International Journal of Plant & Soil Science
3(4): 330-346, 2014; Article no. IJPSS.2014.001

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Structure and Natural Regeneration of *Sterculia setigera* Del. Plants Communities in Sudanian Zone of 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. Author HP and WA realized the field works. Authors MD and KW managed data analyses. Authors KA and KB designed the study. All authors read and approved the final manuscript.

Original Research Article

Received 30th September 2013
Accepted 26th November 2013
Published 20th January 2014

ABSTRACT

Sterculia setigera is a multipurpose savanna tree with socio-economic importance due to its gum and cultural importance in sub-Saharan Africa. The present study was carried out in Togo's Sudanian area to characterize the structure and regeneration potential of *S. Setigera* in order to define a sustainable management plan associated to its valorization as gum species. Data were collected during May and April 2010. The methodological approach was based on forest inventory oriented by the presence of *S. Setigera*. Total height and stem diameter at breast height (dbh) greater than 10 cm of all trees species were measured in 97 plots. In each plot, ecological parameters were recorded and the seedling and suckers (dbh<10cm) of *S. Setigera* were counted. Forty six woody species belonging to 42 genera and 22 families were listed. Fabaceae, Combretaceae, Malvaceae and Moraceae were the dominated families. The prominent species were *S. Setigera*, *Balanites aegyptiaca*, *Lannea acida* and *Diospyros mespiliformis*. Presence/absence data of the overall species recorded in each plot was subjected to multidimensional scaling and results showed 5 plants communities: fallows, croplands, low side savannas, mean side and tablelands savannas and uplands savannas. The structure adjusted by 3-parameter

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Weibull showed reverse “J” shape for class diameter distribution with shape parameter varies between 1 and 3.6 showing a predominance of individuals with small diameter within the overall study area. The height structure showed a bell-shape and left dissymmetric distribution. The regeneration rate is very low (5.21 to 16.15). It is necessary to define a sustainable program for the conservation and valorization of this gum species.

Keywords: Sterculia setigera; structure; sustainable conservation; Togo.

1. INTRODUCTION

In sub-Saharan region, several woody species were recognized for their ecological, socio-cultural and economic importance [1-5]. Sometime important tree species such as wild edible fruits and those which have an economic value (timber tree species and trees which produce non woody forest products) are conserved in farmland by peasants and constitute agroforestry systems [6-10]. The importance of a given species determines its way of management. The most useful species were threatened due to their overexploitation, non-adapted methods of exploitation, the low sustainable management practices, and other threats such as grazing, bush fire and logging [7,10,11]. Facing the human population growth, pauperization and impacts of climate change, these pressures become more and more worrying [12]. Several plants species, especially multipurpose tree species regeneration and dynamics are seriously affected [13,14]. In order to schedule long-lasting management of these species, data such as tree species population structure, their regeneration and the impact of the various pressures are needed.

From family of Malvaceae, *S. setigera* [15] is well known as an indigenous multipurpose tree. It is used especially in human nutrition, traditional medicine, and cosmetics [5,16-20]. This plant species has socio-economic and cultural importance in sub-Saharan Africa [5,21,22]. Its exudate “karaya gum” is mostly extracted from private parkland and in forests in Senegal which is the world’s second largest exporter after India [19]. Within these countries, gum exploitation is a valuable source of income for many indigent smallholders.

In Senegal, several studies were carried out on *S. setigera*. These studies had concerned with socio-economic values [21], agroforestry management [3,23], seedling germination, vegetative propagation and ‘’In vitro’’ micro-grafting of adult material [24,25]. In view of sustainable conservation and improvement gum yield, several studies were realized, particularly on S*. urens* in India [26,27] and *S. setigera* in Senegal [24,25].

In Togo, studies focused on *S. setigera* are scanty until this day, although this tree species is found throughout the country. Despite its socio-economic importance, the species is threatened. Its organs withdrawal mainly for medicinal purposes, socio - cultural status (fetish tree or evil spirits home) and the total ignorance of the economic value of its gum [5, 17] compromise the species survival and regeneration [6]. Based on the economic value and various types of pressures on *S. setigera*, it becomes imperative to define better conservation strategies and promote the gum exploitation. Viewing the income generated by this activity, a reasonable exploitation of *S. setigera* gum can occupy populations, particularly peasant during the dry season [28], generate employments and decrease anthropogenic pressures on biodiversity.

