Discover Conservation

Research

Stands diversity and population structure of five ethnoveterinary woody species according to climatic zone and human disturbance in Benin (West Africa)

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Abstract
Farmers continue to use medicinal plants, alone or in combination with veterinary medicines, to treat animal diseases, especially in developing countries. The study aimed to determine the effect of climatic zone and anthropic disturbance level on the diversity of the natural stand and structures of *Morinda lucida* Benth, *Spondias mombin* L., *Terminalia leiocarpa* (DC.) Baill, *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth, and *Vitex doniana* Sweet, five plant species often used in ethnoveterinary medicine in Benin. A floristic inventory was conducted in 206 plots of 0.15 ha each, distributed across 6 forests/hunting areas as well as surrounding fields and fallow land. The data were analyzed using R software by calculating the importance value index and the population structural parameters (density, basal area, mean height, etc.). The results showed that the floristic composition of the habitats of the five target species varied by climatic zone and disturbance level. *Morinda lucida*, *S. mombin,* and *V. doniana* were available in stands undergoing heavy disturbance in the Guinean zone, whereas *T. leiocarpa* and *C. febrifuga* were more available in the Sudano-Guinean and Sudanian zones. Values of structural parameters of these species were higher in the Guinean zone than in the other two zones. Furthermore, the results of the diameter structure showed *C*-values ranging from 1 to 3.6, suggesting the predominance of young individuals. This suggests strong human pressure on the adults of studied plants. These results should be used to contribute to the sustainable use of these species. Recommendations are made for the sustainable use of these five species, especially *T. leiocarpa* and *C. febrifuga*, which were heavily exploited given their low availability in stands under high human disturbance.

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1 Introduction

In Benin Republic, livestock farming is mainly practiced by smallholders, and the income from the sale of animals is used to pay for schooling, buy cereals during food shortage, and pay for medical care [1–4]. Traditional veterinary medicine continues to play an important role in the treatment of livestock diseases. Ethnoveterinary surveys conducted in recent years have shown that herders use medicinal plants alone or in combination with orthodox drugs to treat animal ailments [5–9]. Unfortunately, ethnoveterinary medicine is threatened by the loss of plant species used by livestock keepers. In this respect, it is becoming increasingly difficult or impossible to obtain parts of plants that are considered very effective by livestock keepers [3].

Ethnoveterinary surveys carried out in Benin have shown that *Morinda lucida* Benth, *Spondias mombin* L., *Terminalia leiocarpa* (DC.) Baill, *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth, and *Vitex doniana* Sweet are very important to the indigenous population [1, 3, 8, 9]. These five plants are widely used on small farms to treat ailments, particularly digestive and reproductive disorders in small ruminants and improve the productivity of sheep, goat, cattle, and poultry farming [3]. Some of these plants are also used to treat human ailments, as food, and in the production of charcoal and furniture [10]. This multiple use of these plants may accelerate the human pressure through their overexploitation. It is, therefore, necessary to assess the structure and availability of these species in their natural habitats in order to identify priority species for conservation and guide their sustainable use.

Population structure of the selected plants are not well documented with respect to climatic zone and human disturbance level in Benin. For example, Assogbadjo et al. [11] investigated the structure of *T. leiocarpa* in Wari-Maro forest in Sudano–Guinean zone only, although the population structure of species can depend on the climatic zone and human pressure level. In addition, Hounkpèvi et al. [12] studied the population structure of *V. doniana* in relation to climatic variability and land cover type while the effect of land use type was not assessed. Overall, the influence of anthropogenic disturbance has not been examined for the target species although their multiples uses that can disturb their population structure.

Assessing the structure of multi-purpose species is very important in the context of the threat to biodiversity posed by climate change and human disturbance [13–16]. It makes it possible to identify priority species for conservation and guide their sustainable use [10]. The structure of a species can be analyzed by using structural parameters such as density, basal area, regeneration density, mean diameter, etc. [11, 12, 15]. Structural parameters are real indicators of information on the population dynamic of the species in absence of long term data. In addition, the availability of species can be assessed by calculating the Importance Value Index (IVI) [10].

Climatic zone and the anthropic disturbance level have been identified as parameters that significantly influence the status, structure and availability of species in their natural environment [14–16]. For instance, the climatic zone and anthropic disturbance level significantly influenced the structure of *Afzelia africana* in Benin [15, 16]. Similarly, Houehanou et al. [17] showed that stand diversity and structure were significantly influenced by the human disturbance level. In this context, it is necessary to address the effect of climatic zone and human disturbance level on the structure of target species.

The aim of the study was to determine the effect of climatic zone and anthropic disturbance level on the structure of *T. leiocarpa*, *V. doniana*, *M. lucida*, *S. mombin*, and *C. febrifuga* and on the diversity and the composition of woody species associated to the stand of the five plants.

2 Methodology

2.1 Study area

The study was carried out in Benin Republic which is divided into three climatic zones. The Guinean zone is located in the south between 1°00′–2°45′ E and 6°30′–7°30′ N, and the Sudanian zone lies to the north between 2°25′–3°40′ E and 9°10′–12°30′ N [18]. The Sudano-Guinean zone is located between the two previous zones between 1°55′–2°25′ E and 8°50′–9°10′ N (Fig. 1). A literature review was used to identify the geographical areas of occurrence of *M. lucida*, *S. mombin*, *T. leiocarpa*, *C. febrifuga*, and *V. doniana* in Benin. This enabled us to observe that some species were widely distributed and occurred in all three climatic zones (e.g., *T. leiocarpa*), while others were less widely distributed (e.g., *M. lucida* occurred only in the Guinean and Sudano-Guinean zones). We then decided to choose two forests/sites per climatic zone (6 in total) for the study. In each climatic zone, the choice of site/forest was based on the occurrence of the study species, the sites where several of the study species occurred were selected. Thus, the Lama and Kétou forests in the Guinean zone, Atcherigbe and Bassila forests in the Sudano-Guinean zone, and the Pendjari and Mekrou hunting areas in the Sudanian zone were selected for the study (Fig. 1). The climatic characteristics of the three zones are summarized in Table 1.

The Lama forest (Latitude: 6°55′ and 7°00 North and Longitude: 2°4′ and 2°12′ East) covers 16,250 ha and is located in southern Benin and consists of the departments of Atlantique (9,750 ha in Toffo) and Zou (6,500 ha in Zogbodomey) [19]. The forest is subject to a sub-equatorial climate with four seasons and irregular rainfall (1,100 mm per year on average). The vegetation comprises of about 248 plant species, i.e. 10% of the total flora of Benin, with the most common families being Rubiaceae (15 species), Caesalpiniaceae (11 species) and Euphorbiaceae (9 species). The population is predominantly Fon, Yoruba and Adja, and practices livestock rearing, agriculture, hunting, trade and crafts. Fallow land is used for agriculture and the collection of forest products such as timber [16]. Like the Lama forest, the Kétou forest (Latitude: 7. 4709° and 7° 28′ 15" North and Longitude: 2.463° and 2°27′ 47" East) is located in southern Benin, in the Guinean zone, and covers about 43,200 ha [20]. The spatial dynamics of the vegetation cover over time show a constant degradation of the vegetation. The regressive evolution of the forest cover is accompanied by a reduction in wood potential.

The Atchérigbé forest is located between 7°30′ and 7°34′ North latitude and 2°04′ and 2°09′ East longitude in the Sudano-Guinean zone and covers about 3,150 ha. It is essentially dominated by savannah plant formations [18]. The forest is partly surrounded by a rural population made up mainly of Fon who farm, raise livestock and produce charcoal. Part of the forest is very degraded, with fallow land, timber harvesting and extensive farming. The Bassila forest (Latitude: 9.0167° and 9° 1′ North and Longitude: 1.6667° or 1° 40′ East) covers an area of about 3,523 ha and its soils are mainly tropical ferruginous or hydromorphic. The vegetation is dominated by *Berlinia grandiflora*, *Cola gigantea*, *Vitex doniana*, *Pterocarpus santalinoides* and *Diospyros mespiliformis*.

Pendjari (Latitude: 10°30′ and 11°30′ North and Longitude: 0°50′ et 2°00′ East) and Mekrou hunting areas (Latitude: 12.40727° and 12° 24′ 26 North and Longitude: 2.82618° and 2° 49′ 34" East) are among the protected areas located in the Sudanian zone [17, 21]. The climate in this area is soudanian tropical type, with annual rainfall of around 1,000 mm. Vegetation is varied, with 241 plant species distributed into 53 families recorded in Pendjari National Park [18]. The vegetation is dominated by the savannahs and woodlands. The reserve is located on a flat peneplain at altitudes ranging from 105 to 200 m above sea level. The plain is bordered to the south by the quartzite Atacora mountain range, whose altitude varies from 400 to 513 m above sea level.

2.2 Study species

Terminalia leiocarpa (Combretaceae) is a fairly common tree species, the distribution of which extends from Senegal through Cameroon to Ethiopia [23]. The species is found in savannahs, dry forests, gallery forests, and equatorial forests [24]. It grows to a height of 15 to 18 m and a trunk diameter of up to 1 m. Flowering takes place between the end of the dry season and the beginning of the rainy season [25]. The wood is hard and resistant to termites and insects. *Terminalia leiocarpa* has been identified in Djakotomey (Guinean zone), Borgou Sud (Sudano-Guinean zone) and Pendjari National Park (Sudanese zone) [25]. The species is found in savannahs, dry forests and forest galleries, on generally compact (clayey) soils.

Crossopteryx febrifuga (Rubiaceae) is a tree species that can vary in height from 3 to 6 m. It is found in the forests and savannahs of West, East, and Southern Africa [23]. The bark is smooth and grey to light brown, and it has a brittle edge. The fruits are in the form of a globular to elliptical capsule of about 1 cm in diameter; they are brown and then black at maturity and have a calyx scar at the top [25]. In Benin, the species occurs in several phytodistricts in all three climatic zones [25]. It is a species well adapted to dry areas.

