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Woody Species Diversity, Structure and Distribution of *Sterculia setigera* Del. in Togo (West Africa)

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Authors' contributions

This work was carried out in collaboration between all authors. Author WA wrote the protocol, performed the statistical analysis and wrote the first draft of the manuscript. Authors BD and WA realized the field works. Authors YAW, FF, MD and KW managed data analyses. Authors KA and KB designed the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aims to contribute to the sustainable management of *S. setigera*, a native gum and multipurpose tree in Togo. Especially, it aims to: (i) Assess the diversity of woody species within *S. setigera* stands, and (ii) Analyze the distribution, abundance and structure

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of *S. setigera* trees, according to contrasting environmental factors and human activities within the different eco-floristic zones of Togo.
Place and Duration of Study: Fieldworks were done from 10 October to 15 December 2013 throughout Togo.
Methodology: Dendrometric and ecological data of *Sterculia setigera* stands were recorded in 350 plots. In each plot, total height and girth of all woody species with diameter at breast height (DBH) ≥ 10 cm were measured and all human activities were recorded. In addition, seedlings and suckers of *S. setigera* species (DBH < 10 cm) were counted. The spatial distribution analysis of the species was done using Geographic Information System (GIS).
Results: Ninety six (96) woody species distributed among 71 genera and 31 families were identified. The highest species richness were recorded in the eco-floristic zone I (82 species), followed by zone III and zone II (41 and 40 respectively). Within these zones, the most representative woody species apart from *S. setigera* are *Vitellaria paradoxa* and *Parkia biglobosa*. In contrast, the most represented woody species in zone V were *Cussonia arborea* and *Odinaacida*. Statistic tests showed a significant difference of *S. setigera* densities following eco-floristic zones (*p*=0.00); especially between zone I and zone V (30.45 stems/ha and 7.57 stems/ha respectively). The overall regeneration rate was weak with a total absence within zone V. This regeneration status could justify the relatively few small stems proportion described by the coefficient of skewness values (g>0). Green Index values (GI, nearest 0) showed a random distribution of the species. The main human activities threatening *S. setigera* stands were bushfire, woodcutting, pasture and agriculture. According to the level of human activities Fisher test showed a significant difference (*p*=0.00), particularly between zone I with highest activities level and zone V with lowest activities (mean, 2.62±1.12 and 1.07±0.26).
Conclusion: The species richness within *S. setigera* stands and the density of *S. setigera* decrease from north to south (respectively from eco-floristic zone I to V). Both density and regeneration of *S. setigera* were shaped by human activities and environmental factors. Weak regeneration highlights that the future existence of the species is jeopardized.

Keywords: Sterculia setigera; forestry inventory; sustainable management, Togo.

1. INTRODUCTION

The distribution, abundance and structure of plant species are shaped by biotic and abiotic factors such as rainfall, temperature, topography, soil, luminosity, and human activities [1,2]. These factors determine the geographic extent of biodiversity and ecosystems. Any fluctuations or changes affecting one factor, affects directly the others and consequently species.

In general, human activities affect plant species demography and mostly multipurpose tree species [3-5]. Agriculture, bushfire, tree cutting, grazing, inappropriate fruits picking and other organs overuse are quoted among these anthropogenic activities. Several researches have confirmed, and determined bushfire as a key factor which contributes in the maintenance of savannah ecosystems, suitable for pastoralism [6,7]. Even if it is known that bushfire contributes to some seeds germination, it consumes in most cases plant seeds and seedlings reducing their regeneration capacity. Sometimes, trees are cut for timber, fuel wood, charcoal production and construction material needs threatening mature individuals [8-10] and reducing seed dispersal. Seed dispersal is also limited by the fruits and seeds overharvesting [4]. Others organs overuse, especially bark and roots harvesting affect also plant survival capacity [11,12].

In West Africa, people use a wide range of plant genetic resources to meet their daily life needs. Plants provide food, medicine, construction material, artistic material, cosmetic, fuel wood, and remain an important source of income for the rural community [13-16]. As a result, human population growth increases the pressure on plant genetic resources, which are threatened or even vanished. Human population explosion induces the erosion of plant resources diversity, soil degradation, and land cover decrease. The ecosystem and environment issues observed are almost generated by the overexploitation of lands, perpetual increase of croplands and the development of urbanization. Understanding the impact of environmental factors and human activities on the diversity, distribution, abundance and structure of plant species are essential for explaining and forecasting their sustainable management.

Sterculia setigera Del. is among multipurpose tree species of Sahel-Sudanian and Guinean savannahs occurring on a wide range of soils, particularly on rocky hills and gravel soils [17,18]. In West Africa, it is distributed from Senegal to Cameroon, and in Oriental Africa from Eritrea to Angola [19]. Apart from indigenous uses as medicine, food, cosmetic, the species has a high economic value [17] due to its gum. The exploitation of this gum is mainly well-known in Senegal, the second world's largest exporter after India.

In Togo, the species is scattered from the northern to southern throughout the country, along climatic gradient, and according to different soil types and geomorphological ranges. Studies focused on this species concerned mainly indigenous ecological knowledge, its use values and management through the country among ethnic groups [12,14,20,21]. These studies showed that the species is well known mainly in medicine, but its gum economic value is ignored by local populations. Studies concerning its structure and regeneration status in sudanian zone highlighted its vulnerability within natural spaces [22] where it is subjected to threats.

Therefore, to achieve sustainable conservation and valorization purposes, this study aims to: (i) assess the diversity of *S. setigera* stands and (ii) analyze the distribution, abundance and structure of *S. setigera*according to contrasting environmental factors and human activities within the different eco-floristic zones of Togo.

