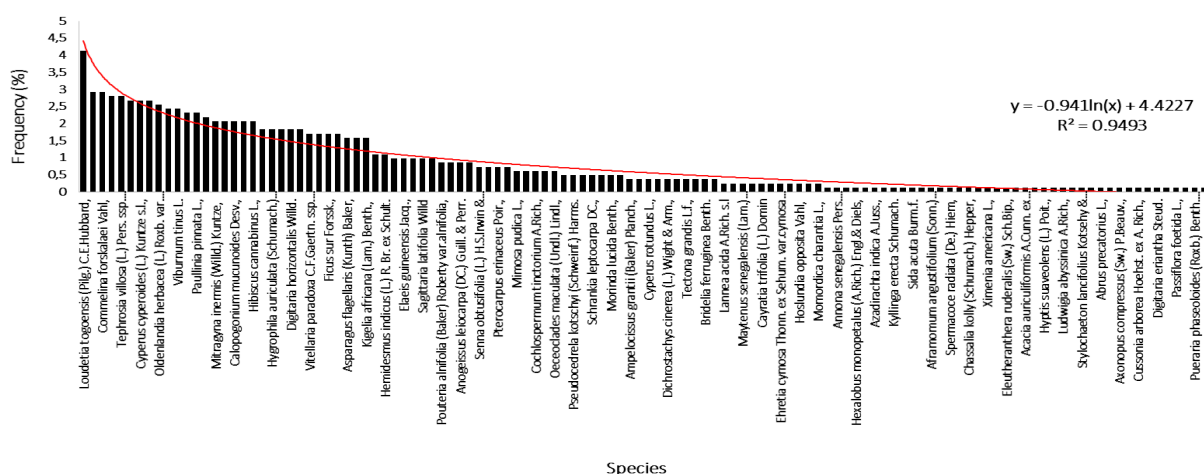


Figure 4. Species rank-frequency curve

The phytogeographic spectrum (Figure 6) shows a dominance of Sudano-Zambézian species (13.20%), followed by Guinean-Congolese species (12.6%), Afro-tropical species (10.8%), African pluriregional species (10.2%), pantropical species (9.9%), species found in both the Guinean-Congolese and Sudano-Zambézian zones (9.31%), Sudano-Guinean species (8.11%), Afro-Asian species (6.6%), paleotropical species (6.01%), cosmopolitan species (5.11%), species native to America (2.4%), species endemic to Dahomey (2.1%), introduced species (1.2%), Afro-American species (0.9%), Afro-Malagasy species (0.9%), and Sudanian species (0.6%).

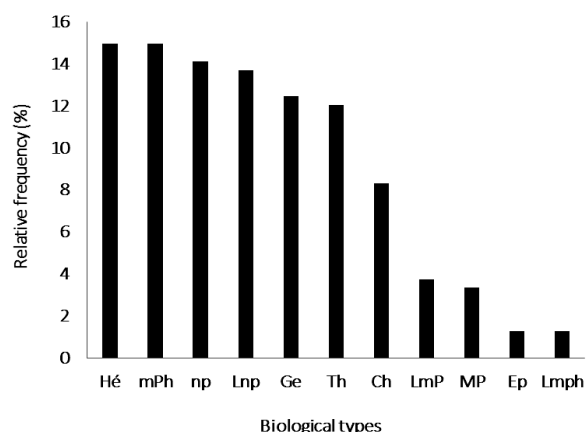


Figure 5. Biological spectra of all species recorded

3.1.2. Typology of plant formations in the Zio Watershed

Ward's method enabled the discrimination of two (2) major groupings of floristic surveys (GI, GII). The GI group corresponds to the plant groups of dry land, while the GII group corresponds to the plant groups of wetlands. These major groups are subdivided into subgroups: GIa, GIb, and GII, based on floristic similarity, vegetation types, and anthropogenic activities. The results are presented in the form of tables and figures, accessible at the end of the document (Table 4 and Figure 7).