Morinda lucida (Rubiaceae) is a tree species found from Senegal to Sudan, Angola, and Zambia that can reach 18 to 25 m in height [23]. The fruits are in the form of several drupes grouped into one; they are almost spherical, 1–2.5 cm in diameter. *Morinda lucida* usually grows in grassy savannahs, exposed slopes, and forests, often on termite mounds. It has been found in Benin at Togba and Niaouli (Guinean zone) and in Zou (Sudano-Guinean zone) in forest galleries, dense forests and wooded savannahs [25].

Spondias mombin (Anacardiaceae) is a tree species with a height of up to 15 m and a trunk diameter of 30 to 50 cm [23]. Although it is also found in America, *S. mombin* is considered to be native to Africa [26]. It is found in Sudanian savannahs

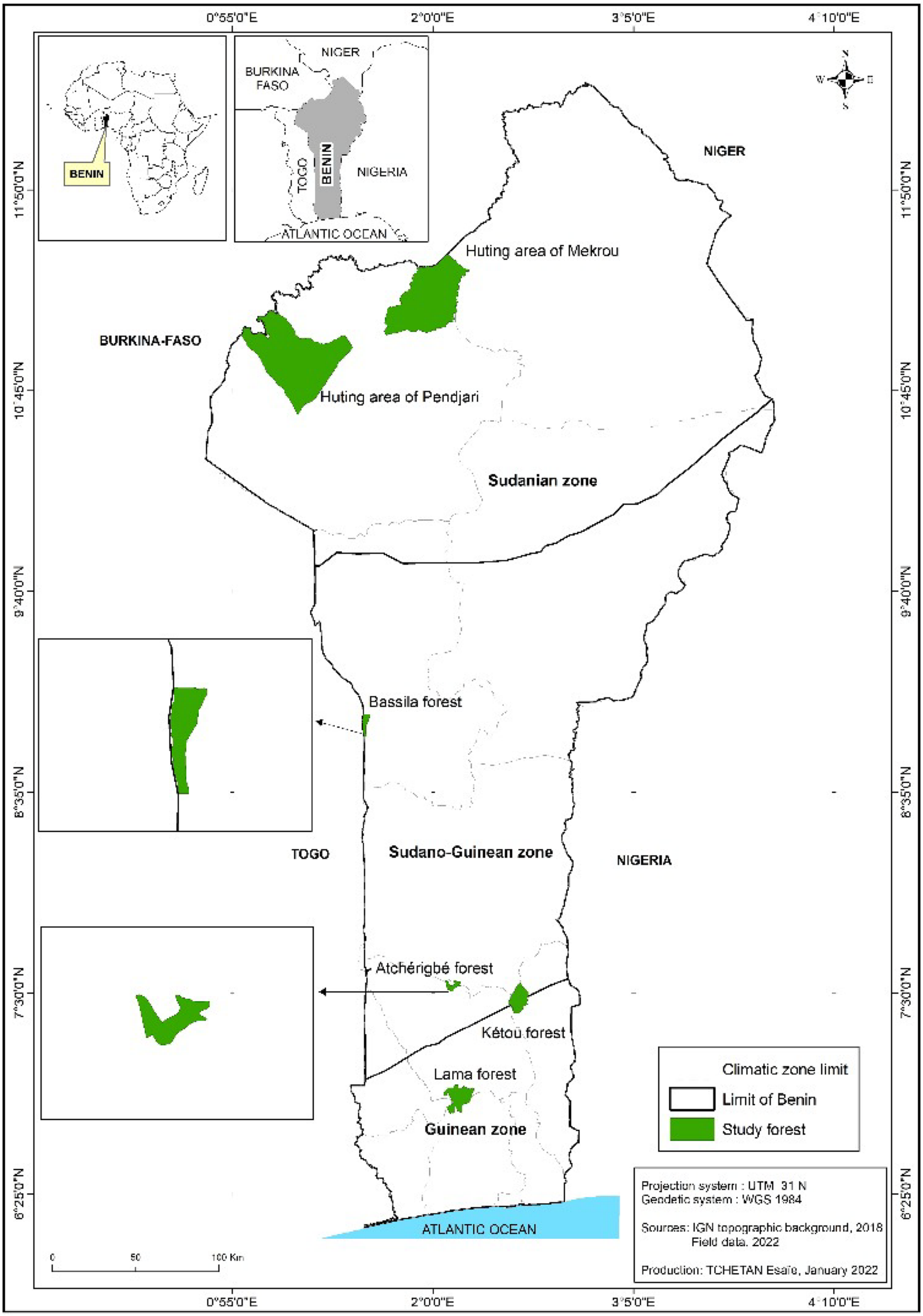

Fig. 1 Map showing the study area and the location of investigated forests

Table 1 Main characteristics of the three climatic zones of Benin [18, 22]

Climatic zones	Rainfall regime	Rainfall (mm)	Relative humidity (%)	Temperature (°C)	Major forest types
Sudanian	Unimodal	1044–1062	54–59	22.1–34.9	Dry forest and riparian forest/ferruginous soils
Sudano–Guinean	Tendency to unimodal	1073–1150	74–77	22.1–33.8	Dry forest, woodland, and riparian forest/ferruginous soils
Guinean	Bimodal	1132–1321	77–84	23.6–33.3	Semi-deciduous forest/ferrallitic soils

and Guinean pre-forest savannahs. The bark is marked with longitudinal crevices. The fruits are ellipsoidal or ovoid and yellow when ripe. In Benin, this species occurs in all three climatic zones [25]. It is often found in fallow land and marshes.

Vitex doniana (Lamiaceae) is a versatile agroforestry species found in a variety of habitats, from forests to savannahs. The tree species can vary from 6 to 25 m in height, and the trunk diameter can reach 160 cm [12]. The bark is finely fissured and fibrous, grey to light brown in colour. The fruit is a globular, hairless drupe, about 2.5 cm long, surrounded at the base by a persistent, cup-shaped calyx, which is blackish at maturity [23]. The wood is light brown, fairly hard, but easy to work with. *Vitex doniana* has been encountered in Benin in savannahs at Aplahoue (Guinean zone), Atchannou (Sudano-Guinean zone) and Gamia (Sudanian zone) [25]. It is often found along rivers [12].

2.3 Sampling design

The plot design is shown in Fig. 2. Data were collected from 0.15 ha (50 × 30 m) plots [10, 11], with four small plots of 0.01 ha (10 × 10 m) each established at the four edges of the main plot to count juveniles (DBH < 10 cm). On average, 34 plots were established at each site (an average of 68 plots per climatic zone): 17 plots in stands under low human disturbance (forest or hunting area) and 17 in stands under high human disturbance (fields and fallow land) [11, 15]. Fields and fallow land are highly vulnerable to human disturbance due to farming, livestock rearing, wood harvesting, charcoal making and other activities carried out by local residents. On the other hand, the forests and hunting areas benefit from special protection from the state (restricted access, no farming, no livestock rearing, no wood harvesting, etc.), thus there is no or lower human disturbance in these areas compared with the fields and fallow land. In each stand, the plots were established where at least an individual of at least one of the target species was present, and a minimum spacing of 500 m was observed between plots. Thus, 206 plots were established, as presented in Table 2. In each plot, we collected the following data: diameter at breast height (DBH), total height of individuals with DBH ≥ 10 cm, number of juveniles in four small plots, and plot coordinates using the global positioning system. Herbarium specimens were prepared for species not identified at the collection sites. Their identification was done using the Analytical Flora of Benin [25]. For the five study plant, Herbarium specimens were authenticated at the National Herbarium of Benin (NHB), University of Abomey-Calavi, Benin (Table 3). Herbarium specimens were kept at NHB. All tree species in plots were identified.

2.4 Data analysis

2.4.1 Floristic diversity of stands

The average number of species, genera, and families inventoried per plot was calculated and compared according to disturbance level (low vs. high) and climatic zone. Diversity indices were calculated using the vegan package of R software [27], and averages were compared according to disturbance level and climatic zone using Student's t-test for two samples and analysis of variance (ANOVA) for three samples. Species accumulation curves were plotted using the specaccum function of the vegan package. The Shannon–Wiener, Simpson, and Pielou indices were calculated per site (climatic zone and human disturbance level) using the following equations:

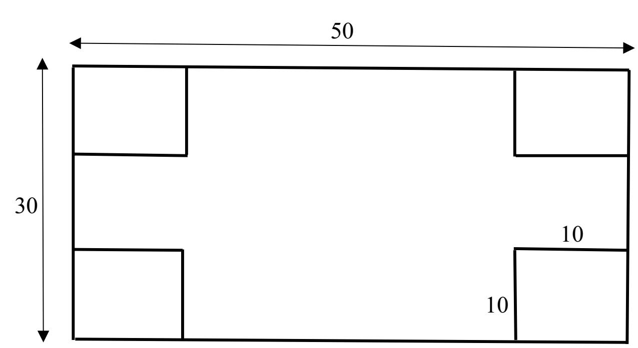

Fig. 2 Diagram showing the plot design used for data collection

Table 2 Distribution of the number of plots installed by climatic zone and forest

Climatic zone	Forest/hunting area	Number of plots	
		Low	High
Sudanian	Mekrou	17	16
	Pendjari	6	32
Sudano-Guinean	Atcherigbe	17	16
	Bassila	15	21
Guinean	Lama	15	17
	Ketou	15	19

Low: Stand under low human pressure, High: Stand under high human pressure

Table 3 Plants studied and their authenticated numbers

Authenticated number	Scientific name	Family
AAC 1504/HNB	*Terminalia leiocarpa* (DC.) Baill	Combretaceae
AAC 1503/HNB	*Crossopteryx febrifuga* (Afzel. ex G. Don) Benth	Rubiaceae
AAC 1507/HNB	*Morinda lucida* Benth	Rubiaceae
AAC 1511/HNB	*Vitex doniana* Sweet	Verbenaceae
AAC 1506/HNB	*Spondias mombin* L	Anacardiaceae

Shannon–Wiener diversity index (H)

$$\mathrm{H} = \sum \mathrm{Pi}\log_2 \mathrm{Pi}\ \text{with}\ \mathrm{Pi} = \frac{\mathrm{ni}}{\mathrm{N}} \tag{1}$$

where *ni* is the number of individuals of species *i* in the plot, *N* is the total number of trees in the plot, *Pi* is the relative abundance of species *i* in the plot, and *H* is the Shannon**–Wiener diversity** index.

