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Full Length Research paper

Impact of charcoal production on woody plant species in West Africa: A case study in Togo

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In Togo, fuel wood and charcoal account for more than 80% of total household energy requirements. Charcoal production results in a high pressure on the commonly used woody species. This study was carried out to assess the impact of charcoal production on the vegetation. Surveys involving 310 charcoal producers from 4 production areas were carried out. In each production area, density, diameter, height and basal area of woody species were measured both in unexploited plots and exploited plots. Inside the 4 charcoal production areas, 158 woody species were identified including 34 regularly exploited for charcoal production, that is, 15 preferred and 19 by default. Diversity indexes (Species Richness, Shannon and Evenness) and variability of densities are significantly higher in unexploited plots than those in exploited plots. The average heights vary between 4 and 7 m inside the exploited plots and from 6 to 9 m inside the unexploited plots. Average diameter and basal area are statistically not different inside unexploited plots and exploited plots. The most common regeneration methods inside the 4 charcoal production areas are seedlings and coppices. The preferred species regenerate better in exploited plots than those exploited by default. The study concludes that the negative effect of charcoal production on natural ecosystems has resulted in the depletion of the biodiversity, density, height, diameter of the stands and basal area of the woody species.

Key words: Charcoal production, plant diversity, woody population sturcture, regeneration.

INTRODUCTION

After clearing for crops, logging is the most important human-driven factor responsible for the reduction of forest cover in sub-Saharan Africa (FAO, 1981; Geist and Lambin, 2002; Arnold et al., 2005). In general, wood represents about 86% of household energy consumption (Broadhead et al., 2001) and the demand is expected to rise to 45% over the next 30 years due to the population growth and increasing needs in this part of the world (De Montalembert and Clement, 1983). These justify the major risks of degradation of plant communities (Amous, 1999) because of the important role woody plants play in watershed protection and regulation of water bodies.

In Togo, fuel wood and charcoal account for more than 80% of national household energy consumption, estimated at 62 kg/year per capita (Fontodji, 2007). Fontodji (2007) reported also that at national scale, an average of 320,000 tons of charcoal is produced every year. This exploitation results in heavy pressure on the woody vegetation estimated at 386,000 ha (FAO, 2007). Charcoal production is high during the dry season across the country and reaches its peak in December, particularly in forest zone (Akpamou, 2003). It is characterized by poor efficiency of 15 to 20% (150 to 200 kg of charcoal per ton of wood) (Girard, 2002). Current charcoal production techniques create a particular pressure on species providing slow combustion charcoal. This quality charcoal is obtained from slow-growing species that are over-exploited (Girard, 2002). To lessen these pressures on the ecosystem, a good knowledge of the woody capacities is required. Unfortunately, studies conducted so far are mainly focused on market circuits and charcoal production techniques (Girard, 1987; Amous, 2000; Matly, 2000; Ministère de l'Equipement, des Mines de l'Energie, et des Postes et Télécommunications (MEMEPT, 2002) and only address slightly the impact of the charcoal indu-

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stry on the ecosystems (Akpamou, 2003; Kouya, 1996).

This study aims at assessing, in addition to numerous human activities operated in the natural ecosystems (bushfires and grazing), the impact of charcoal production on the plant diversity and the structure of plant communities in 4 production areas in Togo. More specifically, the study seeks to:

1. List woody species exploited for the charcoal production in 4 biogeographical zones of Togo (Ern, 1979) and classify them according to the preference and level of exploitation,
2. Assess the impact of charcoal production on the woody population structure and natural regeneration.

Study area

Togo extends over an area of approximately 56,600 km^2 and 5 biogeographical zones (Ern, 1979). This study includes the zones of Sudanian savanna, dry Forest, Guinean savanna and semi-deciduous Forest (Figure 1). Inside each zone, sites of charcoal production or supply basin were selected.

Data collection

The data were collected in 3 steps. First, ethnobotanical surveys were conducted with 310 charcoal producers from supply basin. Semi-structured questionnaires, oral interviews and group discussions (focus groups) were held with charcoal producers. Woody species used in making charcoal and the preferred species were identified and their availability was systematically recorded. The interview techniques used also vernacular names of the plants, material from the species and field visits with the producers.