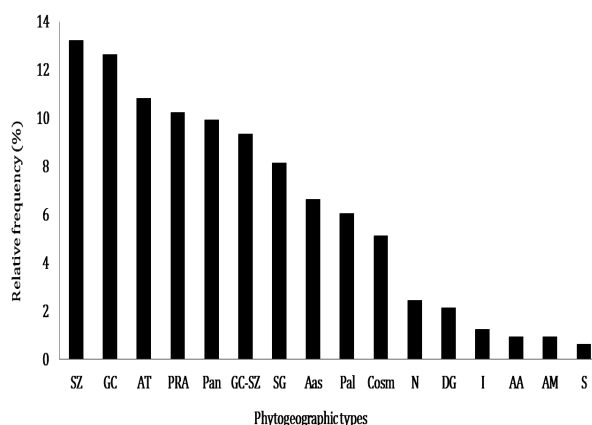


Figure 6. Phytogeographic spectrum of all species recorded

Table 4. Floristic diversity and structural characteristics of plant groups

Groupings	Average density (plants/ha)	Average diameter (cm)	Average height (m)	Basal area (m ² / ha)	Regeneration rate (%)
G1a	91.6	21.41	4.53	90.75	77.5
G1b	88.8	22.12	4.99	65.5	76.5
GII	168.33	22.71	5.48	46.2	80.87

3.1.3. *Zanthoxylum zanthoxyloides* and *Entada africana* shrub savannas (G1a)

The G1a subgroup comprises 18 surveys. These surveys were conducted on plots with an average slope that promotes runoff from the plateaus to the vegetation zone. The soil has a clayey-limino-sandy texture but is low in organic matter. The specific richness includes 25 woody species belonging to 23 genera and 11 families. Fabaceae (8 species), followed by Rubiaceae (3 species), Meliaceae (2 species), Annonaceae (2 species), Verbenaceae (2 species), Moraceae (2 species), Anacardiaceae (2 species), and Rutaceae (1 species) are the most represented families. The five (6) most remarkable species based on their frequency of importance index are: *Zanthoxylum zanthoxyloides* (L.) Zepernick & Timler, *Azadirachta indica* A.Juss., *Entada*

africana Guill. & Perr., *Terminalia avicennioides* Guill. & Perr., *Lannea acida* A.Rich., and *Sarcocephalus latifolius* (Sm.) E.A.Bruce. The average diameter is 21.41 cm, with an average total height of 4.53 m and a basal area of 9.075 m²/ha. The average density is 91.6 plants/ha. The regeneration rate of this group is 77.5%. The most dominant regeneration mode is suckering, as indicated in Table 4 and Figure 7.

3.1.4. Wooded and shrubby savannas of *Lannea acida* and *Millettia thonningii* (G1b)

This subgroup includes 11 records. The specific richness comprises 18 woody species belonging to 17 genera and 9 families. The most represented families are Fabaceae (4 species) and Rubiaceae (4 species), followed by Anacardiaceae and Meliaceae

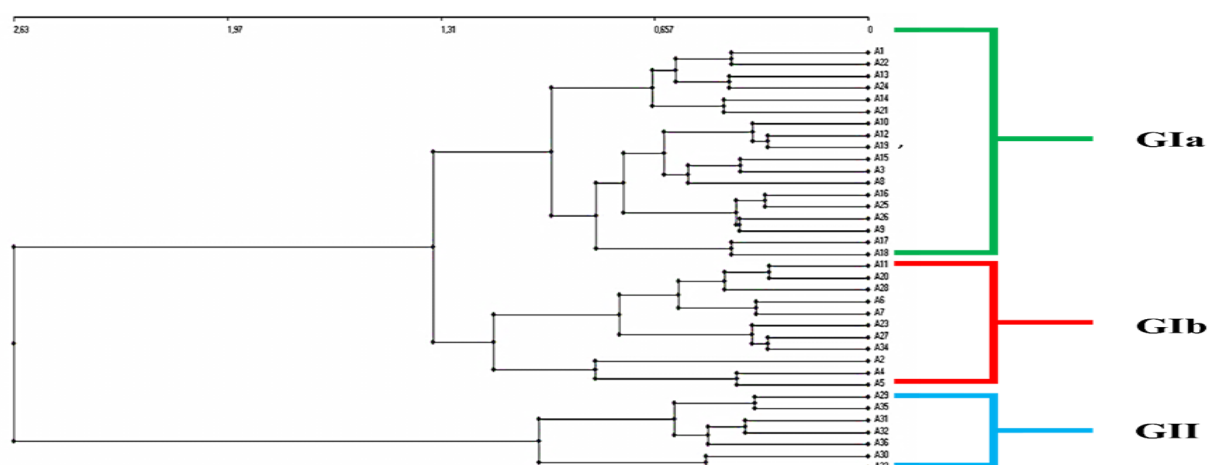


Figure 7. Ascending hierarchical classification of the 36 surveys. The G1 group is subdivided into two groupings, a *Zanthoxylum* group *zanthoxyloides* and *Entada africana* (G1a) and another in *Lannea acida* and *Millettia thonningii* (G1b). The group (GII), group in *M. inermis* and *Lonchocarpus sericeus*.