2. MATERIALS AND METHODS

2.1 Study Area

Togo (56600 km²) with a population of 6 191155 inhabitants and a mean density of 119/km^2 [23] is located between 6º06'N and 11º08'N latitudes and 0°09 W and 1º49 W longitudes on the coast of the Guinean Gulf. The country is subdivided into 5 administrative and economic regions: Savannahs, Kara, Central, Plateaus and Coastal. The southern part of the country (Maritime and Plateaus regions) is more urbanized than the northern ones (Savannahs, Kara and Central regions) where poverty is very acute. The current unemployment rate (between 25% and 33%), the extreme poverty which affects mostly rural population and the recent climatic fluctuations, particularly drought and flooding recurrence induce ecosystems degradation [24-26].

Togo is subdivided into 2 major climatic zones by the 8ºN latitude. The climate type in the southern part is subequatorial with two rainy seasons and two dry seasons. The Northern part has a Sudanian tropical climate with one short rainy season and one long dry season. Based on geo-climatic factors, the country is subdivided into 5 eco-floristic zones [27]: I, II, III, IV and V respectively from northern to southern part. In zone I or northern plains, the vegetation is a mosaic of Sudanian savannahs. The mean annual rainfall varies between 1000 and 1100mm/year and concentrated between May and October. The zone II corresponding to Togolese northern mountains is a mosaic of Sudanian savannahs, open forests and dry dense forests. The annual mean rainfall is around 1300mm/year with a maximum between August and September. Zone III, located in the central east, is the domain of Guinean savannahs and dry dense forests. Rainfall varies between 1200 and 1500 mm/year. Zone IV corresponding to Togo Southern Mountains is characterized mainly by semi-deciduous moist forests. The mean rainfall oscillates around 1800mm/year. The coastal plains, zone V is constituted by a mosaic of forests (sometime small relic of sacred forests), savannahs, thickets and meadows. A deficit rainfall oscillating around 800mm/year marks the coastal plains.

The relief is essentially characterized by Atakora mountain range sling the country from Northeast to Southwest with tops reaching sometime 900m in the southern part. On both sides of this mountain range, are arranged vast plains: Oti and Mô plains in the north and Mono plain in the southeast. Based on geomorphology, four major groups were described [28-30]: inshore sedimentary basin, peneplains (southeast plain covered entire eco-floristic zone III, and the one of Dapaong northern area in eco-floristic zone I), Atakora mountains and hill domains, and the north basin composed by Mango clay plain, Dapaong and Bombouaka sandstone tablelands. The country is shared by three big hydrographic basins: Volta basin in the north modeled by Oti River and its tributaries (Kara, Koumongou), Mono basin in the center, and inshore basin crossed by Zio and Haho rivers.

2.2 Sampling Design and Data Collection

Data were collected from 10 October to 15 December 2013. Before the field survey, 120 squares of 10x10km were chosen on a net grid map of Togo (Fig. 1). These squares were chosen in order to cover the entire study area and correspond to the species stands previously identified. Two neighboring squares were chosen in such a way that they were not contiguous; one square distanced them at least (10km). Squares located within eco-floristic zone IV were not surveyed, because *S. setigera* was not observed during previous studies [12,31]. In each square, 1 to 5 plots were placed according to the presence of the target species. Data were collected within plots sized 30mx30m in savannahs, 50mx50 m in farmlands and fallows, 20 m x 20m in open forests, and 50mx10m in riparian forests. The selection of plot sizes was justified by the fact that they were successfully used in Togo and its neighbouring countries [1,5,22,32-35]. A total of 350 samples were established: 257 in eco-floristic zone I, 27 in eco-floristic zone II, 50 in eco-floristic zone III; and 15 in eco-floristic zoneV. The number of plots per zone were depended on the size of the zone and *S. setigera* stands representativeness. The plots were spaced at least 500m. In each plot, height and diameter of all trees with diameter at breast height (DBH) equal and greater to 10 cm were measured [22,35,36]. Individuals with diameter less than 10 cm were considered as potential regenerations [1,5,22].