The second step, which took place during the dry season, was meant to select inside the charcoal production areas, both unexploited and exploited sites. Inside Sudanian savanna the unexploited plots have been selected in the Kéran Park. In the dry forest areas, the unexploited plots have been selected in the classified forest of Alédjo and Fazao-Malfakassa Park. Inside each area, relevés were carried out in homogeneous geomorphologic and physiognomic units. The number of plots applied lies between 8 and 18. A total of 100 relevés were carried out inside the 4 charcoal production areas. The surface plot covers 900 m^2 (30 × 30 m). In each plot, all woody species were identified as present/ absent. The nomenclature adopted is that of Lebrun and Stock (1991 - 1997). During the survey the uniformity in the plots had been marked in terms of vegetation, geomorphology, texture of the soil, etc. The cover of the strata in the plots is noted in percentage by projection on the ground of the woody species or by the display of the herbaceous in relation to the bare soil (Table 1). In addition, a forest inventory was conducted to measure the dendrometric parameters (circumference and height) of the woody species. The circumference ≥ 10 cm has been measured at breast high (1.30 m of soil) by means of a ribbon. For multistems trees, all the stems have been measured. The height of woody plants has been measured by means of a Blum-Leiss. Each plot was delineated and entered into the GPS for future studies on regeneration.

The third step of the study was carried out during the rainy season, during which the woody species express better their regeneration capacities (Bationo et al., 2005; Ouédraogo et al., 2006). Inside the charcoal production area, 10 plots where randomly selected were five subplots of 25 m² (5 × 5 m) were created (in two of the four corners of each plot). In total, 200 subplots (100 unexploited plots and 100 in exploited plots) were Registered. The woody species < 10 cm in circumference are the individuals taken into account in the regeneration. These stems were counted by species and by methods of regeneration (seedling, sprouting or coppicing and suckering).

Data analysis

Species are classified in preferred species and default species, that is, species exploited when the first choice is not possible. To assess the level of exploitation of each species within charcoal production area, an index N_u has been calculated using the formula

$$N_u = \frac{N_i}{N_{t1}} \times 100$$

Where N_u = Level of use, N_{t1} = number of people interviewed in favour of the use of the species and N_{t1} = total number of respondents in each charcoal production area.

A species is classified in the category I when the number of producers who reported using it more commonly is higher than the number of those who use it by default. To confirm the data from socio economic survey on the availability of the species within the supply basin and those obtained from field relevés in the charcoal production areas, a calculation of the relative frequencies of species has been made using the following formula:

$$F_r = \frac{N_r}{N_{t2}} \times 100$$

Where F_r = relative frequency, N_r = number of plots in which the *i* species is present and N_{t2} = total number of relevés.

The relative density of species has been calculated by the formula:

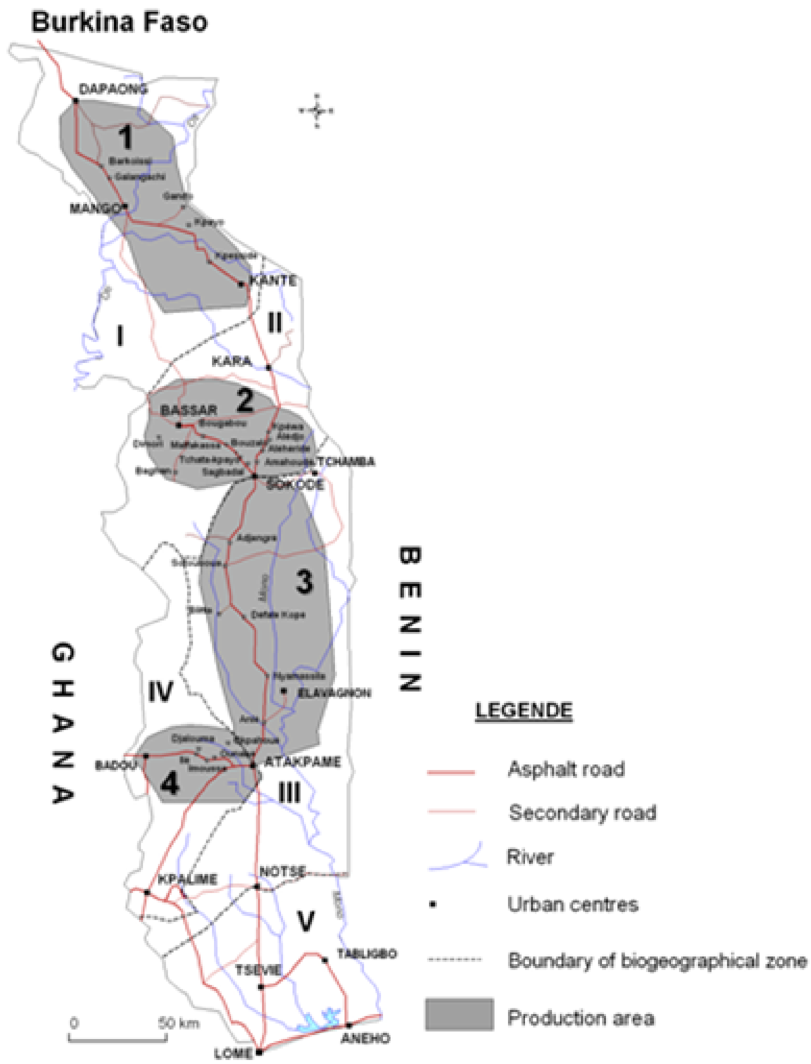


Figure 1. Location of the production areas in the biogeographical zones of Togo. Zone I. Refers to the plains in the north with a Sudan an climate characterized by a rainy season running from June to October and a dry season from November to May, with an average of 6 – 7 dry months. Total rainfall is between 800 and 1000 mm. The predominant vegetation is Sudanian savanna. Zone II. Concerns the hilly dry forest and savannah mosaic zones in the north with a soudano-guinean climate including cool nights at elevated regions and with a rainy season from April to October and a dry season from October to March, characterized by the harmattan. Yearly rainfall is 1200 – 1300 mm, but is very irregular within the year and between years. Zone III. Concerns Guinean savanna in the plains in the centre of the country having a tropical climate characterized by a rainy season from May till October and a dry season of at least 4 months. Total rainfall is between 1200 and 1500 mm per year. The savanna of Central Togo is interspersed with islands of semi-deciduous forest in the southern part and with dry forest in the northern parts. Zone IV. Corresponds to the southern part of Togo Mountains with a transitional subequatorial climate characterized by a long rainy season occurring from March to October and disrupted by a slight decrease in rainfall in August or September. The rainfall amounts range from 1300 to 1600 mm per year. Here, semi-deciduous moist forest is the major vegetation type. Zone V. Refers to the coastal plain in the south under a subequatorial climate characterized by a shortage of rainfall in the coastal part (800 mm/year in Lome, the capital). The landscape offers a mosaic of savanna, agricultural land and pre-reserved forest. Islands of dry semi-deciduous forest are found mainly as sacred forest or as classified forest.

Table 1. Synthesis of ecological characteristics of the sampled plots.