(2 species each). According to the frequency index of importance, *M. inermis* (Willd.) Kuntze, *Lonchocarpus sericeus* (Poir.) Kunth, *Lannea acida* A.Rich., and *Millettia thonningii* (Schumach. & Thonn.) are the species with the highest frequency indices and are therefore characteristic. The average diameter is 22.12 cm, with an average height of 4.99 m and a basal area of 6.55 m²/ha. The average density is 88.8 plants/ha. The regeneration rate of this group is 76.5%. The most dominant regeneration mode is suckering (Table 4 and Figure 7).

3.1.5. Wooded and shrubby savannahs of *M. inermis* and *Lonchocarpus sericeus* (GII)

This subgroup includes 7 surveys. These surveys were conducted on plots with irregular geomorphology, consisting of hollows and bumps. The soil has a clayey-sandy texture with a good representation of herbaceous plants. The specific richness includes 6 woody species belonging to 6 genera and 5 families. Fabaceae and Rubiaceae (2 species each) are the most represented. According to the frequency of importance index, Rubiaceae is the most important family. *Lonchocarpus sericeus* (Poir.) Kunth and *M. inermis* (Willd.) Kuntze are the species with the highest frequency indices and are therefore characteristic. The average diameter is 22.71 cm, with an average height of 5.48 m and a basal area of 4.62 m²/ha. The average density is 168.33 plants/ha. The regeneration rate of this group is 80.87%. The most dominant regeneration mode is suckering (Table 4 and Figure 7).

3.1.6. Demographic structure of woody stands

The analysis of structural characteristics shows that the highest average density (168.33 plants/ha) of woody plants is found in the grouping of *M. inermis* and *Lonchocarpus sericeus* (GII), with an estimated average diameter of 22.71 cm (Table 4). This group also records the greatest average height of woody plants, estimated at 5.48 m, with the highest regeneration rate (80.87%).

The distribution of individuals by diameter classes (Figure 8) has an "L" shape in the 3 groups. In general, the woody plants inventoried have a diameter between 10 and 40 cm. In the *Zanthoxylum zanthoxyloides* and *Entada africana* group (GIa), the woody plants in this group have a diame-