For conservation, sustainable management and valorization of *S. setigera* stands in Togo, it is important to assess their structure and natural regeneration. The present study aims (i) to characterize *S. setigera* structure, (ii) analyze the natural regeneration and (iii) to assess human pressure on *S. setigera* stands in Sudanian area of Togo.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in *S. setigera* stands of ten (10) sites localized in the sudanian area of Togo extended from 0°06'-1°05'E and 8°55' - 11°06'N corresponding to the eco-floristic zone 1 (Fig. 1). It belongs to the northern endemism regional center [29]. This area corresponds to northern plains covered mainly by Mimosaceae and Combretaceae savannas with some shreds of gallery forests along Oti River and its tributaries. The relief is essentially characterized by the Oti alluvial plains. The area was dominated by leached tropical ferruginous soils, lithosols and hydromorphic black soils. The climate is Sudanian with unimodal regime. The annual average temperature is 25°C. The rainfall varies between 800 and 1100 mm. During the last 50 years, this area experienced hard climatic variability with a decreasing tendency of rainfalls and an increasing tendency of temperatures as well as a succession of dry periods and humid periods and change points corresponding to the climatic fluctuations noted generally in West Africa [30].

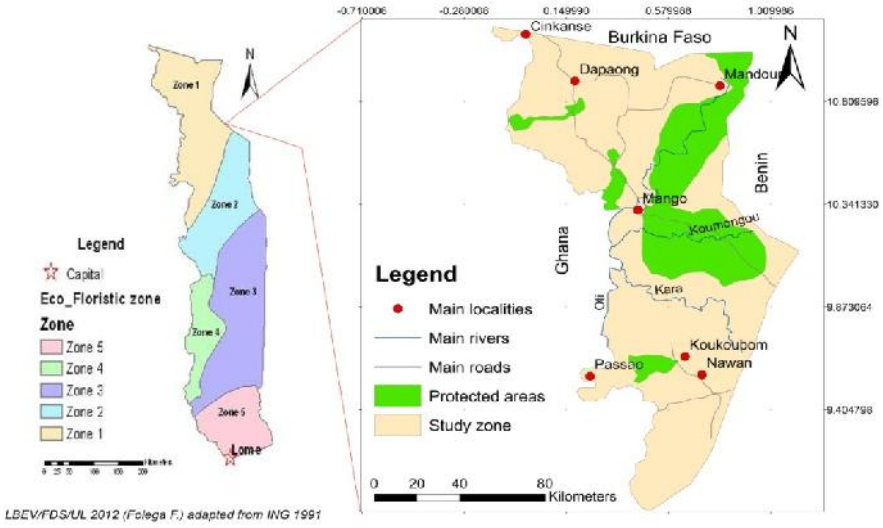


Fig. 1. Study area

2.2 Description of *S. setigera* Del.

S. setigera Del. also known as *S. tomentosa* Guill and Perr., *S. cinerea* A. Rich.is a gum species belonging to Malvaceae family [15]. It is deciduous trees often thrives well on hills, rocky, poor and little deep soils township of northern and north-guinea savannas [31]. The grayish, purplish peel detaches itself in large thin irregular plates, letting appear a smooth and sallow peel. Leaves are simple, densely pubescent and flowering often takes place in the second half of the dry season between February and April in northern zone (at the same

time as the foliation) and fruits maturation in December. Fruits are follicles containing big seeds.

2.3 Data Collection

Surveys were carried out within the *S. setigera* stands representing the variation of topography, land use system, and anthropogenic threats. Dendrometric and ecological data were recorded in 97 plots sized 30 m x 30 m in savannas and 50 m x 50 m in fallows and croplands. The choice of plots area is justified by the fact that they were used successfully in the same region of Togo [1,32-34]. Sampling was oriented according to the presence of *S. setigera*. In each sample plot, all woody species was recorded. Trees total height and diameter at breast height (dbh) greater than 10 cm of all trees were measured and the species recorded. The species seedlings and suckers of dbh < 10 cm considered as potential regeneration were counted. In addition several ecological parameters such as: topography, exposition, vegetation covers, humans activities (bushfire, grazing, dwelling, woodcutting, croplands), type of soil, soil texture, and outcrop were recorded within each plot. Plant species and families names conformed to those set by The Angiosperm Phylogeny Group II [15].

2.4 Data Analyses

The matrix "Plots x species" was submitted to an ascending hierarchical Classification according to the method of Ward with the Community Analysis Package (CAP) version 2.15 software. This analysis had allowed defining *S. setigera* plants communities.

For each plant communities the following parameters were assessed: the species frequency (*F*), the species richness (N_0), the Shannon's Diversity Index (*H*, in bits) and the Pielou's Evenness (*E*) [35,36]. The Pielou's Evenness (*E*) measures the diversity degree of a stand. The mean diameter of the trees (*Dm* in cm), basal area of the stand (*G* in m²/ha), the Lorey's mean height (H_L, in m), and the basal area contribution (Cs, in percent) was computed.