Charcoal production area	Geographical coordinates (Longitude/Latitude)	Vegetation physiognomy	Type of soil	Texture of the top layer of soil (0 - 20 cm)	Average cover of tree stratum (%)	Average cover of grass stratum (%)
Unexploited plots in Sudanian savanna	10°07'28.5''/0°52'01.9''	Wood savanna	Hydromorphic ferruginous	Sandy-silt-clay	24.7 ± 2.7	36.4 ± 10.7
Exploited plots in Sudanian savanna	10°04'44.3''/0°54'25.5''	Shrubby savanna	Hydromorphic ferruginous	Sandy-silt-clay	12.7 ± 5.0	73.8 ± 4.4
Unexploited plots in dry forest	9°16'07.1''/1°12'23.5" 9°08'53.2''/1°00'27.8''	Dry forest	Ferrallitic	Gravelous clay	22.4 ± 2.7	40.6 ± 28.3
Exploited plots in dry forest	9°14'11.5''/1°11'11.4" 9°07'49.3''/1°00'38.9''	Wood savanna and woodland	Ferrallitic	Sandy-clay	20.3 ± 4.9	53.2 ± 13.6
Unexploited plots in Guinean savanna	8°17'49.8''/1°07'34.4''	Wood savanna	Ferrallitic palaeosoil with concretion between 20 and 67 cm in depth	Sandy	15.0 ± 0.0	80.0 ± 0.0
Exploited plots in Guinean savanna	8°17'49.8''/1°07'34.4''	Woodland/ Shrubby savanna	Ferrallitic palaeosoil with concretion between 20 and 67 cm in depth	Sandy	13.9 ± 4.4	68.3 ± 9.2
Unexploited plots in semi-deciduous forest	7°36'02.6''/0°54'08.9''	Semi-deciduous forest, secondary forest	Ferrallitic	Gravelous clay	20.9 ± 6.3	55.0 ± 25.5
Unexploited plots in semi-deciduous forest	7°36'02.6''/0°54'08.9 »	Secondary forest, woodland and shrubby savanna	Ferrallitic	Gravelous-sandy-clay	11.9 ± 3.8	57.5 ± 37.9

$$D_r = 100x\frac{N_i}{Nt_3}$$

Where D_r = relative density: N_i = number of individuals of *i* species; N_{t3} = total number of individuals. The basal area of trees was calculated from the relationship where D = tree's diameter. The relative dominance of species has has been calculated by the relationship.

$$D_{or} = 100\frac{g_i}{G_T}$$, *Dor* = 100 x

Where gi = total basal area of a species; GT = total basal area of all species.

The Importance Value Index (IVI) per species is obtained by the relationship IVI = relative Dominance + relative density + relative frequency. ANOVA tests were conducted by means of Minitab program to compare the dendrometric characteristics between unexploited and exploited areas and then in relation to supply basin. Calculations of diversity indices have also been made it possible to assess the impacts of the charcoal production on the species diversity. These indices are as follows:

$$G = \sum \frac{\prod D^2}{4}$$

1. Species richness (N_o), which represents the total number of species per charcoal production area.

2. Shannon index, where $p_i = \frac{q_i}{Q}$, q_i representing the population of *i* species and *Q* being the total population. Its value increases when the number of species of the collection gets larger or reveals slightly different between the

Table 2. Preferred species for charcoal production in Togo (Category I).

Species \ Charcoal production area	Charcoal production area in Sudanian savanna		Charcoal production area in dry forest		Charcoal production area in Guinean savanna		Charcoal production area in semi-deciduous forest	
	N_u	IVI	N_u	IVI	N_u	IVI	N_u	IVI
Anogeissus leiocarpa	79^{d}	44.6	_	_	96^{d}	15.1	70^{pd}	50
Afzelia africana	27.4^{pd}	0	20.6^{d}	22.4	_	8.6	30^{pd}	37.5
Burkea africana	72.6^{d}	75.9	67.6^{d}	37.4	50^{d}	39.1	_	14.2
Canthium schimperianum	_	_	_	_	_	_	16.3^{d}	0
Combretum spp.	$8.8^{td;d}$	89.2	_	30.2	21^{td}	14.5	37.5^{td}	28.5
Crossopteryx febrifuga	_	58	_	65.5	_	14.5	25^{d}	70.1
Detarium microcarpum	50.1^{td}	58.8	75^{td}	94.2	_	6.3	_	0
Dialium guineense	_	_	_	_	_	_	13.8^{d}	0
Erythrophleum suaveolens	_	_	_	_	88^{d}	0	68.8^{pd}	64.9
Lophira lanceolata	53.2^{d}	0	_	63.7	37^{d}	28.8	42.5^{d}	43.2
Prosopis africana	88.7^{d}	6.3	82.4^{d}	15.2	64^{pd}	12.5	26.3^{d}	0
Pterocarpus erinaceus	48.4^{d}	53	8.8^{d}	32.9	60^{pd}	78.6	50^{d}	29.1
Terminalia glaucescens	_	53.9	73.5^{td}	71.7	_	62.5	36.3^{d}	18.9
Terminalia laxiflora	_	_	_	_	33^{d}	16.1	_	0
Vitellaria paradoxa	56.1^{td}	46.4	20.6^{d}	59	87^{d}	52.3	37.5^{d}	0

_: species non quoted by the producers; td: very available; d: available; pd: little available; N_u: Level of use of a woody species; IVI = relative Dominance + relative density + relative frequency

species encountered;

3 Evenness ($E_q = \frac{I_{sh}}{\log_2 N_0}$) which is the ratio between the diversity observed and the possible maximum diversity given according to N_o.