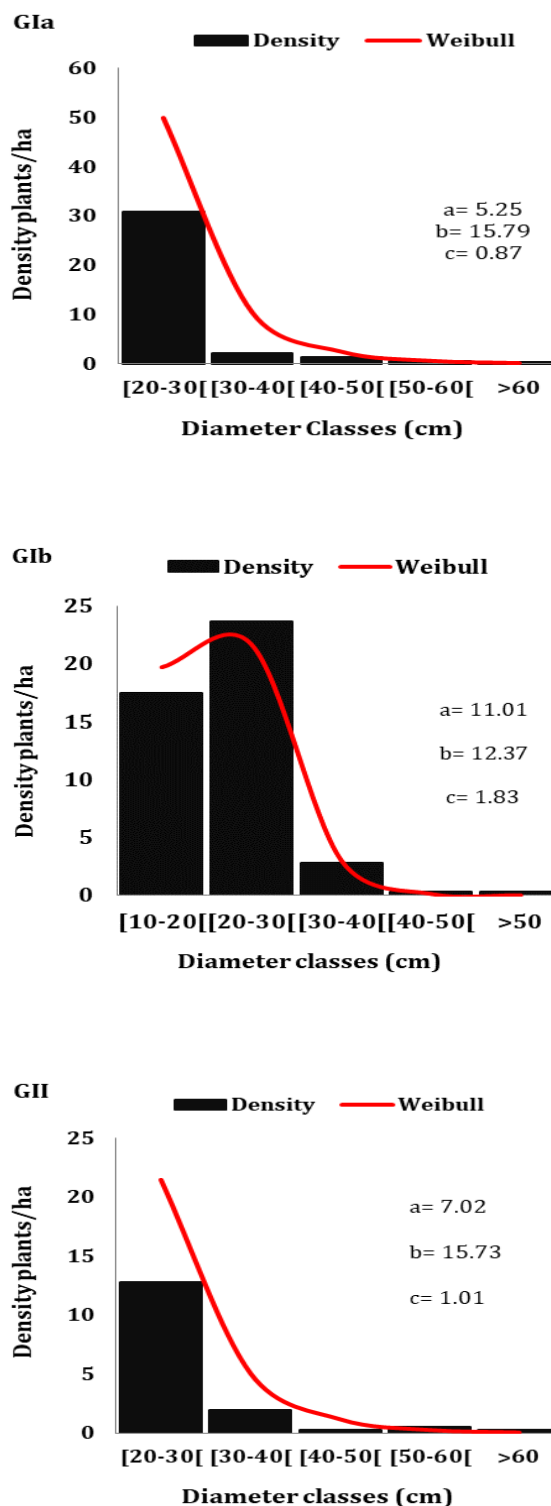


Figure 8. Distribution of diameter classes GIa, GIb and GII

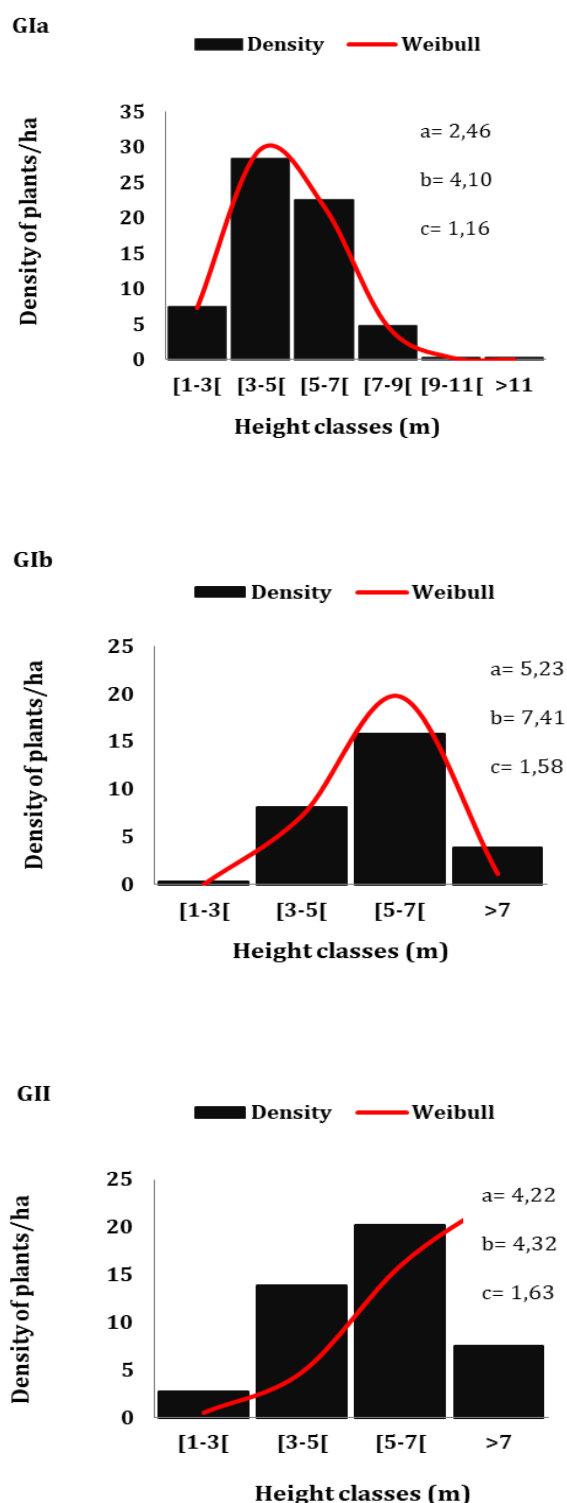


Figure 9. Distribution of height classes GIa, GIb and GII

ter between 10 and 40 cm. However, this group shows some individuals with a diameter greater than 50 cm. The diameter class of 10 to 40 cm is also observed in the *Lannea acida* and *Millettia thonningii* group (GIb). In the GII group, individuals have a diameter of less than 50 cm. This is the *M. inermis* and *Lonchocarpus sericeus* group.