Simpson dominance index (Si)

$$\mathrm{Si} = 1 - \sum (\mathrm{Pi})^2 \tag{2}$$

where *Si* is the Simpson dominance index.

Pielou index (E)

$$\mathrm{E} = \frac{\mathrm{H}}{\log_2 \mathrm{S}} \tag{3}$$

where *S* is the total number of species in the habitat considered, and *E* is the Pielou index.

The Bray–Curtis similarity index (%) was calculated using the vegan package, as suggested by Oksanen [28] and recently used by Compaoré et al. [29]. The Bray–Curtis similarity index allowed us to measure the similarity between the floristic composition of different stands (especially between stands under low and high human disturbances at the same site). An index value of 100% indicates that the compared stands share the same species, whereas a value of 0% indicates that the compared environments have no species in common.

2.4.2 Assessment of availability

The availability of the target species at each site and disturbance level was assessed by calculating the importance value index (IVI).

$$IVI = \sum \left(Fr + Dr + Gr\right) \tag{4}$$

where *Fr* is the relative frequency, *Dr* is the relative density, and *Gr* is the relative dominance.

2.4.3 Population structure of the target species

Structural parameters, such as tree density, basal area, mean Lorey's height, regeneration density, mean height, and mean diameter, were calculated at each site and disturbance level using the following equations:

Density (D)

$$D = \frac{n}{S} \times 10000 \tag{5}$$

where *D* is expressed as the number of individuals per hectare (trees/ha), *n* is the average number of individuals per plot, and *S* is the area covered by the plot (m^2).

Basal area (G)

$$G = \frac{10000\pi}{4S} \sum_{i=1}^{n} di^2 \tag{6}$$

where *G* is the basal area (m^2/ha), *S* is the plot area (m^2), and *di* is the DBH (m) of an individual of the same species.

Mean Lorey's height (Hl)

$$Hl = \frac{\sum_{i=1}^{n} g_{ih_i}}{\sum_{i=1}^{n} g_i} \quad g_i = \frac{\pi}{4} d_i^2 \tag{7}$$

where g_i, h_i, and d_i are the basal area, total height, and diameter of tree *i*, respectively.

Regeneration density (Dr)

$$Dr = \frac{n_i}{s} \tag{8}$$

where n_i is the number of regenerations counted in plot *i*, and *S* is the area of the plot (ha).

Mean height (Hm)

$$Hm = \frac{1}{n} \sum_{i=1}^{n} hi \tag{9}$$

where *n* is the total number of individuals, and *h* is the height (m) of each individual *i* of the same species in the same plot.

Mean diameter (Dm)

$$Dm = \sqrt{\frac{1}{n} \sum_{i=1}^{n} di^2} \tag{10}$$

where *n* is the total number of individuals in the plot, and *di* is the DBH (cm) of an individual *i* of the same species.

The mean values of each of these parameters were calculated for each target plant species and the stand according to climatic zone and disturbance levels (low vs. high). These values were compared according to climatic zone and human disturbance levels using ANOVA or a non-parametric test (Kruskal–Wallis for three samples and

Mann–Whitney for two samples) when the conditions of normality and/or homogeneity of variance were not met even after transformation of the data.

2.4.4 Diameter structure of target species

The trees were grouped into classes of amplitude 5 cm. The resulting distribution was fitted to the three-parameter Weibull distribution (a, b, c) owing to its flexibility:

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} exp\left[-\left(\frac{x-a}{b}\right)^{c}\right] \quad (11)$$

where *x* is the diameter of the tree, *a* is the threshold (a = 10 cm), *b* is the scale or size parameter, which is related to the central value of the diameters, and *C* is the shape parameter related to the considered diameter structure.

3 Results

3.1 Floristic diversity

3.1.1 Diversity of woody species in the stands

A total of 69 tree species belonging to 68 genera and 25 families were inventoried in the 206 plots. Species accumulation curves showed that with an average sampling effort of 15 plots per stand, species richness varied from 12 to 30 (Figs. 3, 4, 5). Most of the identified species belonged to the Fabaceae family (Fig. 6). Indeed, this family was represented by 20.51, 35.15, and 31.82% of the identified species in the Guinean, Sudano-Guinean, and Sudanian zones, respectively. The number of families per plot varied significantly by climatic zone in stands under high human disturbance and by human disturbance level. Indeed, the mean number of inventoried families per plot at the high disturbance level in the Lama forest (1.56 ± 0.63) was significantly lower than that obtained in Atcherigbe forest (4.06 ± 1.39) (Table 4). In addition, the mean number of inventoried families per plot in the Lama forest at the low disturbance level (4.27 ± 1.39) was significantly higher than that obtained at the high disturbance level (1.56 ± 0.63).

Similar to family, the number of genera and species per plot varied significantly by climatic zone and disturbance level (Table 4). In general, the mean number of genera and species per plot in stands under low human disturbance was higher than that obtained in stands under high human disturbance.

3.1.2 Variation of diversity indices by climatic zone and disturbance level

Table 4 shows the variation of diversity indices according to disturbance levels and climatic zones. In general, *H*, *Si*, and *E* varied significantly between climatic zones as well as between disturbance levels (Table 5). Indeed, for low human disturbance level, Bassila forest (Sudano-Guinean zone) was the most diverse (H = 1.26 ± 0.32), while Kétou forest (Guinean zone) was the least diverse (H = 0.76 ± 0.21). However, Pendjari hunting areas were more diverse (H = 1.17 ± 0.31) than the surrounding fields and fallows (H = 0.38 ± 0.21).

The highest *E* was obtained for stands under low human disturbance in Bassila forest (E = 0.20 ± 0.05), which indicates the good distribution of species in this forest. In contrast, the lowest value of *E* was obtained for stands under high human disturbance atPendjari hunting area (E = 0.04 ± 0.03), indicating that species in this habitat are not equally distributed. *Si* varied from 0.15 ± 0.09 to 0.68 ± 0.15, the highest value was obtained for stands under high human disturbance in Atcherigbe forest (0.68 ± 0.15), indicating the low dominance of any particular species group in this habitat.

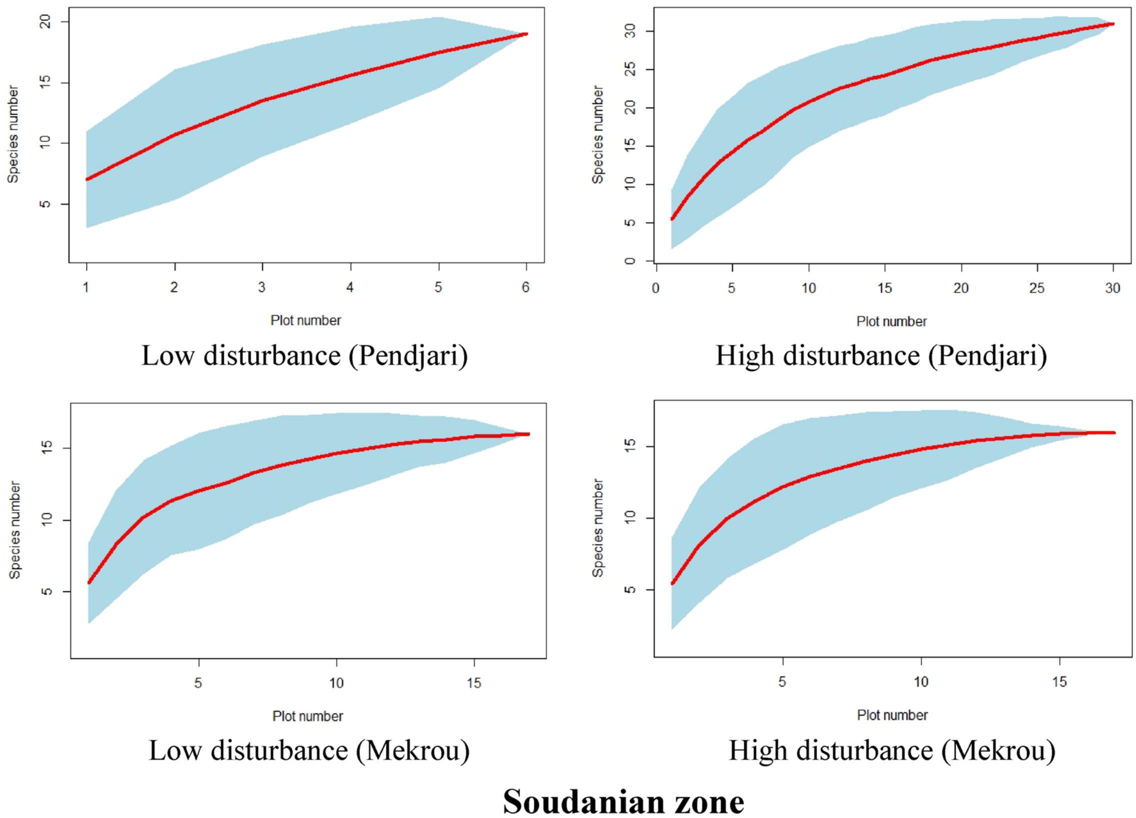

Fig. 3 Species accumulation curves showing variation in species richness of woody species in Soudanian zone as a function of sampling effort

3.1.3 Similarity index between stands under low and high human disturbance

Table 6 presents the Bray–Curtis similarity index according to climatic zone and disturbance level. In general, there was a moderate similarity between stands under low disturbance level and those under high disturbance level. In other words, stands under low disturbance level shared some plant species with those under high disturbance level. The highest Bray–Curtis similarity index value was obtained between stands under low disturbance level and those under high disturbance level (90.95%) at Lama forest (Guinean zone). In contrast, in Bassila forest, most of the species inventoried in stands under low disturbance level were not found in stands under high disturbance level and vice versa (39.05%).