RESULTS

Species used for charcoal production

Inside the four areas, only 15 woody species are preferred in charcoal making while 19 are used by default. Inside the Sudanian savanna, there are 7 preferred woody species with an exploitation mainly centred on *Prosopis africana*, *Anogeissus leiocarpa* and *Burkea africana*. Besides, 5 species were reported as charcoal production species by default (Tables 2 and 3). The charcoal producers are of the view that highly valued species (*Afzelia africana*, *L. lanceolata* and *P. africana*), are no more available. Field inventories show that these species are very scarce or even absent in the stands (IVI, respectively 0, 0 and 6.3%).

Inside the dry forest area, 4 woody species (*P. africana*, *Detarium microcarpum*, *B. africana* and *V. paradoxa*) are used in considerably high proportions while 2 species (*Isoberlinia doka* and *I. Tomentosa*) are used by default. All these species are reported by the producers as still being available. Field inventories confirm the statement of the producers on the status of certain species, the case of *D. microcarpum*, the IVI of which reached 94.2%.

Inside the Guinean savanna, 8 preferred woody species are reported. Data sometimes disprove the point of view of the producers, like the cases of *E. suaveolens* absent from the inventory data (N_u = 88% and IVI = 0%). The species used by default are *D. mespiliformis*, *K. senegalensis* and *Bridelia ferruginea*. Charcoal producers also make use of *Tectona grandis* (N_u = 39%), an introduced species and highly available in the form of plantation (Tables 2 and 3).

Inside the semi-deciduous forest area, 6 preferred woody species are reported among which *E. suaveolens* is the mostly exploited. But these forest

Table 3. Species used by default for charcoal production in Togo (Category II).

Charcoal production area / Species	Charcoal production area in Sudanian savanna		Charcoal production area in dry forest		Charcoal production area in Guinean savanna		Charcoal production area in semi-deciduous forest	
	N_u	IVI	N_u	IVI	N_u	IVI	N_u	IVI
Pericopsis laxiflora	24.2^{d}	0	_	21	_	_	_	_
Albizia spp.	_	_	_	5.6	_	12.5	15^{d}	29.2
Bridelia ferruginea	_	40.9	_	17.5	24^{td}	51.8	_	28.3
Cola gigantean	_	6.3	_	5.6	_	25	13.8^{d}	25.7
Daniellia oliveri	24.2^{td}	9.8	_	76.5	15^{d}	13.9	20^{td}	23.3
Dichrostachys cinerea	_	50.8	_	55.6	_	100	20^{td}	50.7
Diospyros mespiliformis	29^{pd}	13.9	_	_	69^{pd}	25	31.3^{d}	0
Faurea speciosa	_	_	_	_	_	_	60^{td}	16.2
Gmelina arborea	_	6.3	_	21	_	37.5	33.8^{td}	0
Hexalobus monopetalus	_	_	_	_	_	_	27.5^{td}	0
Hymenocardia acida	_	13	_	38.3	_	37.5	20^{td}	41.9
Isoberlinia spp.	_	14	44.1^{td}	48.5	_	51.2	_	25
Khaya spp.	45.2^{d}	15	_	9.4	42^{d}	12.7	18.8^{pd}	25.3
Parinari curatellifolia	_	15.2	_	46.1	_	42.1	27.5^{td}	41.8
Parinari glabra	_	_	_	_	_	_	11.3^{d}	56.1
Parkia biglobosa	21^{td}	12.9	_	5	_	12.8	17.5^{d}	13.3
Pseudocedrela kotschyi	_	20.2	_	27.8	_	64.9	25^{td}	50
Tectona grandis	_	_	_	2.1	39^{td}	_	_	25
Vitex doniana	_	_	_	11.9	_	_	20^{d}	2.3