The distribution of individuals by height classes (Figure 9) has an "L" shape in the grouping of *Lannea acida* and *Millettia thonningii* (GIb). In this group, individuals with a height of less than 10 m are the most represented. In the *Zanthoxylum zanthoxyloides* and *Entada africana* group (GIa), and in the *M. inermis* and *Lonchocarpus sericeus* group (GII), the distribution of individuals by height classes has a bell-shaped curve. This type of distribution indicates a high proportion of individuals of average height (3-7 m) and a low proportion of individuals of small height (1-3 m) and large height (>11 m in the GIa group and >7 m in the GII group).

3.1.7. Correlations between different structural parameters

The study of correlations highlights relationships between the dendrometric characteristics of the subjects studied and reveals the behavior of trees in response to biotic and abiotic environmental factors. The growth relationship between height and diameter is expressed by a linear function with the equation: $y = 0.0328x + 5.1929$, with $R^2 = 0.0411$, as indicated in Table 5 and Figure 10.

The graph indicating this growth relationship shows that the majority of the adult woody plants inventoried have a diameter of less than 30 cm. Below this diameter, the predominance of trees with small diameters does not allow a clear relationship to be deduced between these two parameters. This part of the correlation curve corresponds to the phase of free aerial development of young trees (Figure 10).

This graph also shows that tree height growth tends to stabilize around 8 m. The relationship between crown diameter and tree diameter is expressed by a linear function with the equation: $y = 0.0533x + 1.707$ (D expressing the diameter at 1.30 m), with $R^2 = 0.13$ (Table 5, Figure 11). This graph shows that the average crown diameter stabilizes around 5 m. The relationship between these two parameters is not clear enough, likely due to the

Table 5. Correlations between the different structural parameters

Structural parameters	Average diameter of the crown	Average diameter of the tree at 1.30 meters from the ground	Average total height
Young stand	2.67 ± 0.021	17.88 ± 0.13	5.80 ± 0.13
Mature stand	3.11 ± 0.020	26.66 ± 0.019	6.04 ± 0.019

predominance of small diameters in the stand and overgrazing. A linear function with the equation: $y = 0.3434x + 0.8763$, with $R^2 = 0.15$ (Table 5, Figure 12), expresses the relationship between crown diameter and total tree height.

3.1.8. Characteristics of the stability of stands in *M. inermis*

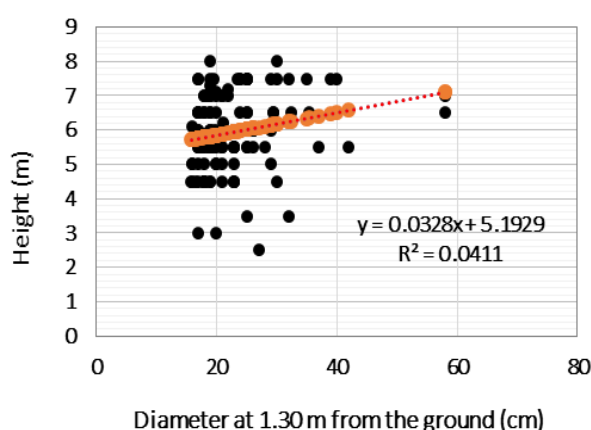
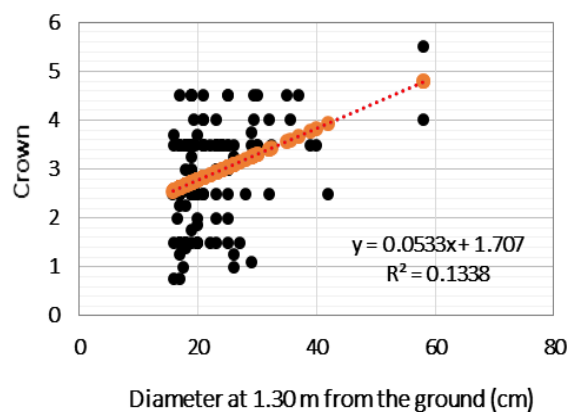
Stand stability is assessed based on the average slenderness coefficient of the stand. The analyses show that in compartment A, the coefficient (CE) is equivalent to $74.63 < 100$, indicating that trees with large diameters and considerable height on the site are very stable and resistant to disturbances. However, CE is $102.02 > 100$ in compartment B, indicating that the stands in this compartment are unstable. Ultimately, young stands are unstable and therefore fragile to anthropogenic disturbances (Table 6).