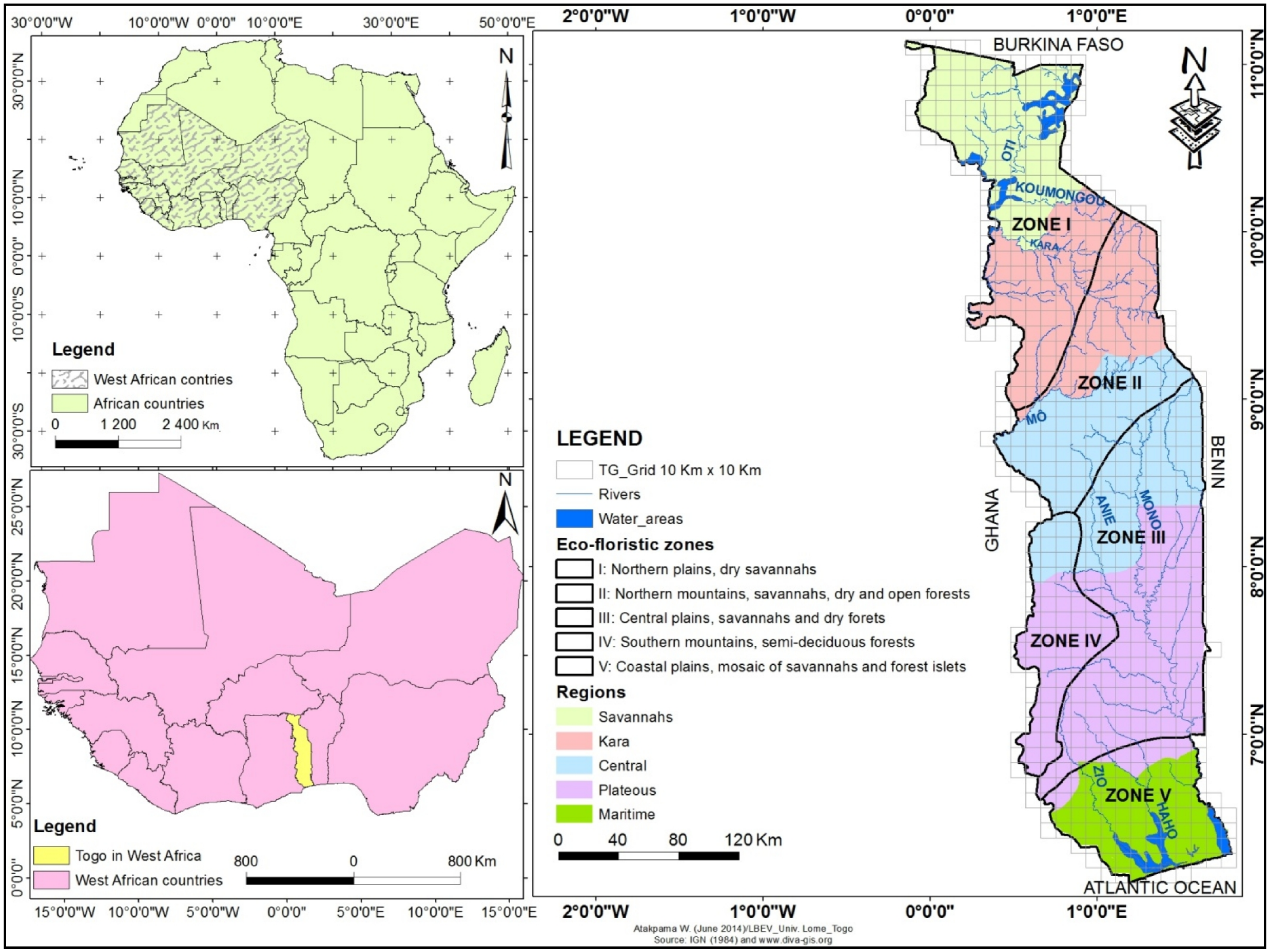

Fig. 1. Administrative/economic, eco-floristic subdivisions and hydrography of Togo and sampling design

Potential regeneration of *S. setigera* (stems with DBH <10cm): saplings and suckers were counted, not in subplot as described by several studies [37,38], since it was quite difficult to come across them. In addition, in each plot, environmental parameters: topography (plain, mountainside, tableland, ravine), exposition, vegetation cover, type of soil, soil texture, outcrop, and human activities (bushfire, woodcutting, plant organs harvesting, grazing, field, hunting and building settlements) were recorded. Geographic coordinates of all plots were recorded using the GPS (Global Positioning System).

2.3 Data Analysis

Data were processed using XLSAT 2008, Minitab 16, and ArcGIS 10. The latter (ArcGIS 10) was used for mapping while the others were used for forestry inventory data processing. Fisher test was used to confirm or denied the observed difference of recorded variables.

All plant species recorded were clustered according to their families following Brunel *et al.* [39], Arbonnier [19] and Akoégninou et al. [40]. For each eco-floristic zone, several parameters were assessed. The diversity of woody species was analysed using the species richness (N_0), Shannon Diversity Index (*H*, in bits), and the Pielou evenness index (*E*) [41]. The mean diameter (*Dm*, in cm), basal area (*G*, in m²/ha), the Lorey's mean height (H_L, in m), mean densities (*D*, in Trees/ha) of woody species (DBH ≥ 10cm) were computed both for all tree species including *S. setigera*. The species richness (*No*) is the total number of species recorded within a target area. The Pielou's evenness measures the similarity of the abundance of the different woody species sampled. Its value varies between 0 and 1. The value tends to 0 when one or few species had higher abundance than others and 1 in the situation where all species had equal abundance. The Lorey's mean height (H_L) is the average height of all trees found in the stand, weighted by their basal area [42]. The place occupied by a given tree species and family encountered in each eco-floristic zone were respectivelydetermined using the Importance Value Index (*IVI*) and Family Importance Value (*FIV*) [43-45].

In addition to the above-mentioned parameters, the regeneration rate, Green's Index, coefficient of skewness and basal contribution were calculated specifically for *S. setigera*. The rate of regeneration (*Nr,* in percentage) corresponding to the quotient between the number of individuals to DBH < 10 cm (*n*) and the overall number of individuals (juvenile and adult individuals) was used to appreciate the potential regeneration of the species. Otherwise, the mode of regeneration (seedlings and suckers, in percentage) was assessed using the ratio between the number of each type of regeneration and the overall number of regenerations (*Nr*). Green's Index (*GI*) [46] was used to appreciate the distribution of *S. setigera* individuals. *GI* varies between 0 (for random distribution of individuals) and 1 (for maximum clumping). The coefficient of skewness (*g*), number of individuals per hectare plotted against class midpoint [47] was used to assess the relative proportion between large and small diameter individuals. The coefficient of skewness, $g < 0$ describes a distribution with relatively few large stems and many smaller ones; in contrary $g>0$ means size distribution with relatively few small stems and many large stems [47,48].The part of *S. setigera* trees in the overall stand basal area of trees was weighted by assessing its basal area contribution (Cs, in percentage).

S. setigera stems were grouped into diameter classes of 10 cm amplitudes using Minitab 16 coupled with Excel. The Minitab 16 helped to calculate the theoretical Weibull parameters while the Excel was used to calculate Weibull densities and construct figures. The structures were adjusted with the 3-parameter Weibull theoretical distribution because of its flexibility and simplicity [49]. The 3-parameter Weibull theoretical density function used is represented as follows:

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

x = tree diameter, a = location parameter corresponds to the lower bound, here to 10 cm, b = scale parameter linked to the central value of tree diameter of the considered stand and c = shape parameter of the diameter structure.