(1) The species richness (N_0) represent the number of species recorded in each stands;

(2) Species frequencies:

$$F = \left(\frac{Ni}{N}\right) \times 100 ;$$

Ni represents the number of individuals of a given species and *N* the overall number of all woody species with dbh ≥ 10 cm

(3) The Shannon's Diversity Index:

$$H = -\sum_{i=1}^{s} \left(\frac{Ni}{N}\right) Log_2 \left(\frac{Ni}{N}\right)$$

(4) The Pielou's evenness :

$$E = \frac{H}{Log_2(N_0)}$$

(5) The mean diameter (*Dm*):

$$Dm = \left(\frac{1}{N}\sum_{i=1}^{N} d_i^2\right)^{\frac{1}{2}} ; di \text{ represent the diameter of the } i-th \text{ tree in cm}$$

(6) The basal area of the stands (*G*)represent the sum of the cross-sectional area at dbh for tree with diameter greater or equal to 10 cm:

$$G = \frac{\pi}{4S}\sum_{i=1}^{N} 0{,}0001 \times d_i^2 \; ; S \text{ is the stands size per ha}$$

(7) The Lorey mean height (H_L) is the average height of all trees found in the stand, weighted by their basal area[37]:

$$H_L = \frac{\sum_{i=1}^{N} g_i h_i}{\sum_{i=1}^{N} g_i} \text{ with } g_i = \frac{\pi}{4} d_i^2$$

(8) The basal contribution (Cs) is the part of *S. setigera* tree in the overall basal area in the stands:

$Cs = \frac{Gs}{G}$; *Gs* the basal area of *S. setigera* tree in the stands.

Tree-density (*D*) was expressed in trees/ha. The rate of regeneration (*Nr*), the quotient between the number of individuals to dbh< 10 cm (*n*) and the overall number of individuals permitted to appreciate the potential of regeneration of the species.

(9) $Nr = \frac{n}{N+n} \times 100$; *n* is the mean density of tree with dbh< 10 cm and N is the mean density of tree with dbh ≥ 10 cm in the stands.

In addition, individuals of *S. setigera* were grouped into diameter and height classes with using Minitab 16 coupled with Excel. The species individuals were grouped respectively into diameter classes and height classes of 10 cm and 2 m amplitudes. The structures were adjusted with the 3-parameter Weibull theoretical distribution because of its flexibility and simplicity [38]. 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 represents, *b* = scale parameter and c = shape parameter of the structure.

The matrix "Plots x anthropogenic threat'' was use to evaluate the frequency of the different threats encountered. The importance of an anthropogenic threat was weight using following formulas: $F_{at} = \frac{n}{N} \times 100$; *n* = number of plots where a given anthropogenic threat was found in a given stand and *N* = total number of plots for the same stand.

3. RESULTS

3.1 Species Richness

Dendrometric measures concerned 1054 woody trees of which 573 were *S. setigera*. Forty six wood species belonging to 42 genera and 22 families have been inventoried. The most representative families are: Fabaceae (10 species), Combretaceae (5 species), Malvaceae (4 species) and Moraceae (4 species). The most represented species are: *S. setigera, Balanites aegyptiaca, Diospyros mespiliformis*, *Anogeissus leiocapa* and *Lannea acida*.

3.2 Vegetation Characterization

The multidimensional scaling showed 5 plant communities (G1, G2, G3, G4 and G5) grouped according to the following parameters: species composition, topography and anthropogenic threats (Fig. 2). G1 and G2 groups are found on plains and Low-hillsides especially on gravelly soil. The others plant communities (G3, G2 and G5) are found on rocky hills and tablelands (Fig. 3 & 4). The latters are less impacted by human activities.

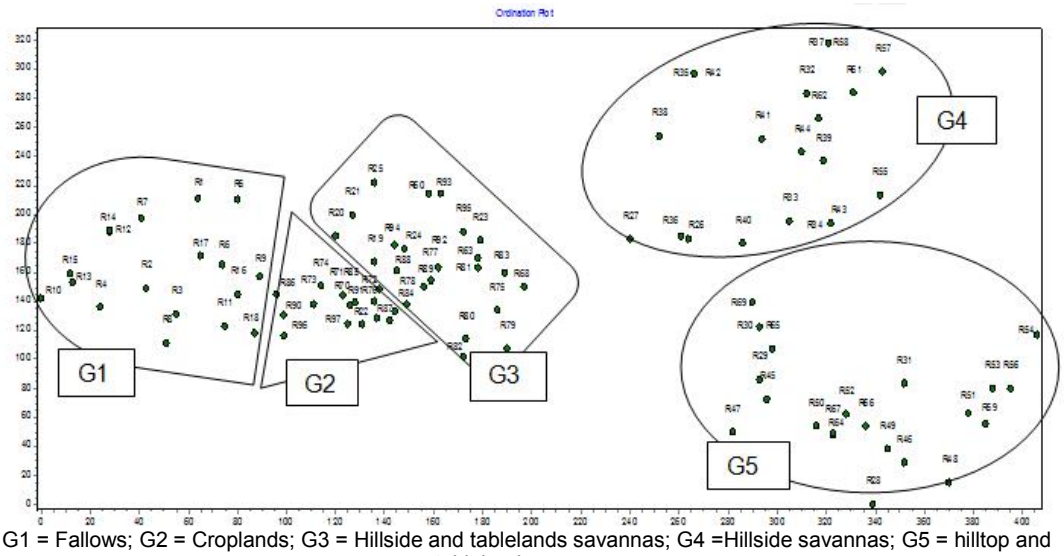
Plains and low-hillsides plant communities (G1) had 18 plots constituted by fallows found in Bassar and Dankpen prefecture. The species richness was 23; the Shannon diversity and the Pielou Evenness are estimated respectively about 3.48 bits and 0.77 (Table 1). *S. setigera*, *Lannea acida*, *Isoberlinia doka* and *Vitellaria paradoxa* were the most abundant species. The mean density was 66.67 trees/ha with a basal area of 4.46 m^2/ha. The density of *S. setigera* was 22.22 stems/ha and its regeneration rate was 12.20. The mean tree height and diameter of *S. setigera* were 11.77 m and 22.02 cm respectively.