_: species non quoted; td: very available; d: available; pd: little available; N_u: Level of use of a woody species; IVI = relative Dominance + relative density + relative frequency.

forest have almost disappeared; the charcoal producers rely on dry dense forest species (*A. leiocarpa* and *P. erinaceus*) but mainly on woody species of secondary forest and savanna. Several species are also used by default including *Faurea speciosa*, *Parinari glabra*, *Parinari curatellifolia*, *Albizia adianthifolia*, *Canthium schimperianum*, *Dialium guineense*, *Cola gigantea* and *Vitex doniana* (Table 3).

Plant diversity and dendrometric characteristics

In total, 158 woody species were listed in the study plots. They belong to 43 families and 121 genera. The most represented families with at least 10 species are Rubiaceae (20 species), Caesalpiniaceae (12 species), Combretaceae (12 species), Mimosaceae (12 species), Moraceae (12 species) and Euphorbiaceae (10 species). The flora is more diversified (number of families, genera and species) inside unexploited plots than exploited plots (Tables 2 and 3). The calculation of diversity indexes confirms the difference between both plots. In dry forest, Sudanian and Guinean savanna, the unexploited plots show higher diversity indexes (Species Richness, Shannon and Evenness) than those in the exploited plots. In semi-deciduous forest, the trend is reversed; Species Richness and Shannon indexes appear slightly lower inside the unexploited plots than in the exploited plots. This can be explained by the greater diversity of the secondary plant communities that grow after the exploitation of forest as well as forest strips along the rivers. The Evenness values are similar in wet plant communities (Guinean savanna and semi-deciduous forest), showing despite the pressure a fairly homogeneous distribution of species inside the exploited plots as well as in the unexploited plots.

The density difference between exploited plots and unexploited plots was significant ($F_{1, 15}$ = 19.97, P = 0.001) inside Sudanian savanna (437 stems/ha to 1037 stems/ha) and Guinean savanna (577 stems/ha to 1058 stems/ha). It was more significant between dry forest (522 stems/ha to 1,227 stems/ha) and semi-deciduous forest (329 stems/ha to 561 stems/ha). The average heights vary little from 4 to 7 m inside the exploited plots and 6 to 9 m inside the unexploited plots. The ANOVA of the average height indicated a significant difference between the unexploited plots and exploited in the Guinean savanna ($F_{1, 7}$ = 15.11, P = 0.008) and in the dry forest ($F_{1, 9}$ = 13.97; P = 0.006) as compared to the Sudanian savanna ($F_{1, 15}$ = 2.28, P = 0.154). However, in the semi-deciduous forest, the values were not significantly different. The average diameter ranges from 8.4 to 16.26 cm inside the exploited plots and 11.42 to 14.91 cm inside the unexploited plots. In the semi-deiduous forest, the average

Table 4. Comparison of the specific diversity between unexploited plots for charcoal production and exploited plots.

Charcoal production area	Unexploited plots			Exploited plots		
	Species Richness	Shannon Index	Evenness	Species Richness	Shannon Index	Evenness
Sudanian savanna	48	5.50	0.96	30	4.55	0.93
Dry forest	76	5.97	0.96	52	5.16	0.92
Guinean savanna	47	5.24	0.97	33	4.79	0.96
Semi-deciduous forest	43	5.29	0.98	75	6.10	0.98

Table 5. Variation of the floristic diversity and dendrometric characteristics unexploited plots for charcoal production and exploited plots.