3.2 Availability and structure of target species

3.2.1 Target woody species availability

Table 7 shows the Importance Value Index (IVI) of *T. leiocarpa*, *V. doniana*, *M. lucida*, *S. mombin*, and *C. febrifuga* in relation to climate zones and human disturbance levels. In general, *T. leiocarpa* showed the highest IVI values in stands under low or high disturbance in Sudano-Guinean and Sudanian zones. In Guinean zone, the species was more available in the Lama forest under low human disturbance with an IVI of 145.02%. However, *C. febrifuga* showed the highest IVI values in Pendjari and Mekrou hunting areas (Sudanian zone) in stands under low or high disturbances. IVI values were higher in stands under low human disturbance compared with those under high disturbance level. In Sudano-Guinean zone, *C. febrifuga* was most available in Bassila forest but only in stands under low disturbance with an IVI of 70.99% (Table 7).

In summary, *S. mombin*, *M. lucida*, and *V. doniana* showed the highest IVI values in Guinean and Sudano-Guinean zone in stands under high human disturbance. *Spondias mombin* had the highest IVI value (IVI = 168.36%) in Lama forest under

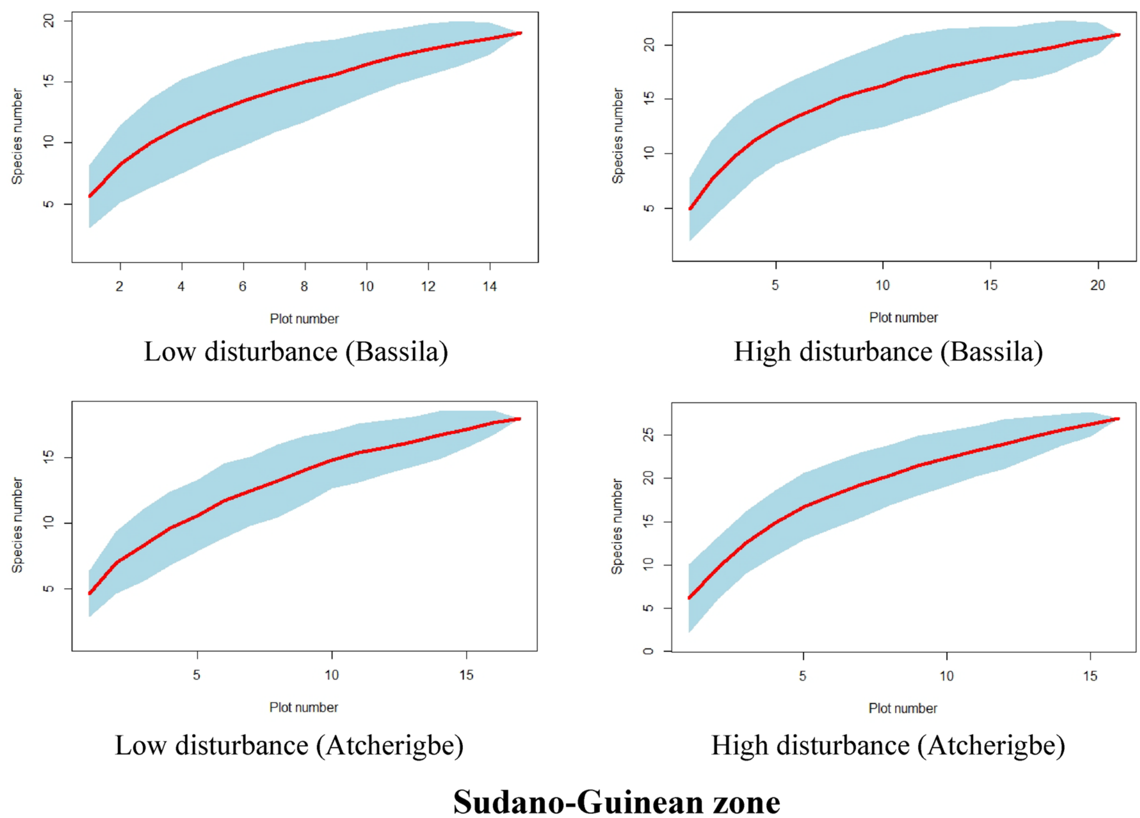

Fig. 4 Species accumulation curves showing variation in species richness of woody species in Sudano-Guinean zone as a function of sampling effort

high human disturbance (Table 7). However, *S. mombin*, *M. lucida*, and *V. doniana* were also available in Kétou forest in stands under low human disturbance.

Regarding climatic zone, *S. mombin*, *M. lucida*, and *V. doniana* were more available in Guinean zone, whereas *C. febrifuga* was more available in Sudanian and Sudano-Guinean zones. However, *T. leiocarpa* was found in all three climatic zones.

Concerning the level of human disturbance, *S. mombin*, *M. lucida*, and *V. doniana* were more available (high IVI values) in stands under high human disturbance compared to *T. leiocarpa* and *C. febrifuga* which were more available in stands under low human disturbance (Table 7).

3.2.2 Structural characteristics of target species

Table 8 presents the mean values of the structural parameters of the five species according to climatic zone and disturbance level in the stands where they were most available. In general, most of the structural parameters varied significantly by climatic zones and disturbance levels.

The mean density of *T. leiocarpa* varied significantly with respect to climatic zone ($P = 0.017$). Indeed, the mean density in stands under low disturbance level in Lama forest (Guinean zone) ($D = 40 \pm 36$trees/ha) was significantly higher than that obtained in stands under low disturbance in Atcherigbe forest (Sudano-Guinean zone) ($D = 12 \pm 12$ trees/ha). Similar to the mean density, the mean tree height, mean basal area, mean regeneration density, and mean diameter of *T. leiocarpa* varied significantly by climatic zones (Table 8). The highest values of these parameters were obtained in Guinean zone (the Lama forest). Some structural parameters of *T. leiocarpa* also varied significantly by disturbance levels. The mean diameter of *T. leiocarpa* trees in stands under low disturbance ($Dm = 22.00 \pm 6.18$ cm) in Atcherigbe forest was significantly higher than that obtained in stands under high disturbance ($Dm = 12.95 \pm 2.65$ cm) ($P = 0.003$).

The mean height and mean diameter of *C. febrifuga* trees varied significantly by climatic zones, whereas mean density and mean regeneration density varied significantly by human disturbance levels (Table 8). Indeed, the mean density in stands under low disturbance ($D = 20 \pm 16$trees/ha) in the Pendjari hunting areas was significantly higher than that

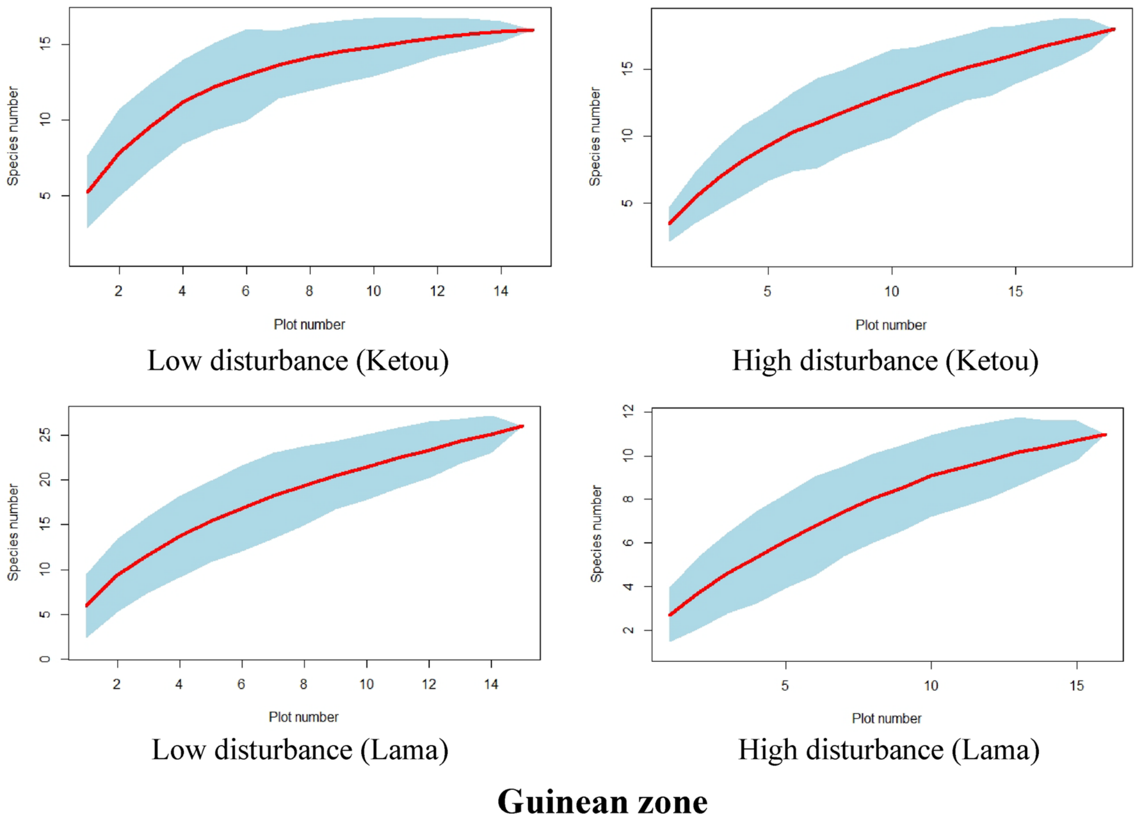

Fig. 5 Species accumulation curves showing variation in species richness of woody species in Guinean zone as a function of sampling effort