Low-hillsides plant communities (G2) are made up of 14 plots composed of croplands localized principally in Kantindi village in Tône prefecture. The species richness was 6; the Shannon diversity and the Pielou Evenness are estimated respectively to 1.81 bits and 0.70. *S. setigera* and *Balanitesa egyptiaca* were the most represented species. The mean density was 65.87 trees/ha with a basal area of 7.2 m^2/ha. The density of *S. setigera* was 18.00 stems/ha and its regeneration rate was 16.0. The mean height and diameter of *S. setigera* were 09.97 m and 27.84 cm respectively.

Hillsides and tablelands plant communities (G3) are composed of 24 plots installed in woody and shrubby savannas localized in Kantindi. The species richness was 12; the Shannon diversity and Pielou Evenness were 2.66 bits and 0.74. *S. setigera*, *B. aegyptiaca,* and *Diospyros mespiliformis* were the most represented species. The mean density was 88.89 trees/ha with a basal area of 8.45 m^2/ha. The density of *S. setigera* was 45.83 stems/ha and its regeneration rate was 10.0. The mean height and diameter of *S. setigera* were 11.04 m and 27.09 cm respectively.

Hillsides woody savanna plant communities (G4) are composed of 20 plots localized in Dapaong in Tône prefecture. The species richness was 10; the Shannon diversity and the Pielou Evenness were 1.16 bits and 0.30. The most abundant species were *S. setigera*, *Prosopis africana* and *B. aegyptiaca.* The mean density was 73.89 trees/ha with a basal area of 4.48 m^2/ha. The density of *S. setigera* was 60.56 stems/ha and its regeneration rate was 16.15 respectively. The mean height and diameter of *S. setigera* were 10.99 m and 26.15 cm respectively. These plant communities are characterized by the best representativeness of *S. setigera* (Cs = 80.71).

Hilltops and tablelands woody savannas plant communities (G5) localized in Dapaong were composed of 21 plots. The species richness was 14; the Shannon diversity and the Pielou Evenness were respectively 2.33 bits and 0.65.The most represented species were *S. setigera*, *B. aegyptiaca* and *P. africana*. The mean density was estimated at 85.71 trees/ha with a basal area of 9.46 m^2/ha. The density of *S. setigera* was 48.15 stems/ha with regeneration rate of 16.15. The mean height and diameter of *S. setigera* 14.12 m and 28.78 cm respectively.



G1 = Fallows; G2 = Croplands; G3 = Hillside and tablelands savannas; G4 =Hillside savannas; G5 = hilltop and tableland savannas

Fig. 2. Factorial correspondence analysis ordination of97 plots in the system axes 1 and 2

Fig. 3. *S. setigera* stands found on hilltop at Dapaong
Photo W. Atakpama, April 2013

Fig. 4. *S. setigera* stands found on hilltop at Kantindi
Photo W. Atakpama, March 2013

3.3 Diameter and Height Class Structure of *S. setigera*

The diameter class distribution showed a reverse "J" shaped curve except from the G1 where the distribution showed a bell-shape distribution (Fig. 5.1). In the overall stand, trees with 10-30 cm were more abundant. The "J" distribution were observed within the different groups ($1 < c < 3.6$) means a stands with a predominance of trees with small diameter [39].

The height class structure of *S. setigera* within the five plant communities showed a bell-shape ($1 < c < 3.6$) and a left dissymmetric distribution. The most represented individuals are those having height between 4 to 8 m in the croplands (G2), 8 to 10 m in fallows (G1) and 8 to 24 m in savannas (G3, G4 and G5) (Fig. 5.2).