Charcoal production area	Plots	Average density ($N.ha^{-1}$)	Average diameter (cm)	Average Height (m)	Basal area ($m^2.ha^{-1}$)	Species number	Genera number	Number of families
Sudanian savanna	exploited plots	437.5 ± 211.5[a]	9.6 ± 6.1[b]	4.5 ± 2.4[b]	4.4 ± 2.6[a]	30	22	11
	unexploited plots	894.9 ± 411.5	11.7 ± 9.3	6.1 ± 3.6	18.2 ± 9.7	48	41	22
Dry forest	exploited plots	513.8 ± 126.90[a]	9.4 ± 5.8[a]	4.3 ± 2.2[a]	4.9 ± 1.6[a]	52	43	23
	unexploited plots	526.1 ± 438.8	12.5 ± 8.9	6.7 ± 3.7	17.9 ± 10.7	76	67	28
Guinean savanna	exploited plots	613.9 ± 37.2[a]	8.4 ± 6.5[b]	3.9 ± 2.6[b]	5.4 ± 4.5[a]	33	30	18
	unexploited plots	1315.7 ± 301.9	12.6 ± 8.5	6.1 ± 3.4	22.8 ± 8.7	47	35	19
Semi-deciduous forest	exploited plots	344.4 ± 46.3[b]	16.26 ± 19.3[b]	6.9 ± 6.0[b]	17.1 ± 19.5[b]	75	62	27
	unexploited plots	527.8 ± 135.3	15.2 ± 12.5	8.9 ± 4.8	15.9 ± 9.9	43	36	17

[a] Average value in exploited plots significantly different from the one in unexploited plots;
[b] Average value in exploited plots not significantly different from the one in unexploited plots.

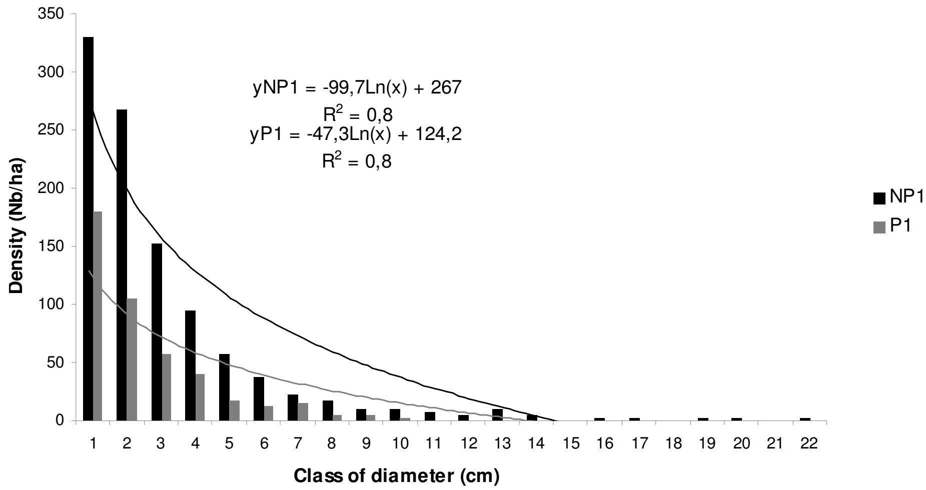
gap of the average diameter is small inside the unexploited plots and exploited plots. The basal area inside the Guinean savanna is from 2.70 to 19.20 m^2/ha, 4.44 to 18.21 m^2/ha inside the Sudanian savanna and 4.49 to 26.18 m^2/ha inside the dry forest. In the semi-deciduous forest, the trend is reversed; 17.1 m^2/ha for exploited plots and 15.9 m^2/ha for unexploited plots. The variation in basal area between exploited plots and unexploited plots is significantly important in all the plant communities (Tables 4 and 5). The variance analysis revealed a significant difference ($F_{1, 15}$ = 12.89, P = 0.003) between exploited plots and unexploited plots inside the Sudanian savanna. Inside the dry forest, it is very significant ($F_{1, 9}$ = 18.11, P = 0.003) in the two plots. The trends are the same inside the Guinean savanna ($F_{1, 7}$ = 106.11, P = 0.001). However, inside the semi-deciduous forest, the variation is small.