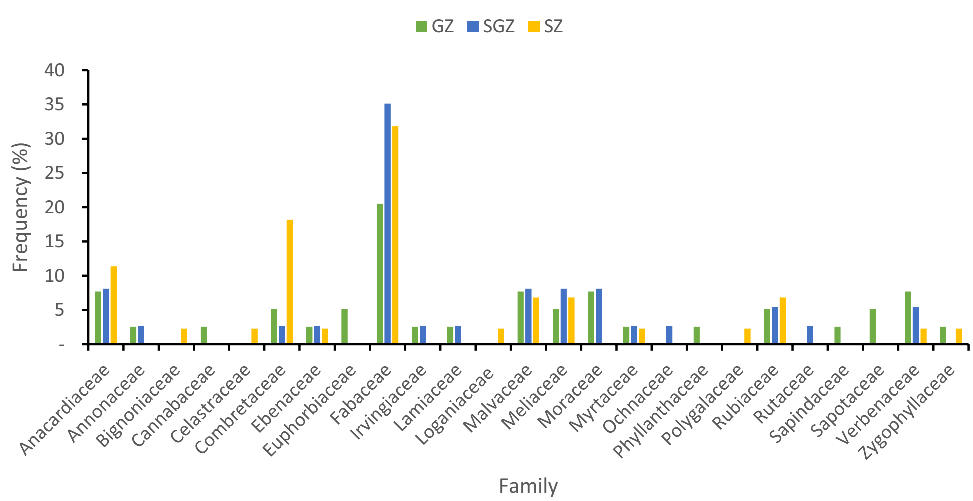

Fig. 6 Tree families inventoried in the three climatic zones. *GZ* Guinean zone, *SGZ* Sudano-Guinean zone et *SZ* Sudanian zone

obtained in stands under high disturbance (D = 6 ± 16trees/ha) (P = 0.049). Furthermore, individuals inventoried in Bassila forest (Sudano-Guinean zone) were larger (Dm = 28.89 ± 36.75 cm) than those in the Mekrou hunting area (Sudanian zone) (Dm = 23.19 ± 15.67 cm).

The structural parameters of *M. lucida* were calculated for the Guinean zone only. It was, therefore, not possible to test the effect of climatic zone on the structural parameters of this species. The mean tree density in stands under low disturbance in Kétou forest (D = 5 ± 4 trees/ha) was significantly higher than that obtained in stands under low disturbance in the Lama forest (D = 1 ± 3 trees/ha) (P = 0.009). On the other hand, the mean regeneration density in the Lama forest (high disturbance) (Dr = 76 ± 115trees/ha) was significantly higher than that obtained in Kétou forest (high disturbance) (Dr = 1 ± 6 trees/ha). Note that the mean values of the structural parameters in stands under

Table 4 Average number of families, genera, and species inventoried per plot according to disturbance level and climatic zone

Human disturbance	Guinean zone		Sudano-Guinean zone		Sudanian zone		P-value
	Lama	Ketou	Bassila	Atcherigbe	Pendjari	Mekrou	
Family							
Low	4.27 ± 1.39 (15)	3.87 ± 0.83 (9)	3.27 ± 0.96 (11)	3.35 ± 0.70 (9)	3.67 ± 1.37 (8)	3.82 ± 1.24 (7)	0.124
High	1.56 ± 0.63 (7)	2.42 ± 0.77 (10)	2.90 ± 0.89 (9)	4.06 ± 1.39 (12)	2.73 ± 1.23 (10)	2.19 ± 0.75 (7)	0.000
P-value	0.000	0.000	0.252	0.071	0.104	0.000	
Genera							
Low	4.93 ± 1.62 (25)	4.27 ± 1.16 (15)	4.47 ± 1.36 (18)	3.65 ± 0.93 (16)	5.83 ± 2.23 (17)	4.71 ± 1.72 (15)	0.032
High	1.56 ± 0.63 (10)	2.47 ± 0.70 (17)	3.86 ± 1.46 (19)	4.88 ± 1.86 (26)	4.53 ± 2.13 (27)	2.75 ± 1.24 (16)	0.000
P-value	0.000	0.000	0.212	0.026	0.184	0.000	
Species							
Low	4.93 ± 1.62 (23)	4.27 ± 1.16 (14)	4.47 ± 1.36 (17)	3.65 ± 0.93 (16)	5.67 ± 2.16 (17)	4.71 ± 1.72 (14)	0.047
High	1.56 ± 0.63 (10)	2.47 ± 0.70 (17)	3.86 ± 1.46 (18)	4.75 ± 1.77 (23)	4.50 ± 2.05 (28)	2.75 ± 1.24 (17)	0.000
P-value	0.000	0.000	0.212	0.037	0.215	0.000	

The values between brackets represent the absolute frequency, Low: Stand under low human pressure, High: Stand under high human pressure

Table 5 Shannon, Simpson and Pielou diversity indices according to disturbance level and climatic zone

Human disturbance	Guinean zone		Sudano-Guinean zone		Sudanian zone		P-value
	Lama	Ketou	Bassila	Atcherigbe	Pendjari	Mekrou	
Shannon index							
Low	1.04 ± 0.22	0.76 ± 0.21	1.26 ± 0.32	0.89 ± 0.19	1.17 ± 0.31	1.10 ± 0.37	0.000
High	0.52 ± 0.27	0.73 ± 0.33	0.91 ± 0.39	1.42 ± 0.41	0.38 ± 0.21	0.86 ± 0.42	0.000
P-value	0.000	0.781	0.007	0.000	0.000	0.094	
Simpson index							
Low	0.50 ± 0.10	0.35 ± 0.13	0.63 ± 0.15	0.44 ± 0.09	0.52 ± 0.14	0.52 ± 0.17	0.000
High	0.29 ± 0.17	0.38 ± 0.18	0.44 ± 0.19	0.68 ± 0.15	0.15 ± 0.09	0.46 ± 0.23	0.000
P-value	0.000	0.580	0.002	0.000	0.000	0.387	
Pielou index							
Low	0.16 ± 0.03	0.13 ± 0.05	0.20 ± 0.05	0.16 ± 0.03	0.18 ± 0.05	0.19 ± 0.06	0.000
High	0.13 ± 0.07	0.13 ± 0.06	0.14 ± 0.06	0.21 ± 0.04	0.04 ± 0.03	0.17 ± 0.08	0.000
P-value	0.159	0.795	0.004	0.000	0.000	0.387	

Low: Stand under low human pressure, High: Stand under high human pressure

high disturbance were higher than those obtained in stands under low disturbance, although the differences were not significant (Table 8).

Similar to *M. lucida*, the structural parameters of *S. mombin* were calculated for the Guinean zone only. However, comparisons were made between collection sites and disturbance level. Trees inventoried in Kétou forest were larger (Dm = 52.41 ± 9.38 cm) than those found in the Lama forest (Dm = 37.27 ± 12.10 cm). Furthermore, the mean regeneration density in Lama forest (high disturbance) (Dr = 56 ± 60 trees/ha) was significantly higher than that obtained in Kétou forest (high disturbance) (Dr = 5 ± 13 trees/ha) (P = 0.003).

The mean diameter of *V. doniana* varied significantly by disturbance level (P = 0.035). Trees inventoried in stands under high disturbance in Kétou forest were larger (Dm = 29.60 ± 0.00 cm) than those found in stands under low disturbance (Dm = 18.80 ± 4.59 cm).

3.2.3 Diameter structure of the target species

The diameter structure of the five species was calculated for the habitats where they were most available.

Table 6 Bray–Curtis similarity index (%) between the different habitat types

	La_low	La_high	Ke_low	Ke_high	At_low	At_high	Ba_low	Ba_high	Me_low	Me_high	Pe_low
La_high	90.95	–	–	–	–	–	–	–	–	–	–
Ke_low	91.49	69.60	–	–	–	–	–	–	–	–	–
Ke_high	89.64	57.45	50.97	–	–	–	–	–	–	–	–
At_low	79.78	89.95	65.38	75.55	–	–	–	–	–	–	–
At_high	87.95	88.46	62.83	64.71	53.94	–	–	–	–	–	–
Ba_low	65.58	94.87	64.07	84.82	63.24	70.26	–	–	–	–	–
Ba_high	70.11	84.83	55.15	70.12	56.07	58.87	39.05	–	–	–	–
Me_low	68.42	96.08	80.38	87.18	66.96	72.99	39.95	40.74	–	–	–
Me_high	76.60	90.40	74.19	74.19	64.62	59.11	56.89	49.26	44.91	–	–
Pe_low	91.11	96.46	82.76	83.22	89.52	86.77	76.40	73.85	58.10	59.77	–
Pe_high	92.09	98.66	88.30	90.85	90.76	82.81	68.44	68.99	64.38	69.92	60.81

La_ low Stand under low pressure in the Lama forest, *La_ high* Stand under high pressure in the Lama forest, *Ke_ low* Stand under low pressure in the Ketou forest, *Ke_ high* Stand under high pressure in the Ketou forest, *At_ low* Stand under low pressure in the Atcherigbe forest, *At_ high* Stand under high pressure in the Atcherigbe forest, *Ba_ low* Stand under low pressure in the Bassila forest, *Ba_ high* Stand under high pressure in the Bassila forest, *Me_ low* Stand under low pressure in the huting area of Mekrou, *Me_ high* Stand under high pressure in the huting area of Mekrou, *Pe_ low* Stand under low pressure in the huting area of Pendjari, *Pe_ high* Stand under high pressure in the huting area of Pendjari