The variation of the regeneration rate can be owed to the human pressures. A total of 5 anthropogenic threats were identified. The main activities are: grazing, bush fires and wood withdrawal (Fig. 6). Bush fires made during dry season destroyed the seeds and sapling and reduced the species survival and growth potential (Fig. 7a). Grazing impact also the species regeneration (Fig. 7a) and organs withdrawal especially bark for medicinal uses affect adult trees survival.

In spite of the disturbances of *S. setigera* stands and its poor regeneration, the basal contribution (Cs generally greater than 50 %) and densities (Table 1) showed that the species is well represented and have the biggest diameter individuals by comparison to others woody species around. However its stands are jeopardized by human's activities especially quasi monospecific stand of Dapaong which is jeopardized by the extension of Dapaong city.

Table 1. Dendrometric characteristics of groups: mean, coefficient of variation (cv) and probability values (*p*)

Parameters	G1 (n = 18)		G2 (n = 14)		G3 (n = 18)		G4 (n = 18)		G5 (n = 18)		*p*
	mean	cv (%)	mean	cv (%)	Mean	cv (%)	mean	Cv(%)	mean	cv (%)	
S. setigera											
Density (*D*, stems/ha)	22.22	47.1	18.00	53.2	45.83	62.1	60.56	71.8	48.15	62.7	0.001
Diameter (*Dg*, cm)	22.08	39.3	27.84	40.8	27.09	50.9	26.15	42.7	28.78	37.1	0.006
Basal area (*G*, m²/ha)	2.50	97.9	3.96	124.5	4.99	114.9	3.94	94.3	4.54	96.1	0.146
Height (H_L, m)	11.77	21.15	09.97	30.0	11.04	29.3	10.99	42.3	14.12	45.1	0.000
Basal contribution (*Cs*, %)	56.17	43.3	55.03	35.8	59.02	45.6	80.71	36.7	48.00	50.6	0.004
Regeneration density (Nr, sapling/ha)	3.09	173.2	3.43	136.4	5.10	209.5	11.67	297.0	2.65	259.9	0.474
Regeneration rate (*Rr*, %)	12.20	-	16.00	-	10.00	-	16.15	-	5.21	-	-
Global											
Density (*D*, trees/ha)	66.67	59.1	23.71	59.3	88.89	89.5	73.89	67.7	85.71	53.7	0.829
Diameter (*Dm*, cm)	29.46	34.6	37.53	45.9	35.27	37.0	29.11	19.6	41.54	22.4	0.000
Basal area (*G*, m²/ha)	4.46	113.3	7.20	293.0	8.45	120.8	4.88	94.2	9.46	92.5	0.058
Height (H_L, m)	11.77	17.1	10.70	31.5	10.65	21.4	10.93	25.7	13.26	31.3	0.000
Species richness (N_0, species)	23	-	6	-	12	-	10	-	14	-	-
Shannon's diversity (*H*, bits)	3.48	-	1.81	-	2.66	-	1.16	-	2.33	-	-
Pielou's evenness (*E*)	0.77	-	0.70	-	0.74	-	0.30	-	0.65	-	-