3.2. Different categories of use of *M. inermis*

At the end of the investigation, it appears that the species *M. inermis* provides rural populations with various goods and services. According to all the areas surveyed, *M. inermis* is used in different categories: pharmacopoeia (70.08%), fodder (77.68%) (the species is heavily consumed by animals), service wood (84.52%), firewood (91.33%) by local populations (Figure 13). It is also used as timber for making furniture (57.64%).

3.2.1. Perception of conservation threats to *M. inermis*

Data analysis reveals ongoing threats to the conservation of *M. inermis*. These include habitat destruction (41%), which is very clearly perceived by local populations, followed by overexploitation, particularly excessive wood harvesting (26%). The

**Figure 10.** Linear regression of height growth as a function of diameter**Figure 11.** Linear regression of crown growth as a function of diameter

third significant factor concerns overgrazing (17%), followed by changes in land use patterns (9%) (Figure 14). The remaining factors, such as fire and invasive species, are negligible (7%) com-

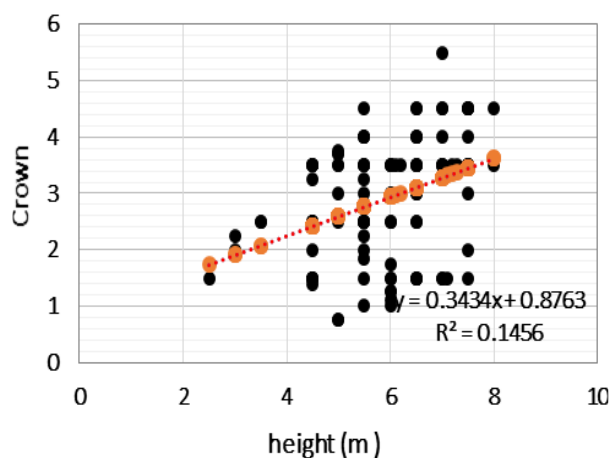


Figure 12. Linear regression of height growth as a function of crown

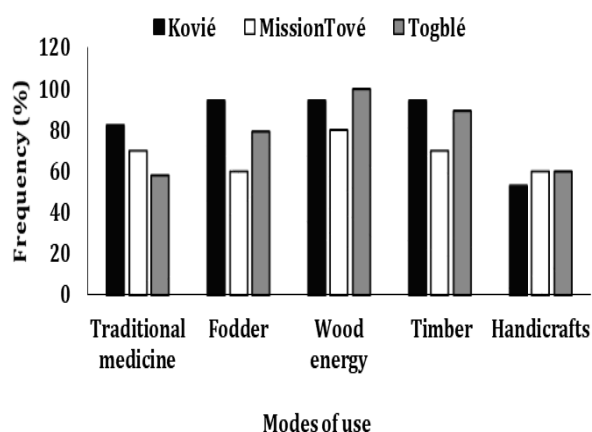


Figure 13. The different categories of use of *M. inermis*

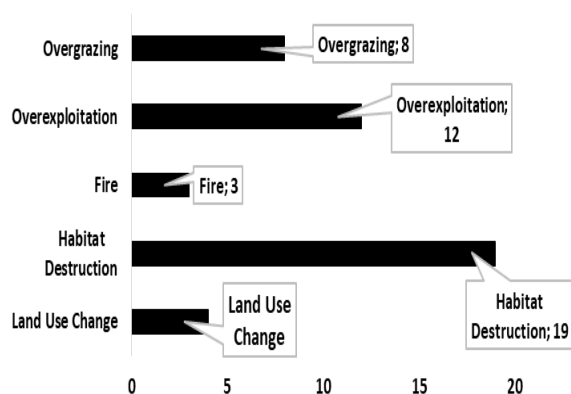


Figure 14. The different factors considered as threats to *M. inermis*

pared to the others, based on surveys and simple observations made in the field.

4. Discussion

4.1. Characteristics of the structural diversity of *M. inermis* stands

The floristic analysis of the Zio micro-basin identified 120 species divided into 112 genera and 51 families. This specific richness is lower than the observations made by [Seou et al. \(2022\)](#) on the vegetation of the Zio basin in southern Togo, where 371 species were inventoried, divided into 271 genera and 82 families. This difference could be explained by the study area, topography, climatic conditions, and the effects of anthropization.