Table 7 Importance Value Index (IVI) (in percent) for the five species studied in relation to climate zone and human disturbance level

Species	Site											
	Guinean zone				Sudano-Guinean zone				Sudanian zone			
	Lama		Ketou		Bassila		Atcherigbe		Pendjari		Mekrou	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Terminalia leiocarpa	145.02	0	0	3.95	75.63	65.64	61.31	24.44	2.81	4.64	72.97	91.99
Crossopteryx febrifuga	0	0	25.85	15.17	70.99	9.37	0	5.65	28.7	17.9	56.21	51.3
Morinda lucida	0	22.08	10.56	60.27	0	3.97	14.64	19.61	0	0	0	0
Spondias mombin	8.25	168.36	55.06	73.68	0.92	11.02	0	10.27	0	0	0	10.91
Vitex doniana	0	19.96	11.01	5.09	4.61	20.1	8.88	8.97	0	0	33.64	2.66

Low: Stand under low human pressure, High: Stand under high human pressure

Figure 7 shows the diameter structure for *T. leiocarpa*. This species presented *C*-values between 1 and 3.6 with the exception of trees inventoried in stands under high disturbance in Atcherigbe forest. This indicates the predominance of young trees. In general, individuals of classes 15–20 cm and 20–25 cm were the most abundant. Climatic zone and disturbance level did not influence the diameter structure of *T. leiocarpa* stems. However, the presence of large individuals (50–55 and 70–75 cm) at a lower density in stands under low disturbance in the Mekrou hunting area is worth noting, in contrast to stands under high disturbance, which showed only young individuals.

The diameter structure of *C. febrifuga* individuals showed a straight skewness with *C*-values ranging from 1.05 to 2.6, indicating the predominance of young individuals in the stands (Fig. 8). Similar to *T. leiocarpa*, the diameter structure of *C. febrifuga* individuals did not vary by disturbance level or climatic zone. In general, individuals of class 10–15 cm had a higher density compared to the other classes.

The diameter structure of *M. lucida* trees was calculated for Kétou forest (Fig. 9). For both disturbance levels, the species showed *C*-values between 1 and 3.6, indicating the predominance of young individuals. Individuals of class 15–20 cm had a higher tree density.

In Kétou forest, the diameter structure of *S. mombin* showed a straight skewness with *C*-values ranging from 1.46 to 3.41 (Fig. 10), which is characteristic of stands dominated by young individuals. Disturbance level did not influence the diameter structure of *S. mombin* trees. However, in contrast to stands under low disturbance (Kétou forest), large individuals (60–65 and 65–70 cm) were present in stands under high disturbance.

Table 8 Structural parameters of the five plants according to the climatic zones and the disturbance level

Parameter	Human disturbance	Guinean zone		Sudano-Guinean zone		Sudanian zone		P-value
		Lama	Ketou	Bassila	Atcherigbe	Pendjari	Mekrou	
Terminalia leiocarpa								
D	Low	40 ± 36		26 ± 49	12 ± 12		16 ± 16	0.017
	High			13 ± 17	7 ± 10		10 ± 19	0.405
	P-value			0.331	0.200		0.335	
G	Low	4.89 ± 4.27		2.99 ± 3.16	0.58 ± 0.40		1.79 ± 1.52	0.000
	High			1.20 ± 1.49	0.27 ± 0.19		2.51 ± 3.39	0.007
	P-value			0.168	0.043		0.522	
Hl	Low	19.55 ± 3.71		16.48 ± 3.37	16.42 ± 4.25		20.27 ± 4.00	0.046
	High			13.22 ± 3.38	11.62 ± 3.55		16.92 ± 2.73	0.056
	P-value			0.052	0.028		0.082	
Dr	Low	157 ± 151		48 ± 88	60 ± 40		109 ± 95	0.015
	High			35 ± 76	63 ± 57		63 ± 111	0.108
	P-value			0.608	0.899		0.207	
Hm	Low	18.36 ± 3.32		15.11 ± 2.70	16.28 ± 4.21		19.22 ± 4.14	0.059
	High			13.11 ± 3.21	11.13 ± 2.85		16.25 ± 2.11	0.024
	P-value			0.163	0.015		0.119	
Dm	Low	41.72 ± 10.60		30.05 ± 10.45	22.00 ± 6.18		34.36 ± 16.98	0.001
	High			23.39 ± 7.08	12.95 ± 2.65		34.41 ± 16.69	0.001
	P-value			0.105	0.003		0.995	
Crossopteryx febrifuga								
D	Low			29 ± 37		20 ± 16	15 ± 14	0.633
	High					6 ± 16	7 ± 11	0.792
	P-value					0.049	0.086	
G	Low			1.30 ± 1.41		0.32 ± 0.26	0.86 ± 0.68	0.109
	High					0.80 ± 1.79	0.53 ± 0.47	0.692
	P-value					0.569	0.255	
Hl	Low			10.48 ± 1.92		–	12.48 ± 1.98	0.023
	High					–	12.46 ± 2.65	
	P-value						0.984	
Dr	Low			84 ± 70		25 ± 16	81 ± 101	0.652
	High					23 ± 30	63 ± 82	0.076
	P-value					0.784	0.572	
Hm	Low			9.77 ± 1.62		–	12.32 ± 1.90	0.003
	High					–	12.35 ± 2.53	
	P-value						0.976	
Dm	Low			19.20 ± 4.40		13.23 ± 1.83	23.19 ± 15.67	0.032
	High					17.46 ± 7.28	21.55 ± 10.54	0.329
	P-value					0.229	0.797	
Morinda lucida								
D	Low		2 ± 5					
	High	1.18 ± 2.62	5 ± 4					0.009
	P-value		0.116					
G	Low		0.32 ± 0.14					
	High	0.18 ± 0.18	0.39 ± 0.31					0.299
	P-value		0.752					
Hl	Low		7.94 ± 1.51					
	High	8.33 ± 3.51	9.60 ± 1.89					0.403
	P-value		0.268					

Table 8 (continued)

Parameter	Human disturbance	Guinean zone		Sudano-Guinean zone		Sudanian zone		P-value
		Lama	Ketou	Bassila	Atcherigbe	Pendjari	Mekrou	
Dr	Low		2 ± 6					
	High	76 ± 115	1 ± 6					0.016
	P-value		0.898					
Hm	Low		7.67 ± 1.89					
	High	8.33 ± 3.51	9.55 ± 1.82					0.413
	P-value		0.208					
Dm	Low		18.36 ± 2.89					
	High	17.37 ± 8.64	23.79 ± 8.03					0.248
	P-value		0.378					
Spondias mombin								
D	Low		4 ± 8					
	High	7 ± 8	3 ± 6					0.149
	P-value		0.869					
G	Low		2.22 ± 3.38					
	High	1.03 ± 0.73	1.99 ± 1.14					0.057
	P-value		0.876					
Hl	Low		16.10 ± 4.32					
	High	12.24 ± 3.42	15.51 ± 3.29					0.090
	P-value		0.772					
Dr	Low		5 ± 14					
	High	56 ± 60	5 ± 13					0.003
	P-value		0.956					
Hm	Low		10.80 ± 3.56					
	High	12.33 ± 3.45	15.38 ± 3.31					0.104
	P-value		0.055					
Dm	Low		33.66 ± 20.79					
	High	37.27 ± 12.10	52.41 ± 9.38					0.020
	P-value		0.117					
Vitex doniana								
D	Low		2 ± 3					
	High	1 ± 2	1 ± 2					0.495
	P-value		0.054					
G	Low		0.19 ± 0.10					
	High	0.62 ± 0.37	0.46 ± 0.00					0.655
	P-value		0.022					
Hl	Low		11.00 ± 3.37					
	High	11.00 ± 1.41	7 ± 0.00					0.156
	P-value		0.188					
Dr	Low		0					
	High	16 ± 61	11 ± 36					0.732
	P-value		0.215					
Hm	Low		11.00 ± 3.37					
	High	11.00 ± 1.41	7 ± 0.00					0.156
	P-value		0.188					
Dm	Low		18.80 ± 4.59					
	High	33.50 ± 10.61	29.60 ± 0.00					0.695
	P-value		0.035					

D Density (trees/ha), *G* Basal area (m^2 /ha), *Hl* Lorey's mean height (m), *Dr* Density of regenerations (trees/ha), *Hm* Mean height (m), Dm: Mean diameter (cm)