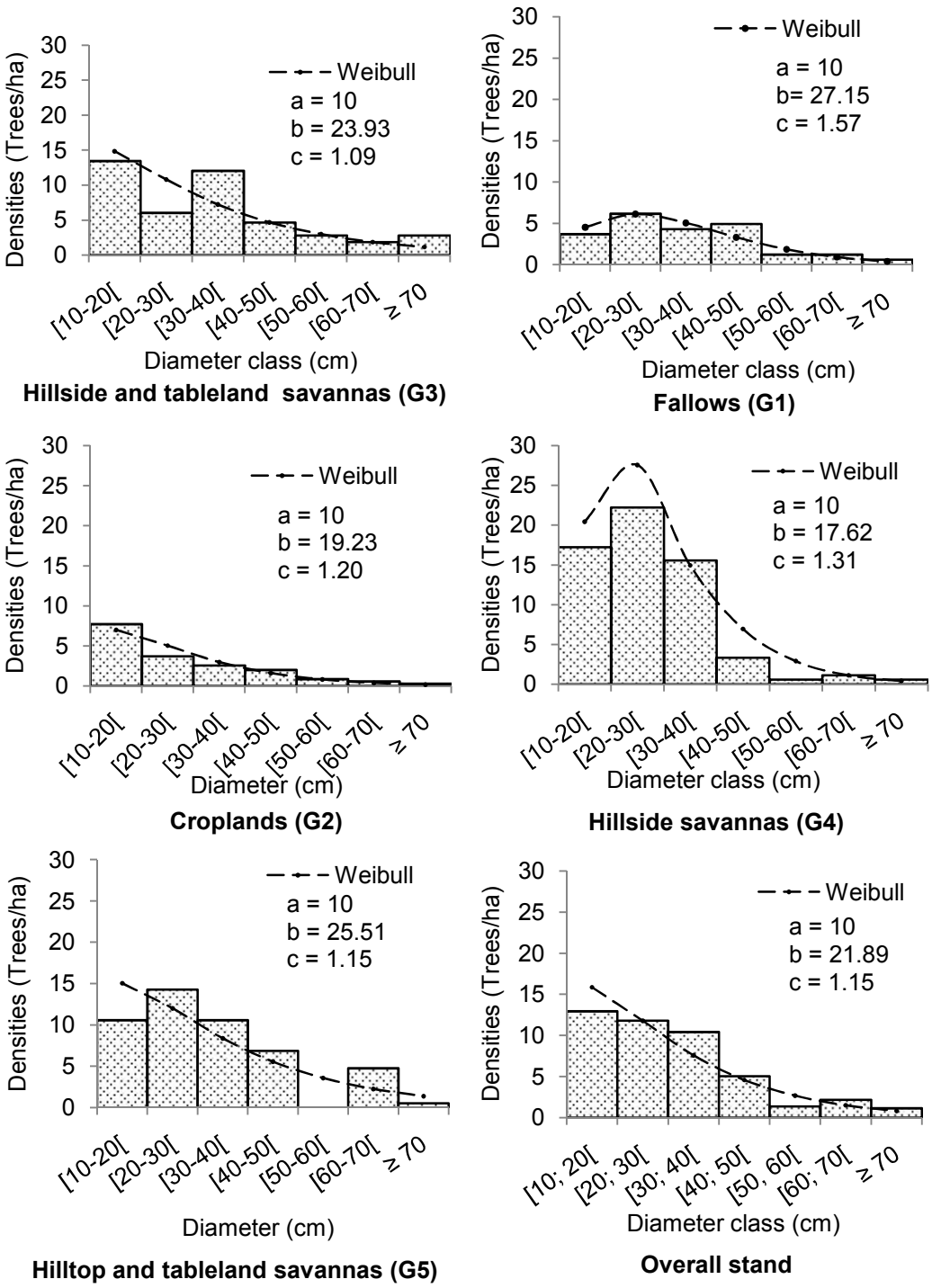


Fig. 5.1. Diameter structure of *S. setigera* population within the discriminated groups