Seven different threats: woodcutting, pasture, bushfire, charcoal production, plant materials harvesting, agricultural practices and hunting were recorded in each sample. Anthropogenic threats were assessed using the relative frequency of each threat recorded in each given eco-floristic zone. The relative frequency is the ratio of the number of plots where a given threat was recorded by the total number of plots. Anthropogenic threat levels were weighted by using the mean number of threats recorded by plot. Anova-One Way test was performed to determine whether the level of threats was significantly different or not.

The species spatial distribution was analyzed using Geographic Information System (GIS) software, ArcGIS 10. For this analysis, all plots coordinates were coupled to the densities of *S. setigera* (Stems/ha) and projected on eco-floristic map of Togo. The spatial analysis of distribution was realized using Neutral Neighboring Interpolation technic. This technic was chosen because the distribution generated is close to the reality.

3. RESULTS

3.1 Species Composition

A total of 21638 stems of woody species, including 1087 individuals of *S. setigera* with DBH ≥ 10 cm were measured. In general, 96 woody species distributed among 71 genera and 31 families were recorded. The most representative families were Combretaceae (13 species), Mimosaceae (10), Moraceae (8), Anacardiaceae (7), Caesalpiniaceae (7), Fabaceae (6), and Rubiaceae (6).

Woody species richness and correspondent families differed according to eco-floristic zones. The highest species richness was recorded in eco-floristic zone I (82 species, 67 genera and 27 families) with Shannon Diversity Index and Pielou Evenness of 3.83 and 0.61, respectively. It was followed by zone III and II with species richness nearest similar of 41 and 40, respectively. These zones had the same Pielou's Evenness of 0.78, but Shannon Diversity Index was 4.17 and 4.09, respectively for zones II and III. Only seven woody species were recorded within the zone V. The Shannon Diversity and Pielou Evenness were respectively 1.12 and 0.41. Within the 3 first zones the Important Value Index (*IVI*) showed that the most representative woody species companion of *S. setigera* Del. are *Vitellaria paradoxa* (C. F. Gaertner) and *Parkia biglobosa* Jacq (Table 1). The IVI pointed out that *S. setigera* was more represented in eco-floristic zone I and III than II. Their respective IVI values were 190.24, 174.88 and 146.95. In contrast, the most represented woody species companion in eco-floristic zone V were *Cussonia arborea* Hochst. And *Odinaacida* (A. Rich.) Oliv.

The Family Important Value (FIV) showed that the most important families were *Sterculiaceae, Mimosaceae and Combretaceae* for the eco-floristic zone I, II and III while

Sterculiaceae, Mimosaceae and Araliaceae were most important within eco-floristic zone V (Table 2).

3.2 Structural and Regeneration Characterization

The density of the overall woody species and target species varied considerably following eco-floristic zones. The highest density of *S. setigera* was recorded in eco-floristic zone I (30.45 stem/ha and 71.50 all species considered) while the lowest was found in eco-floristic zone II (7.57 stems/ha and 39.67 trees/ha for all species). It seems quite similar in the two others zones: III and V respectively 19.84 stems/ha and 21.48 stems/ha (Table 3). Statistic test showed a significant difference of *S. setigera* densities according to eco-floristic zones, especially between zone I and V (p = 0.00). The variation of *S. setigera* densities within each eco-floristic zone was shown by Fig. 2. According to this figure, the species is more distributed and abundant within eco-floristic zone I and II.

Table 1. The three most important species of *S. setigera* stands in each eco-floristic zone

Eco-floristic zones	Species	*FREQ sp*	*DEN sp*	*DOM sp*	*IVI*
Zone I	*S. setigera* Del.	100.00	42.59	47.66	190.24
	V. paradoxa(C. F. Gaertner)	24.18	6.75	4.61	35.54
	*P. biglobosa*Jacq.	16.39	4.18	6.20	26.78
Zone II	*S. setigera* Del.	100.00	19.80	27.16	146.95
	*P. biglobosa*Jacq.	41.67	20.30	35.45	97.43
	V. paradoxa(C. F. Gaertner)	50.00	10.15	8.95	69.10
Zone III	*S. setigera* Del.	100.00	26.01	48.88	174.88
	V. paradoxa(C. F. Gaertner)	57.73	15.01	6.79	79.54
	*P. biglobosa*Jacq.	14.43	3.75	6.98	25.17
Zone V	*S. setigera* Del.	100.00	80.88	91.13	272.01
	*C. arborea*Hochst.	20.00	8.82	5.62	34.44
	O. acida (A. Rich.) Oliv.	6.67	2.94	0.90	10.50

FREsp = Relative frequency, DENsp = Relative density, DOMsp = Relative dominance and IVI = Important Value Index

Table 2. The four most important families according to eco-floristic zones

Eco-floristic zone	Family	Genera	Species	FIV
Zone I	*Sterculiaceae*	1	1	91.46
(F = 27, G = 67, N_0= 82)	*Mimosaceae*	6	9	29.26
	Combretaceae	6	10	26.28
	Anacardiaceae	6	7	19.74
ZONE II	*Mimosaceae*	1	1	58.26
(F = 19, G = 34, N_0 = 40)	*Sterculiaceae*	1	1	49.45
	Combretaceae	3	6	28.42
	Moraceae	1	4	22.17
Zone III	*Sterculiaceae*	1	1	77.32
(F = 19, G = 37, N_0 = 41)	*Combretaceae*	4	7	33.16
	Mimosaceae	4	5	30.37
	Caesalpinioideae	5	5	25.11
Zone V	*Sterculiaceae*	1	1	186.29
(F= 6, G = 7, N_0 = 7)	*Mimosaceae*	2	2	33.52
	Araliaceae	1	1	28.73
	Anacardiaceae	1	1	18.12

F = Number of family; G = Number of genera; N_0 = Species richness, FIV = Family Importance Value

The difference between woody species densities and *S. setigera* coupled with girths influenced the basal contribution. The latter was most elevated in Zone V, followed by zone III and I. It was noticed that the spatial extends of *S. setigera* stands within eco-floristic zone V is restricted in the northwest. The other characteristics such as height, diameter and basal area of the overall woody species were summarized in Table 3.