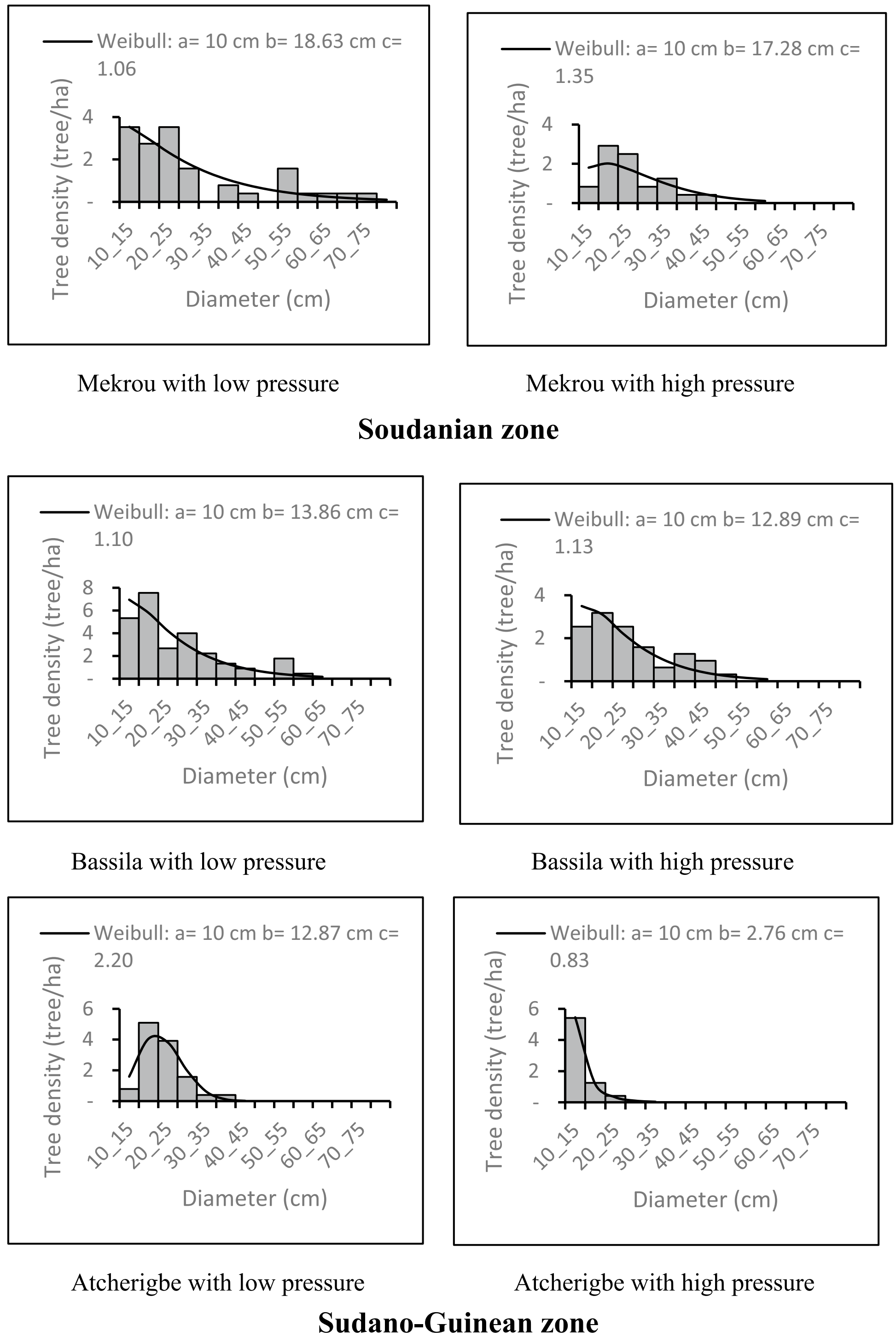

Fig. 7 Diameter structure of *Terminalia leiocarpa* according to disturbance level and climatic zones

4 Discussion

Natural resources, especially medicinal plants, continue to play an important role in the treatment of animal diseases, especially in poor countries, where livestock keepers often do not have access to orthodox l drugs [30]. Therefore, it is necessary to pay attention to the main plants used in ethnoveterinary medicine in order to assess their structure and guide their sustainable use. In the present study, we assessed the effect of human disturbance and climatic zone on the structure of *M. lucida*, *S. mombin*, *T. leiocarpa*, *C. febrifuga*, and *V. doniana*, the five main

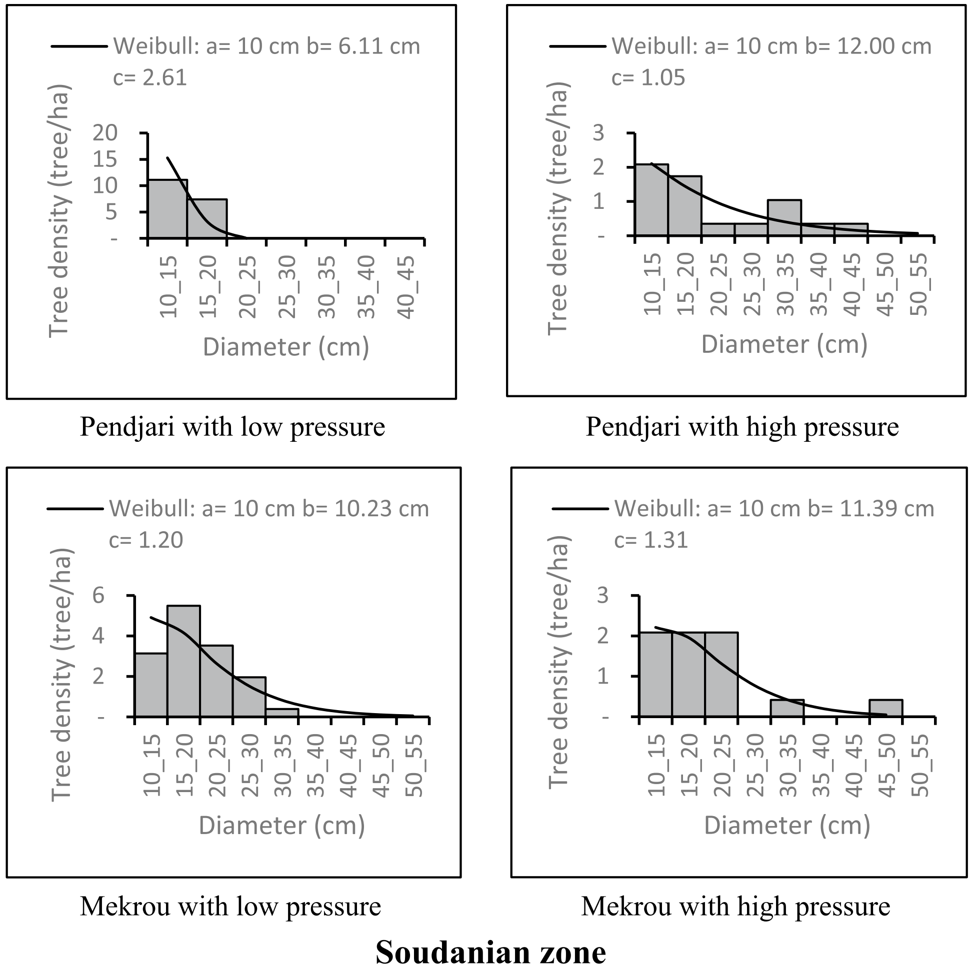

Fig. 8 Diameter structure of *Crossopteryx febrifuga* according to disturbance level in Soudanian zone

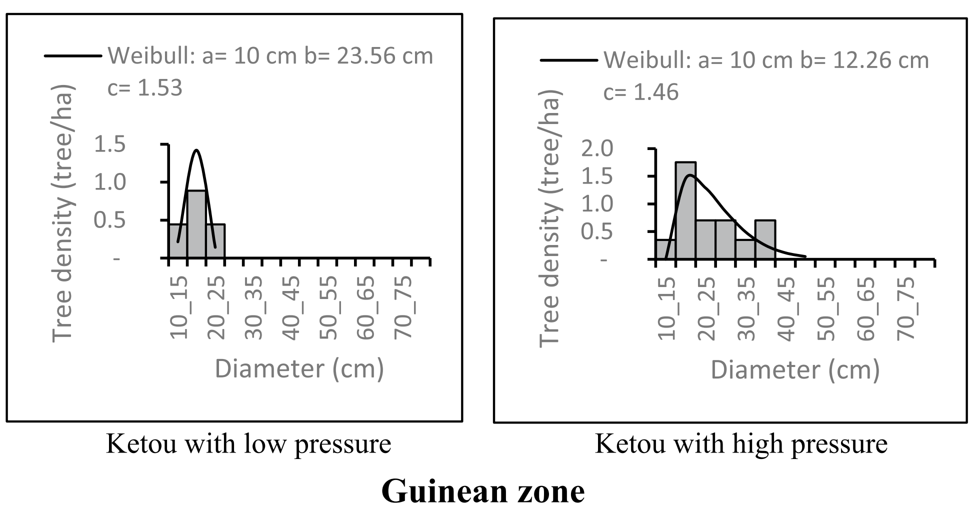

Fig. 9 Diameter structure of *Morinda lucida* according to disturbance level in Guinean zone

plants used in the treatment of animal diseases in Benin. The effect of anthropogenic disturbance and climatic zone on the structure of *A. africana* was assessed previously [15, 16]. However, this is the first study of the effect of these two parameters on the structure of the five studied plants. However, some of the five plant species did not have a geographical distribution that covered all three climatic zones. This was the case, for example, with *M. lucida*, which was found in the Guinean and Sudano-Guinean zones, whereas *C. febrifuga* was present in the Sudanian and

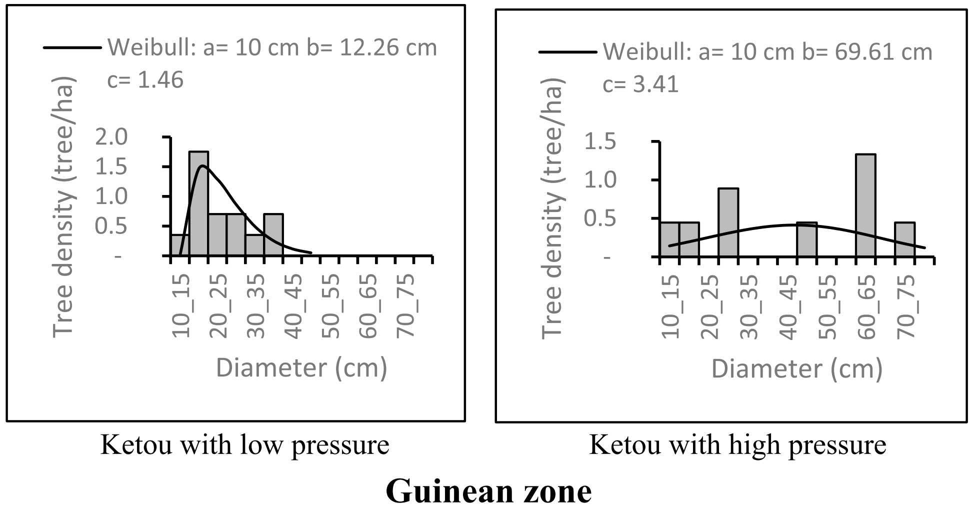

Fig. 10 Diameter structure of *Spondias mombin* according to disturbance level in Guinean zone

Sudano-Guinean zones. This disparity in the geographical distribution of target species in the three climatic zones may be linked to the ecological requirements of each species. The other plants such as *T. leiocarpa* were widely distributed and were found in all three climatic zones of Benin. A better understanding of climate and human disturbance effects on forest resources is necessary if we are to manage these resources in a context of changing climate for a sustainable use [16].