The dominance of Guinean-Congolese and Sudano-Zambézian species in all the inventoried biotopes confirms that the study area belongs to the Sudanian savannah zone ([Karimi & Peng, 2004](#); [Rajoelison et al., 2008](#)). Palm groves, wooded and shrubby savannahs, flooded savannahs of pond formations, open forests, and gallery forests are also associated with this zone. The same trend is observed in the work of [Folega et al. \(2014\)](#) and [Bawa et al. \(2022\)](#), with the predominance of Fabaceae, Asteraceae, and Rubiaceae, which is characteristic of open forests and shrubby and wooded savannahs in Sudanian zones. The dominance of Sudano-Zambézian species reflects the existence of a relatively humid tropical climate in the study area, which is favorable to the development of forest ecosystems. This dominance is also reported in the work of [Akoègninou et al. \(2006\)](#) in Benin.

Table 6. Characteristics of the stability of stands in *M. inermis*

Structural parameters	Coefficient of slenderness (Htotal / D1.30m)	Stand stability
Mature stand	74.63 < 100	Stable stand
Young stand	102.02 > 100	Unstable stand

EC > 100: unstable stand; EC < 100: stable stand; With total H = total height of the shaft; D1.30m = Diameter of the tree at 1.30 meters from the ground Unstable stand

The dendrometric study of species provides information on their physiognomic characteristics in relation to their living environments. Compared to other species, the *M. inermis* populations have a fairly high basal area, between 46.21 and 90.75 m²/ha. This is explained by their high density in the micro-basin. The distribution of individuals by diameter classes follows an "L" structure that fits a logarithmic trend curve in all the studied formations. The three discriminated groups have a Weibull shape coefficient ($c = 0.87$ for GIa; 0.98 for GIb; 1.83 for GII; 1.013). In general, woody plants with a diameter between 20 and 30 cm are clearly dominant, while the other classes are poorly represented. The low representation of woody plants with diameters between 10 and 20 cm in the GIb group is explained by the fact that shrub savannahs at higher altitudes have smaller diameters. These results also reveal an unbalanced demographic structure, marked by an under-representation of young plants and small diameter classes (Souley et al., 2018). This imbalance reflects insufficient natural regeneration, a direct consequence of the intensive exploitation of *M. inermis* for wood energy. Such a situation could compromise the sustainability of stands in the medium and long term, as the low presence of young individuals does not ensure the renewal of cut mature trees. These observations align with similar studies conducted in West Africa, where the same woody species are subject to anthropogenic pressures. Several studies have shown that unregulated wood exploitation often leads to a drastic reduction in young plants and an impoverishment of the demographic structure of woody species (Bawa et al., 2022; Cisse et al., 2020).

As for the distribution of woody plants by height classes, it follows an "L" shape for the grouping of *Lannea acida* and *Millettia thonningii* (GIb). This indicates a predominance of small individuals and a low proportion of large individuals. The distribution of individuals by diameter classes presents a decreasing exponential curve (L-shaped curve). These results are similar to those of Folega et al. (2014), who also found L-shaped structures and strong anthropization in the gallery forests of the Sudanian zone. This distribution is similar to that described in the Togodo Reserve by Adjonou et al. (2016). For the *Zanthoxylum zanthoxyloides* and *Entada africana* group (GIa), as well as the

grouping of *M. inermis* and *Lonchocarpus sericeus* (GII), the distribution by height classes is bell-shaped. This type of distribution reflects a high proportion of individuals of average height and a low proportion of individuals of small and large height (Souley et al., 2018). The structural characteristics of these three groups suggest that the significant regeneration in the different groups is linked to the anthropization of the environment. The high proportion of individuals with a diameter between 20 and 30 cm, and the low proportion of individuals with a diameter between 10-20 cm and 30-40 cm, testify to the strong anthropization of the ecosystems in the Zio basin. The rate of natural regeneration, particularly the number of young plants in the GIa and GIb groups compared to the GII group, shows the pressure exerted on certain species (*M. inermis*, *Vitellaria paradoxa*, *Vitex doniana*), preventing their natural renewal and indicating a risk of future scarcity of these species if no sustainable management measures are implemented. Indeed, populations use wood as their main source of energy (Kaboré, 2015; Seou et al., 2022).