Two types of regeneration were identified: seedlings and suckers. The regeneration rate of seedlings was higher than suckers (Table 3). The overall regeneration rate showed a weak regeneration of the species. Juveniles individuals were absent in eco-floristic zone V. The GI value showed a random distribution of the species.

Table 3. Dendrometric characteristics of *S. setigera* overall stand of each eco-floristic zone: mean, standard deviation and probability values

Parameters	Zone I	Zone II	Zone III	Zone V	*p*
S. setigera					
Mean height (H_L, in m)	10.82±4.23	11.64±4.03	12.38±7.84	10.53±2.86	0.05
Mean diameter (*Dm*, in cm)	34.34±16.91	38.78±17.17	39.88±22.21	32.02±11.04	0.10
Density (*D*, stems/ha)	30.45±41.34	7.57±12.64	19.84±16.01	21.48±18.32	0.00
Basal area (*Gs* in m²/ha)	2.82±0.19	0.89±0.11	1.57±0.17	2.09±0.06	0.34
Regeneration density (*R*, stem/ha)	8.53	4.29	3.77	0.00	-
Regeneration rate (*Nr*, in %)	21.88	36.21	15.96	0.00	-
Seedlings rate (in %)	59.36	100.00	82.76	0.00	-
Suckers rate (in %)	40.64	0.00	17.24	0.00	-
Green's Index (*GI*)	0.05	0.03	0.13	0.16	-
Coefficient of skewness (*g*)	3.46	0.65	1.26	0.48	-
Overall woody species					
Mean height (H_L, in m)	11.28±4.04	11.65±4.25	11.66±5.36	10.53±2.86	0.51
Mean diameter (*Dm*, in cm)	30.45±16.90	42.49±16.02	29.09±16.56	32.02±11.04	0.00
Mean density (*D*, trees/ha)	71.49±180.8	39.67±76.2	48.44±86.2	26.56±27.9	0.30
Basal area (*G*, in m/ha)	5.91±0.20	3.29±0.11	3.21±0.12	2.14±0.06	0.45
Basal contribution (*Cs*, in %)	47.66	26.74	48.87	93.42	-

The distribution of *S. setigera* individuals by diameter classes shows a reverse ''J'' shape curve in zone I and III (shape parameter c corresponds respectively to1.20 and 1.00). This distribution occurs within population with a predominance of small individuals (Fig. 3). Comparing diameter class densities, they were higher in zone I than zone III. A left dissymmetric bell-shape is observed in zones II and V (c, 1.40 and 1.97, respectively) where individuals with DBH ≥ 80 cm are absent. Within these two latter zones, most individuals were concentrated respectively in the [20-30] and [30-40] diameter classes.

3.3 Anthropogenic Threats Level

Among seven human activities identified; five were identified to be recurrent in the area: bushfire, woodcutting, pasture, plant materials (barks, leaves, fruits, and roots) harvesting and agricultural practices. The two other activities (charcoal production and hunting), representing less than 17% of disturbances identified were seldom observed (Fig. 4). In general, the main activities within *S. setigera* stands are bushfires (34.29 %), followed by woodcutting (27.10 %) and pasture (21.10 %). Bushfires are started sometimes deliberately by cattle herders in order to provide pasture for their animals or rodent hunters with the goal to flush out rodents. To reduce the density of trees, peasants burned quite often stem collars during field settlements. Sometimes trees spared are edible fruit and vegetable trees well known and appreciated due to their social or economic importance. On the top of these three major activities, agriculture (8.15%) and plant materials harvesting (8.03%) were also identified as factors affecting woody species structure and abundance.