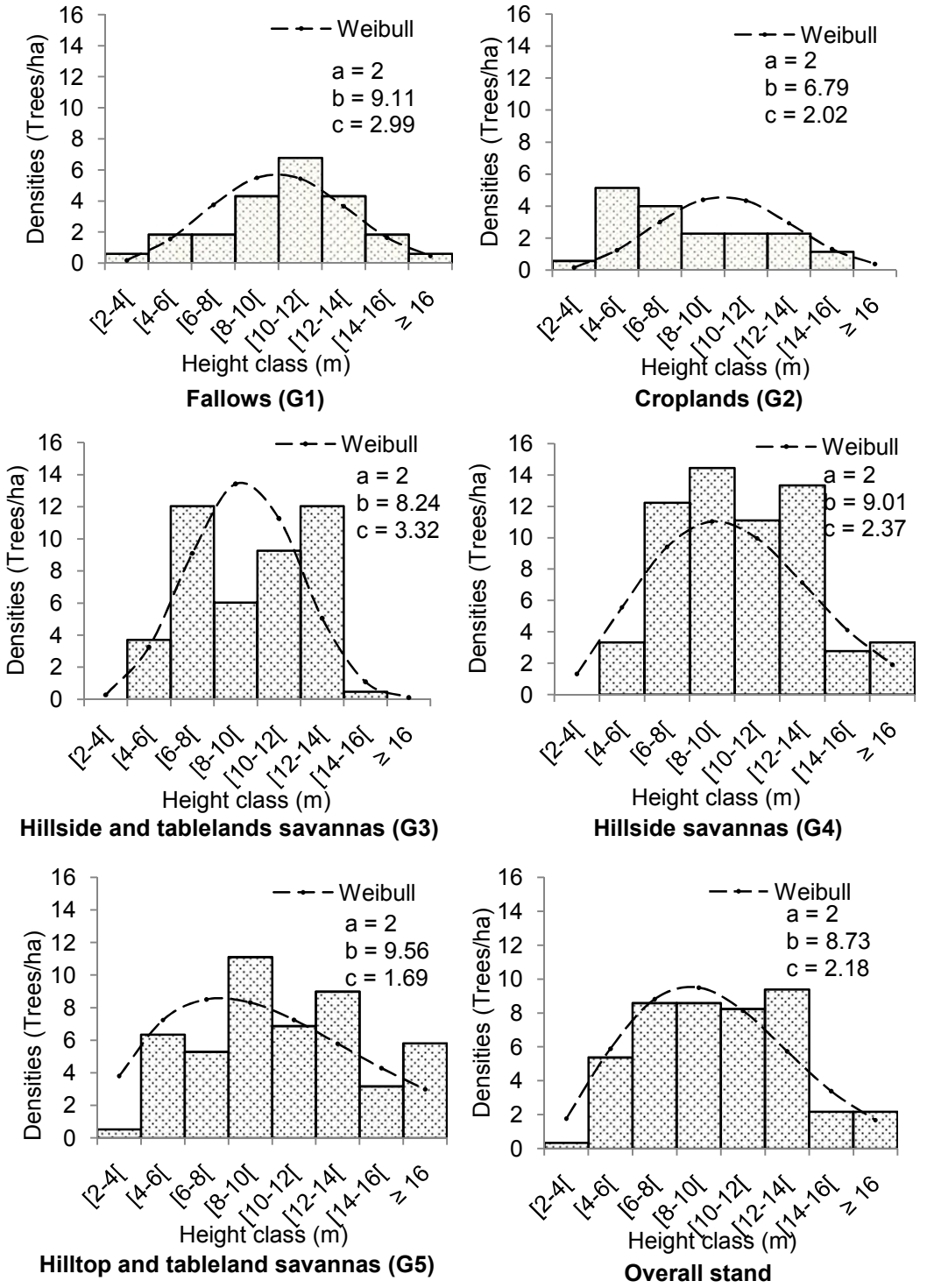


Fig. 5.2. Height structure of *S. setigera* population within the discriminated groups

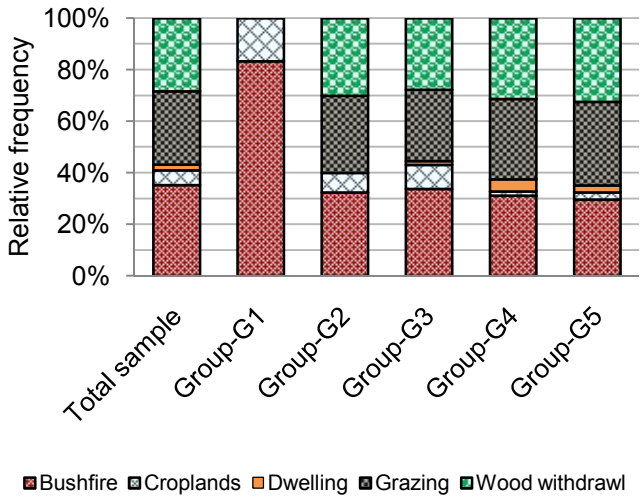


Fig. 6. Human's activities repartition within *S. setigera* stands in Soudanian zone of Togo