4.1 Floristic diversity of stands

The present study showed that the species richness of the habitats of *M. lucida*, *S. mombin*, *T. leiocarpa*, *C. febrifuga*, and *V. doniana* varied by climatic zones and disturbance levels. The Sudanian zone had a higher species richness than the other climatic zones, while stands under low disturbance had a high value for species richness. These results are in line with those of Mensah et al. [31], who observed the high species richness of *A. africana* stand in the Sahelo-Sudanian zone, a dry zone. The high species richness of stands in the Sudanian zone can be justified by the presence of several biosphere reserves that play a major role in the conservation and distribution of natural resources. Furthermore, the high species richness obtained in stands under low disturbance suggests a harmful effect of human disturbance on the floristic diversity of the stands of target species and corroborates the results of Houehanou et al. [21]. Indeed, the overexploitation of certain plant species in stands under high human disturbance may partly explain the loss of biodiversity. This finding confirms the results of Agbani et al. [32], who stated that stands under low pressure are prime locations for biodiversity conservation.

The mean values of *H'*, *Si*, and *E* varied significantly by climatic zone and disturbance level (Table 4). The highest values of *H'* and *E* were obtained in Bassila forest (Sudano-Guinean zone), which indicates the high diversity of species in this stand. This high diversity in the Sudano-Guinean zone can be justified by its transitional climatic conditions, which are favorable to most plant species identified in Benin [18]. The Sudano-Guinean zone is a transition zone between the humid zone (Guinean zone) in the south and the dry zone (Sudanian zone) in the north. This transitional zone has favorable climatic conditions for most plant species and, therefore, constitutes a refuge zone, especially for species from the Guinean and Sudanian zones in the context of climate change. In general, stands under low disturbance showed a high diversity compared to those under high human disturbance. These results corroborate those of Houehanou et al. [21], who found that stands of *A. africana* under low disturbance showed higher diversity compared to those under high pressure in the Pendjari Biosphere Reserve. This observation confirms the disturbance of biodiversity by anthropogenic activities. Indeed, logging, agriculture, grazing, and therapeutic use of natural resources are the main human activities that contribute to biodiversity loss [10, 11, 33, 34].

Calculation of the Bray–Curtis similarity index led to the conclusion that there was an average similarity between stands under low disturbance and those under high human disturbance levels. These results confirm those obtained for some nature reserves in Burkina Faso [29]. The similarity of tree species between stands under low disturbance and those under high disturbance can be explained by the presence of certain species that are resistant or not affected by anthropic pressure in stands under high disturbance and, therefore, belong to both types of stands (low and high disturbance). Those species are preserved by the farmers in agricultural landscapes because of their usefulness. On the other hand, the dissimilarity between the two types of stands could be explained by the introduction of certain exotic species into the stands under high disturbance by the local population [15, 16].

4.2 Availability and structure of the five woody species

T. leiocarpa and *C. febrifuga* were ecologically important in stands under low or high disturbances in the Sudano-Guinean and Sudanian zones. *S. mombin*, *M. lucida*, and *V. doniana* were more available in stands under high disturbance in the Guinean zone. The disparity in the availability of the five species by climatic zone and disturbance level can be explained by the intrinsic ecological requirements of each species on the one hand and by the importance of the differential use of each species on the other. Furthermore, the specific climatic characteristics of each climatic zone could explain the disparity in the availability of the different species. These different results are in line with the published literature, which state that climatic factors influence the distribution and ecological availability of plants [15, 16, 35]. Furthermore, the work of Hounkpèvi et al. [12] showed that *V. doniana* is a wetland species that is often found near rivers. *Crossopteryx febrifuga* seems more adapted to dry areas [10, 17, 29]. *Terminalia leiocarpa* was more available in stands under low disturbance in the Guinean zone. This suggests a negative influence of anthropogenic disturbance on the availability of this species in this zone. These results disagree with data from the literature, which state that *T. leiocarpa* is resistant to anthropogenic disturbance [11]. Such difference may depend on the degree of the human disturbance that affects the populations of *T. leiocarpa*.

Some species (*S. mombin*, *M. lucida*, and *V. doniana*) were more available in stands under high disturbance in the Guinean zone. These results may be explained by the selection and protection of certain plant species by the local population given their socioeconomic and therapeutic importance to their livelihood sustainability. These species are preserved by farmers during land clearing, which cut most woody species in cultivated areas. They can be promoted as potential agroforestry species for their sustainable use. Moreover, some plants are considered sacred species and benefit from special protection by the population [32].

Most of the structural parameters of the five studied plant species varied by climatic zone (Table 6). In general, the mean values for species structural parameters in the Guinean zone were higher than those for the Sudanian zone. This can be explained by the fact that the Guinean zone is characterized by a long period of rainfall (about 9 months) and, therefore, allows for continuous plant growth, whereas the Sudanian zone has a short period of rainfall (about 6 months). These results corroborate those of Mensah et al. [15], Assogbadjo et al. [16], and Atanasso et al. [35], who concluded that climatic factors influence the structural parameters of *A. africana*. The mean values of some species structural parameters for stands under low disturbance were higher than those obtained for stands under high human disturbance. For example, in Atcherigbe forest, the mean diameter of *T. leiocarpa* individuals in stands under low disturbance (22.00 ± 6.18 cm) was significantly higher than that obtained in stands under high human disturbance (12.95 ± 2.65 cm) ($P = 0.003$). This difference may be due to the combined effect of anthropogenic disturbance, including selective logging of adult individuals and pruning branches to feed livestock and treat disease, in stands under high human disturbance. These various human disturbances are not observed, or only to a limited extent, in stands under low human disturbance levels, due to restricted access to the population.

We analyzed the effect of stand floristic diversity on the structure of the five target plants. We noted that in the Guinean zone, where there were more species per plot, the mean values of the structural parameters of the target plants were generally higher than those obtained in the other two climatic zones (Tables 4 and 8). This suggests that a high floristic diversity improves tree structural parameters, but it may simply be the influence of climatic conditions [15, 16]. This suggests that a high floristic diversity improves the structural parameters of the trees, but it may simply be the influence of climatic conditions. Indeed, the Guinean zone benefits from the best climatic conditions (humidity, rainfall, temperature, etc.) compared with the other climatic zones.

The diameter structure of the five target species does not vary by climatic zone or disturbance level. In general, the diameter class distribution of individual trees of the target species showed a straight skewness with *C*-values ranging from 1 to 3.6, suggesting the predominance of young individuals. Such distributions have been observed for some of these target species in West Africa [21, 33, 34, 36]. The predominance of young individuals means that the population of the studied species is regenerating and foretells bright prospects for these plants. Furthermore, the pruning of adult individuals and the death of large trees can also lead to a predominance of young individuals. The cutting of adult individuals is a very common practice in Benin, and the wood obtained is used to make furniture or charcoal. In our study, the predominance of young individuals could be caused by the cutting of large trees. Indeed, the target species are widely used in Benin in traditional medicine, as human and animal food, furniture, construction, and fuel wood, among others [10].

5 Conclusions and sustainable use of the studied species

Due to the adverse effects of anthropogenic disturbance and climate change on natural resources, knowledge of the structure of the most widely used plant species is necessary to identify priority species for conservation and guide their sustainable use. The present study characterized the stands of five medicinal plant species used frequently in ethnoveterinary medicine in Benin. The structure of *M. lucida*, *S. mombin*, *T. leiocarpa*, *C. febrifuga*, and *V. doniana* were determined regarding the influence of climatic and anthropogenic disturbance levels on their diversity and structural parameter. The results showed that the floristic diversity and the species richness of the stands of the five species varied according to climatic zone. In addition, the structural parameters of the target species were influenced by anthropogenic disturbance. Therefore, it is necessary to take these specificities into account in the framework programs for the sustainable use and the conservation of these resources in their natural environments. Furthermore, *M. lucida*, *S. mombin*, and *V. doniana* were more available in stands under high disturbance in the Guinean zone, whereas *T. leiocarpa* and *C. febrifuga* were available in stands under high or low disturbance in the Sudano-Guinean and Sudanian zones. Thus, the local population in southern Benin can continue to make rational use of *M. lucida*, *S. mombin*, and *V. doniana* for their various uses. Similarly, the local population in central and northern Benin, especially the livestock farmers, can continue to use *T. leiocarpa* and *C. febrifuga* for feeding and treatment of animal diseases or other uses. However, they must avoid overexploitation because these plants are already under high anthropological pressure. The use of the five target plants must be rational because some resources are already adversely affected by human disturbance. This is the case for *T. leiocarpa*, which was absent from stands under high disturbance in the Guinean zone, while it is present in stands under high disturbance level in the Sudano-Guinean and Sudanian zones. Thus, it is desirable to promote the five studied species in Benin's agroforestry systems for sustainable use and better conservation, particularly for *T. leiocarpa* and *C. febrifuga,* which were under strong pressure in stands under high disturbance. Assistance can be provided for the regeneration and survival of young plants in their natural habitats. Finally, the artificial cultivation of these five species could be used for medium-term sustainable efforts.

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Data availability All data generated or analysed during this study are included in this published article.

Declarations

Competing interests The authors declare that they have no competing interests.

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