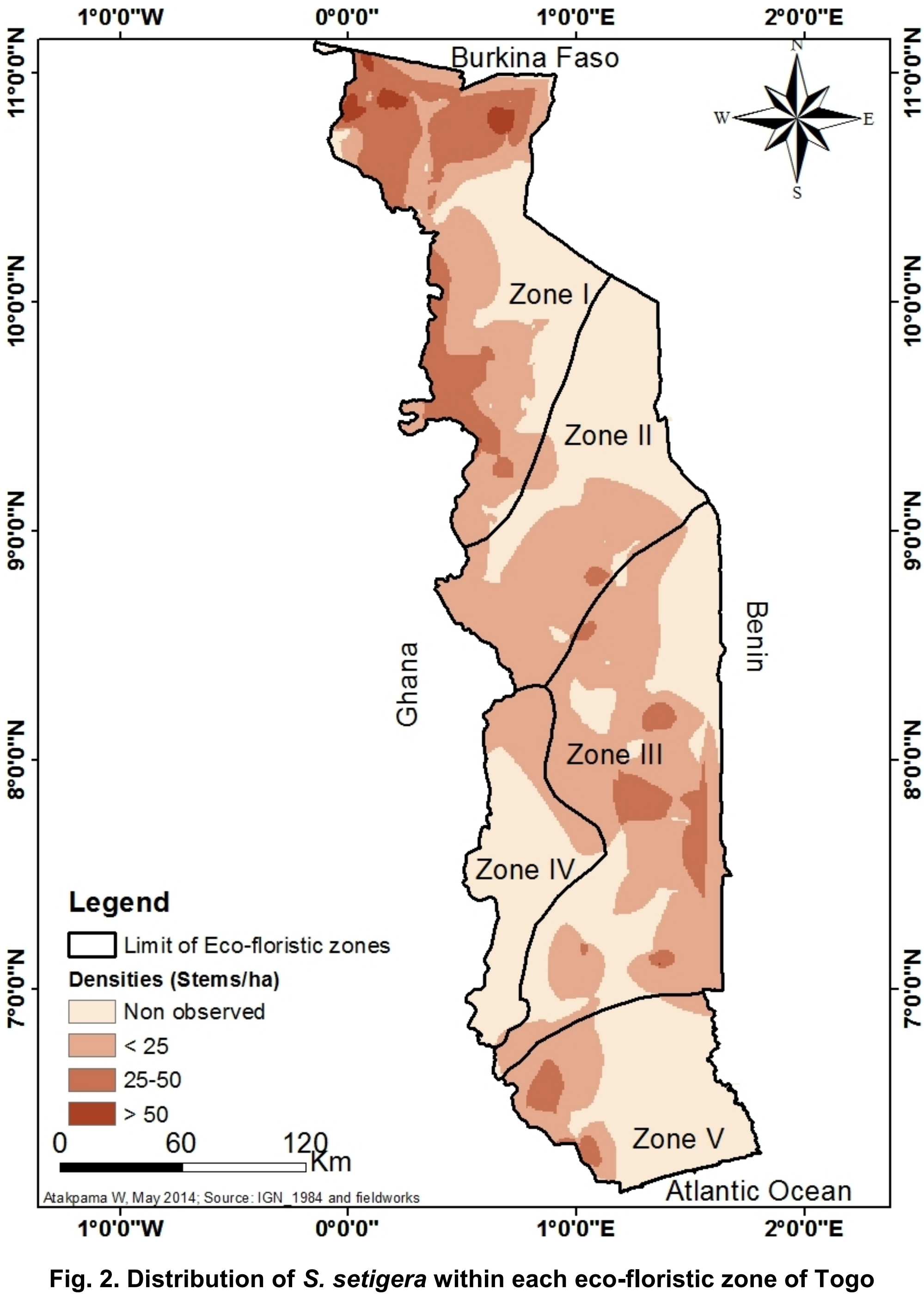

Fig. 2. Distribution of *S. setigera* within each eco-floristic zone of Togo

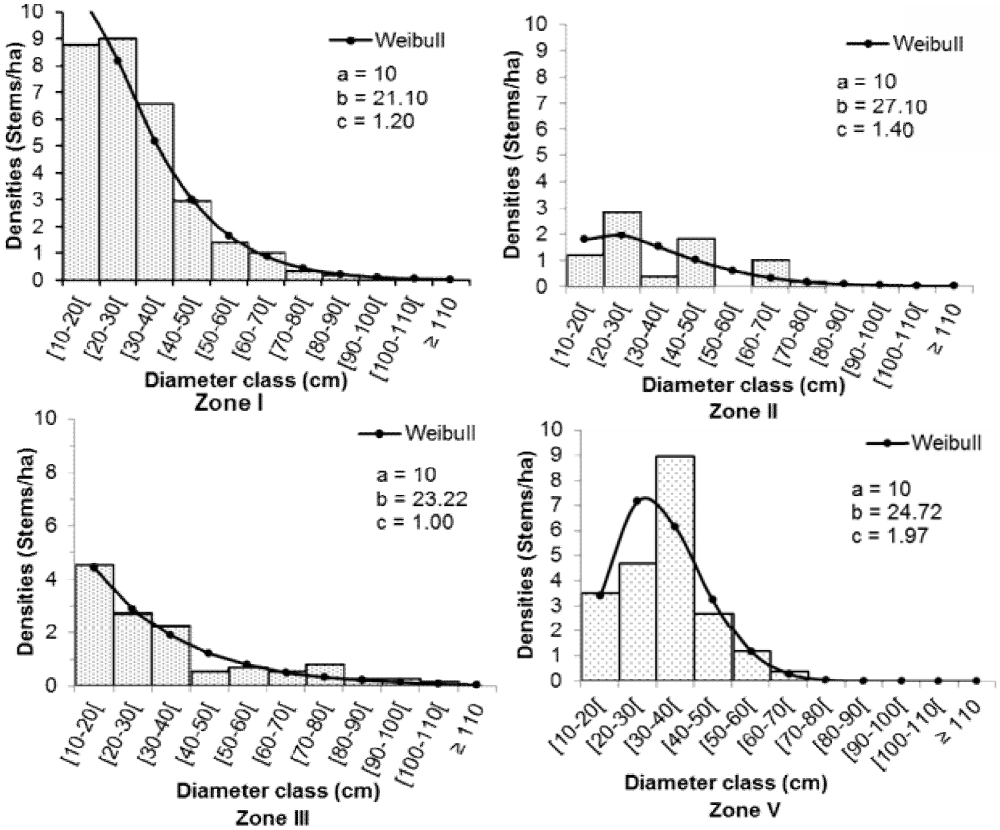

Fig. 3. Diameter class distribution of *S. setigera* population according to eco-floristic zone

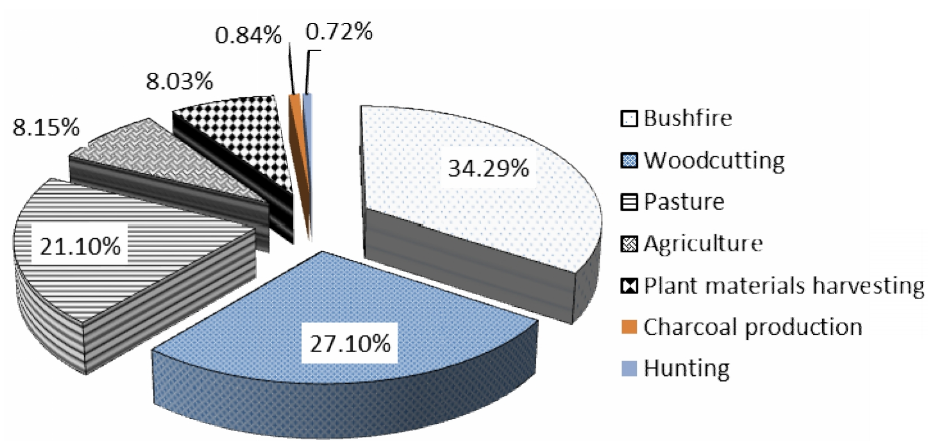

Fig. 4. Frenquencies of human activities identified winthin S. setigera stands in Togo