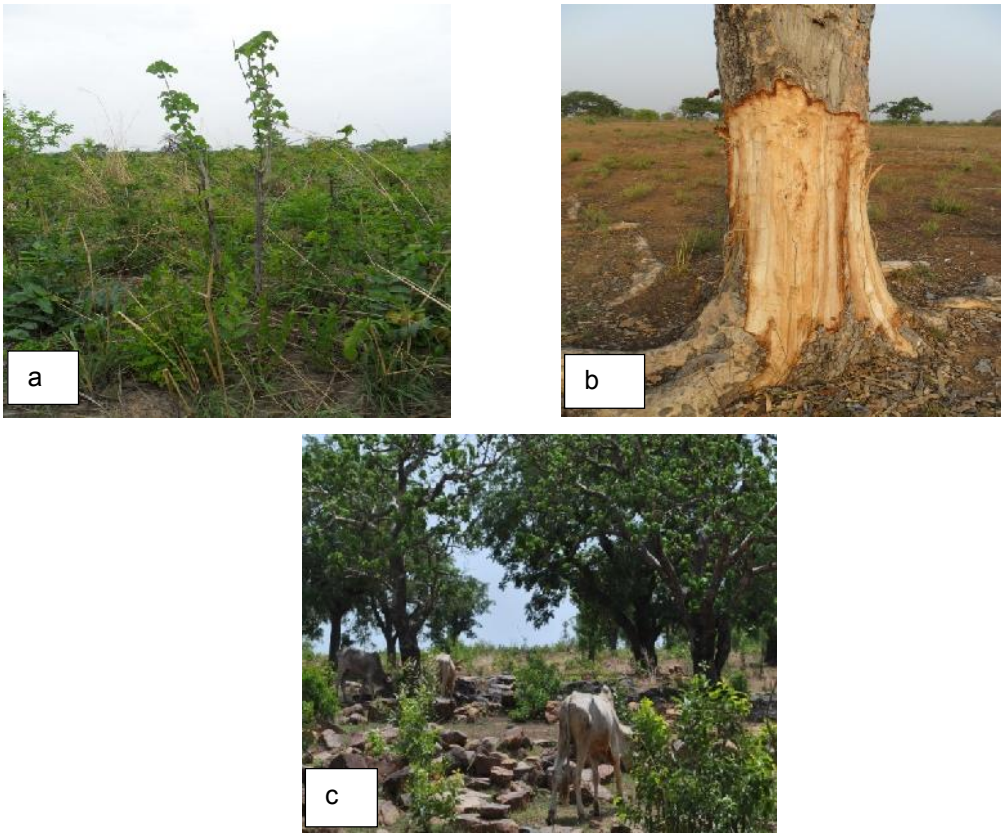


Fig. 7. Differents activities encountered within *S. setigera* stands

a. saplings after bush fire, b. Stem bark withdrawl, c. Cow pasture in Kantindi tableland
Photo: W. Atakpama, April 2013

4. DISCUSSION

The least density of *S. setigera* was observed in plain and low side (22.22 stems/ha) within fallows and croplands. The highest densities of *S. setigera* were found on hillsides and tablelands communities. The relative variation of densities can be explained by the anthropogenic pressures and topography. Human's activities especially agricultural practices contributed to the reduction of tree during farms cultivation. The difference of densities could be also due to soil texture [31]. The density observed in plain and low side are comparable to those observed by [40] in protected area of Yalé and unprotected area of Boala (22 trees/ha) in the sudanian dry forest of Burkina Faso. It is also comparable to the finding of [41] within afforested formations of Mosebit in Ethiopia (18 trees/ha). The densities of the species in hill side and tablelands plant communities are comparable to those observed by [42] in Northern Burkina Faso (53 trees/ha and 47 trees/ha). The bush fires destroyed saplings and check negatively seedling growth. Therefore, human activities reduce sapling growth and seedling survival. All these threats justified the low regenerate rate observed through the study area. The poor or the absence of *S. setigera* regenerations was also observed by [43]. Even if *S. setigera* have a high seed production in fields [14], its low regeneration rate in field is justified by the fact that, in the cropland saplings were systematically destroyed by indigenous because it is considered as a malevolent tree [5,17].This confirm the fact that the farmers preference determined the way of management and species conserved in agroforestry systems [44]. Moreover, the rocky hills area where the species often grow [31,45] do not favor the seeds germination. In addition, *S. setigera* seeds have a long delay of germination (two weeks) and would require a longer humid season in natural habitat to assure a good germination [42]. Thus, climatic fluctuations noted generally in West Africa [30] is another cause which could affect the species regeneration capacity.

The diameter structure of *S. setigera* is asymmetric positive indicating that the stands were dominated by small diameter individuals ($1 < c < 3.6$). Diameter classes in bell showed the best representation of middle diameter individuals. The observed structure was similar to the one of *S. setigera* observed by [42,46] respectively in the hills Park of Zoundwéogo and Nahouri and in the oriental part of the Burkina Faso. The same structure had been described by [47] for *Afzelia africana* in the Lama Forest reserve of Benin.

Diameter structure in "J" reverse shape characterizes gradual densities decreasing from smallest to biggest diameters. Within these plant communities the species was found mainly on the rocky hills zone. The latter finding agrees with the one of [31,45]. The demographic state showed the way of woody management. In the farmers the non-used or non-preferred trees species are generally cut down while the most useful ones are saved. A similar structure was described respectively for *Anogiessus leiocarpa* in the Oti-Kéran Park open forests [48] and within *Parkia biglobosa* parkland [1] in northern part of Togo.

4. CONCLUSION

Forty six wood species belonging to 42 genera and 25 families have been counted. Fabaceae, Combretaceae, Malvaceae and Moraceae were the most represented families. This study showed that topography and human activities influenced the *S. setigera* density, structure and regeneration. The regeneration rate of *S. setigea* illustrates that the natural regeneration is lacking in all the study areas. Poor regeneration endangers the future maintenance of the species. Based on the stands structure analysis, the anthropogenic

pressures impact the densities of the species. Effective conservation strategies are needed for sustainable management of the species. Sound knowledge of the species potentialities through the different climatic zone of Togo, its regeneration status and dynamics are essential to check the negative impact posed by anthropogenic pressures to this gum species. The integration of *S. setigera* in the agroforestry systems and its gum valorization could help to a sustainable management of the surroundings southern soils relatively poor and improve household incomes.

ACKNOWLEDGEMENTS

Our heartfelt to Cosmetic Valley for financial support during field work and the Laboratory of Botany and Plant Ecology (University of Lomé) for technical support. Authors thank Dr Fousseni Folega who provided the map of the study area. We thank also anonymous reviewers for their informative comments and suggestions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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