4.2. Correlations between different structural parameters

The correlation between tree height and diameter is expressed by a linear function with the equation: $y = 0.0328x + 5.1929$, with $R^2 = 0.041$ (Figure 10). The graph indicating this growth relationship shows that most of the adult woody plants inventoried have a diameter of less than 30 cm. The weak correlation can be explained by the mix of species and their respective physiology. The study shows a correlation between areas with high cutting pressure and a significant reduction in the number of individuals, particularly in small diameter classes, which would indicate excessive exploitation of young trees. The most degraded areas are those close to villages, compared to more distant areas (Boussim et al., 2005; Bognounou, 2009). According to Adjonou et al. (2009), beyond a diameter of 40 cm, the regression curve shows a perfect relationship between diameter and height. The present study also shows that tree height growth tends to stabilize around 8 m, which is lower than the observation of Adjonou et al. (2016) in the Togodo Forest, where this growth stabilizes at 25 m.

4.3. Different categories of use of *M. inermis*

Socio-economic surveys conducted as part of this study show that the local population is heavily dependent on *M. inermis* for their energy, craft, construction, and medicinal needs. These surveys also provided insight into the local perception of the importance of the species (Dossou et al., 2012; Dourma et al., 2018). The exploitation of this species as fuelwood is the most common use mentioned by women in all the surveyed localities. This economic dependence partly explains the excessive pressure exerted on the stands of this species (Seou et al., 2022). However, these unsustainable exploitation practices risk compromising future access to this resource, creating a vicious cycle of natural resource depletion.

4.4. Perception of conservation threats to *M. inermis*

Despite the important functions that the species provides for local populations, it is now highly threatened by factors such as habitat destruction, overexploitation (excessive wood harvesting), overgrazing, and changes in land use patterns. These factors have led to a considerable decline in this species and a reduction in the size of natural formations, resulting from high pastoral loads, late vegetation fires, and clearing for agricultural purposes (Bawa, 2017; Hervé et al., 2020). The growing demand for wood energy in the study area is identified as one of the main factors responsible for the degradation of *M. inermis*. The results highlight a strong correlation between the proximity of wood energy exploitation areas and the decrease in population densities of the species (Souley et al., 2018).

This raises concerns about the unsustainable exploitation of wood resources, which not only threatens the species but also disrupts the local ecological balance. Similarly, agriculture, wildfires, and population growth are the main causes of the degradation of the vegetation cover in the surveyed habitats of *M. inermis*. In response to the increasing demands related to population growth, farmers often clear new fields to meet household needs, leading to the regression of vegetation cover (De Haan, 1997; Adjonou et al., 2009).

4.5. Perspectives and measures for sustainable management of *M. inermis* populations

The use of *M. inermis* wood in charcoal production represents the main activity driving changes in vegetation cover in the study area. However, to limit the impact of the demand for wood energy on *M. inermis* stands, management measures are required, including:

- Regulation of exploitation through the introduction of quotas or rotation of cutting areas.
- Reforestation or assisted regeneration programs in the most degraded areas.
- Raising awareness among local populations about sustainable resource management and promoting alternatives to wood energy (e.g., improved stoves or other energy sources).
- Conservation measures in critical areas, such as protected areas or managed community forests.

5. Conclusion

The present study, conducted in the Zio River micro-basin in southern Togo, identified a total of 120 species divided into 112 genera and 51 families. It characterized the *M. inermis* populations through the description and analysis of their dendrometric parameters, densities, health, and ecology. The most represented families are Poaceae, followed by Fabaceae, Rubiaceae, Annonaceae, and Asteraceae. The most represented species are *Loudetia togoensis*, *Chromolaena odorata*, *Sarcocephalus latifolius*, *Cyperus cyperoides*, and *Panicum maximum*. The study on the demographic structure of *M. inermis* populations in the Zio River watershed highlights the significant impact of the increasing demand for wood energy on this woody species, as well as the challenges posed for its natural regeneration and conservation. The results showed a worrying decrease in young individuals in the stands, a sign of excessive anthropogenic pressure and insufficient regeneration to guarantee the sustainability of the species. The heavy exploitation of *M. inermis*, particularly in areas close to villages and easy access points, leads to the progressive degradation of forest resources. If no sustainable management measures are quickly implemented, this species risks irreversible decline, affecting not only the lo-

cal ecosystem but also the populations dependent on wood energy for their daily needs.

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