The distribution and the importance of anthropogenic activities vary across eco-floristic zones (Fig. 5). Anthropogenic activities decrease from north zone to the south (zone I to V). Zone I recorded more activities than the zone V. Except in zone V, all human activities were observed in the remaining three zones. Only three activities were pointed out in zone V. These activities were bushfire, followed by agriculture and woodcutting. Zone I distinguished itself, especially by the importance of plant materials harvesting and pasture. Exclusively in eco-floristic zone V, it was observed the attack of *S. setigera* individuals by a parasite as Loranthaceae taxon. Fig. 6 shows images of human activities encountered affecting *S. setigera* individuals described above.

According to the level of human activities, Fisher test showed a significant difference (p=0.00) particularly between zone I and V (mean number of human activities corresponded respectively to 2.62±1.12 and 1.07±0.26). In contrast, there is no significant difference between Zone II and III (1.85±0.83 and 1.82±0.91).

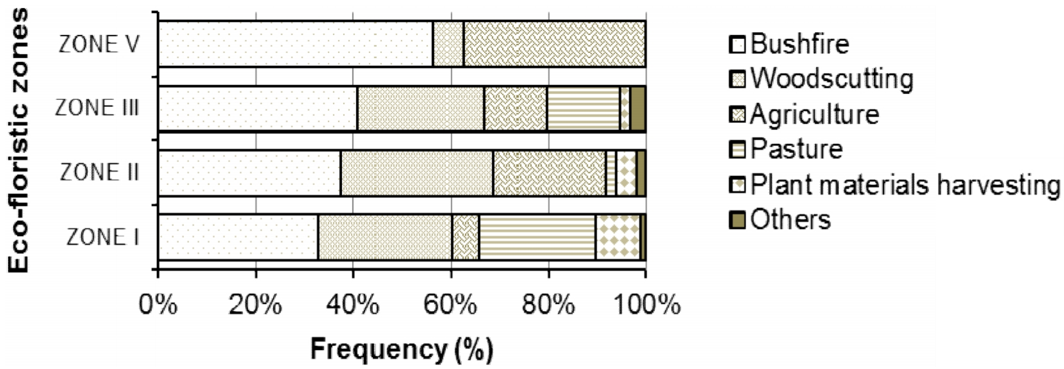

Fig. 5. Human activities distribution and importance according to eco-floristic zones

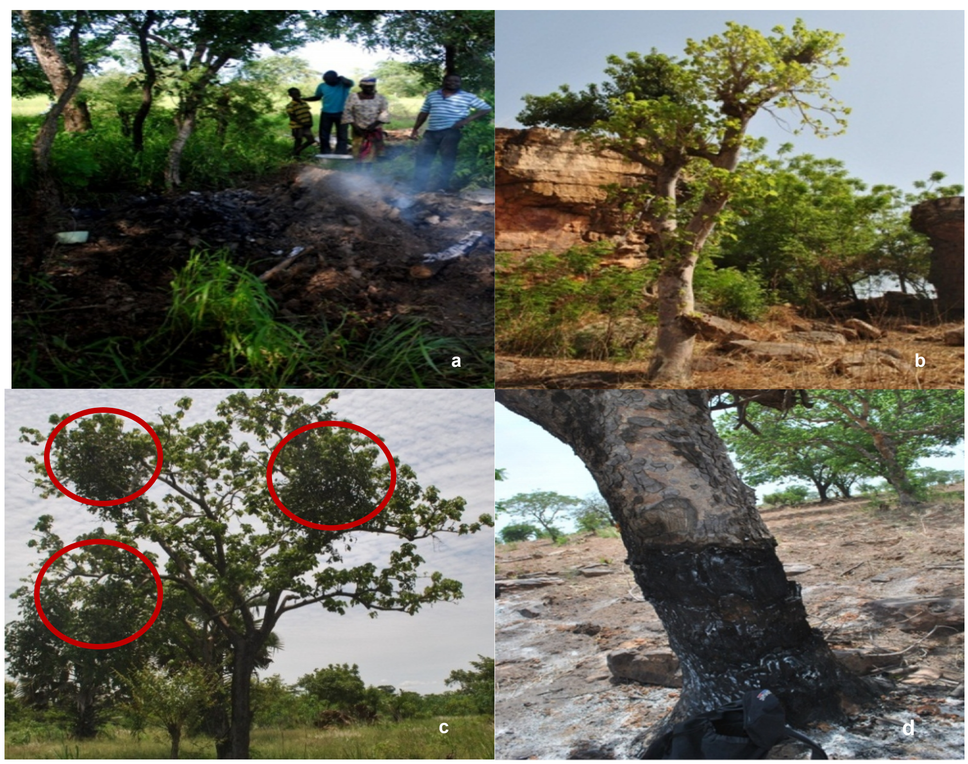

Fig. 6. Threats encountered within *S. setigera* stands a. charcoal production, b. mutilated stem, c. parasite infested individual, d. stem burned in a farmland

4. DISCUSSION

Species richness and alpha diversity of *S. setigera* stands were higher in eco-floristic zone I (82 woody species) while they were lower in zone V (seven species) situated respectively in the northern part and the southern part of the country. Atakpama et al. [22] reported almost 2 times less woody species (46 belonging to 42 genera and 22 families) within *S. setigera* stands in Sudanian zone. This difference could be due to the size of study area which is greater than the one reported by Atakpama et al. [22]. Even though, species diversity should be strongly affected by sampling area, the similar species number recorded in eco-floristic zone II and III where sampling plots were 2 times greater showed that this is not always true. Therefore, the differences according to geographic area could be linked to the elevation, climate type (rainfall, temperature and evapotranspiration) and human activities. Moreover, the human population growth and urbanization can be considered as key factors, which adjust the alpha diversity of plant species. These two factors coupled with farmers' selective actions on woody species component within their fields may affect the variation in alpha diversity. Zone V is reported as the most urbanized with highest human population density by comparison to zone I [23], where poverty is very acute [50]. In accordance with the study on the indigenous knowledge and the biodiversity management in Togo reported by Akpagana [51], the highest species richness in zone I showed a close relationship between southern part ethnic groups and plants. The common uses and the importance of plants in the livelihood of these ethnics groups [12,21] could justify their conservation, even outside natural stands, in parklands and their management during clearance.

The Green index used as an indicator of the degree of clumping shows that *S. setigera* is randomly distributed throughout the entire country. This distribution pattern could be due to anthropogenic threats since this random distribution increases from the south to north according to the anthropogenic threats gradient. It could be also linked to the regeneration type of the species when it was regenerated less by suckers. The random distribution observed was similar to the one of *Vitexdoniana* found in agroforestry parklands by Oumorou et al. [3]. Our results are contrary to those obtained for *V. doniana* [3] and *Isoberlinia* spp [52] in less disturbed stands. The suckering ability of these plants by opposition to *S. setigera* was pointed out as a factor that favors this distribution type. They were rather subjected to treatment by the owners of fields and their distribution depends on their uses.

The density of *S. setigera* in eco-floristic zone I was 4 times higher than in eco-floristic zone V. Both zones I and V are the antipodes of the country (northern and southern) with different climate, soil, topography and land use types. As described by several authors [18,19], the gravel soil, hill top environment where the species is often occurring and the rainfall of eco-floristic zone I are more suitable as potential habitat for the growth of the species. The implication of elevation and human activities in the abundance of the species were previously described in the Sudanian zone [22]. The highest use knowledge of this species in this zone remains also a favorable factor for its conservation by opposition to the eco-floristic zone V [12].

The coefficient of skewness ($g>0$) for size distributions showed the relative existence of the few small stems and many large stems within the overall stands. The diameter class distribution in ''J'' reverse corresponding to zone I and II which recorded the highest densities. The left dissymmetric distribution characterized shape parameters values ($1<c< 3.6$) describe the predominance of small diameter individuals [53]. In contrary shape parameter value ($c=1$), exponentially decreasing distribution observed in zone III characterize populations in extinction [54]. Even though, diameter class distribution is not a good predicator of population dynamics it is a shortcut in the absence of direct estimates of population size through time [47]. Therefore, the present findings suggest that *S. setigera* population could decline if any management decisions are not taken. This state is corroborated by the low regeneration rates.

There is a significant difference of the species regeneration. The weak regeneration could be justified by the relative few small stems proportion described by the coefficient of skewness values (g>0). Relatively, the regeneration density was more elevated in eco-floristic zone I, followed be zone II and III. Particularly, the eco-floristic zone V is devoid of young individuals. The absence of young individuals could be owed to the dispersal limitation of the species in this zone by parasite plant species (*Loranthceae* family) noted exclusively in this zone. The low regeneration rate noted shows that the species future stands were jeopardized. Several authors reported the low regeneration of *S. setigera* [38,55,56]. The poor regeneration was linked to human activities and the longtime germination of the species [57] which limit the germination in its natural habitat. However the swollen roots of *S. setigera* seedlings is a stock of water and nutriments which help them to survive drought as geophyte [38].

Three major anthropogenic threats appear to be recurrent: bushfire, woodcutting and pasture. These activities were also mentioned by other studies in Togo [7,36,58,59]. They vary from one zone to another and decrease from north to south of the country. Agriculture/bushfire destroys seeds and young individuals, decrease plant growth, reduce flowering and fruiting. Consequently, it reduces the plant dispersal and regeneration. The pasture affects also young individuals' growth, since they were browsed or trampled underfoot during grazing. The woodcutting affects particularly adult trees. According to Sankaran et al. [60], within savannahs, fire and browse affect negatively plant species recruitment, growth and structure. The fire was also reported to increase mortality and decrease regeneration of woody plant species [61].

5. CONCLUSION

Based on our results, woody species diversity within *S. setigera* stands decreases from northern to southern part of the country due to the variation of topography, climate type, and human activities. Globally, 96 woody species belonging to 71 genera and 31 families were recorded. Apart from *S. setigera*, the most represented woody species recorded in eco-floristic zones I, II, and III were *P. biglobosa* and *V. paradoxa*. However in zone V, companion and important woody species of *S. setigera* were *C. arborea* and *O. acida*. The distribution, the abundance, the structure and the regeneration of *S. setigera* were also affected by human activities, climate factors, topography, and soil type. Particularly; the abundance of *S. setigera* as well as human activities levels decrease from north to south latitudes. The eco-floristic Zone I, characterized by gravel soil, rocky hills domains, and Sudanian tropical climate was point out as the area where *S. setigera* is more represented. In the overall stands, the study showed weak regeneration of *S. setigera*, but eco-floristic zone V distinguished itself by the absence of regenerations. Among the seven human activities identified, the study highlighted bushfire, woodcutting and pasture as main threats on woody species diversity, structure, abundance and regeneration of *S. setigera*. These findings showed that future existence of the species throughout the country and especially zone V is jeopardized. In order to promote sustainable management of *S. setigera*, further studies focusing on multi-criteria analysis of factors affecting abundance and distribution of the species, its suitable potential habitat and gum yield are needed. Monitoring the natural regeneration and growth dynamic of the species within permanents plots should be established according to human activities' level.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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