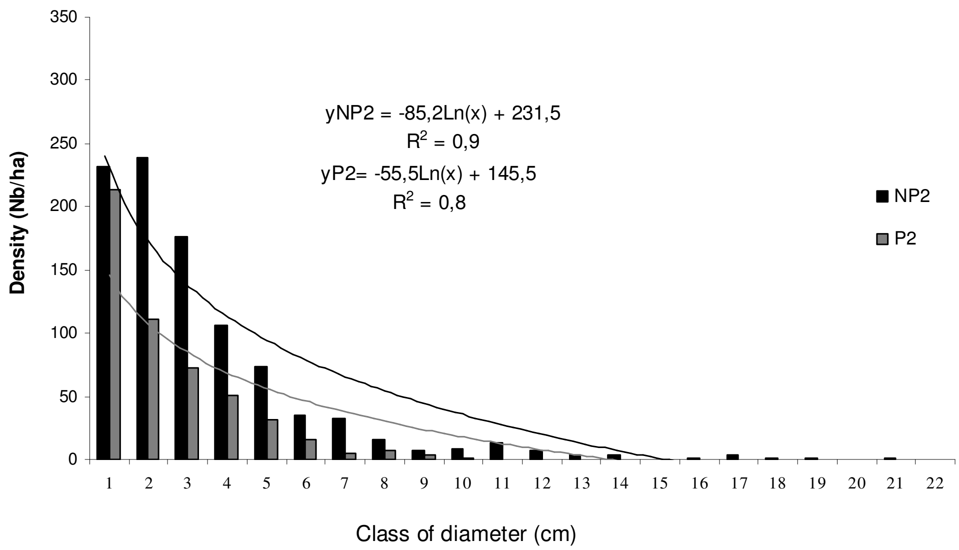
Demographic structure

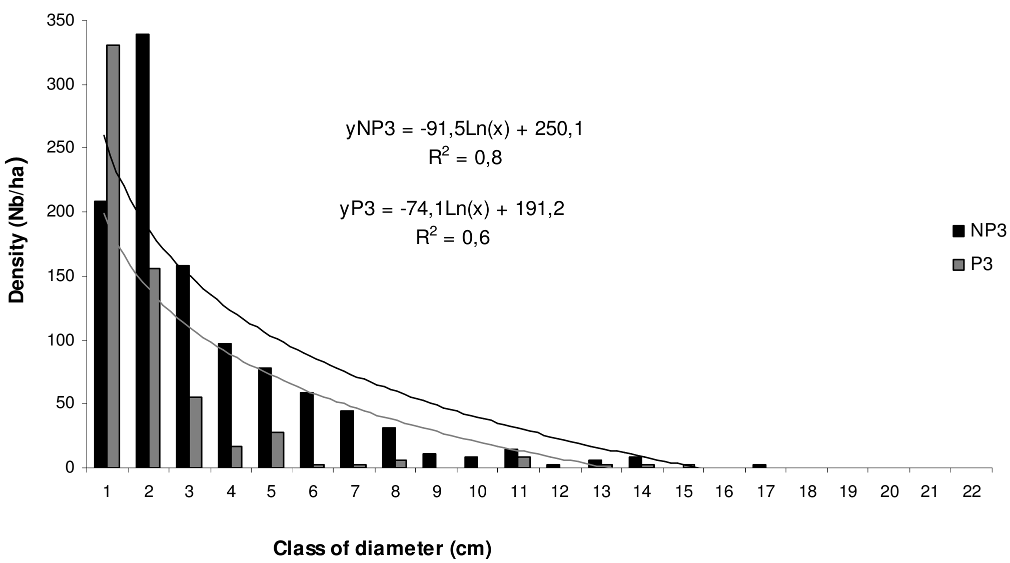
The distribution per class of circumference follows the same tendency as well inside exploited plots as unexploited plots within the 4 charcoal production areas. Regressions between the densities per hectare and the circumference of trees at breast high (1.30 m) fit better with a logarithmic function (Figure 2). It is clear that exploited plots distributions are always the lowest compared to the unexploited plots.

Regeneration

The two most common types of regeneration are seedlings and coppices. The highest densities


yNP1 = -99,7Ln(x) + 267
R2 = 0,8
yP1 = -47,3Ln(x) + 124,2
R2 = 0,8
NP1
P1
Density (Nb/ha)
Class of diameter (cm)


yNP2 = -85,2Ln(x) + 231,5
R2 = 0,9
yP2= -55,5Ln(x) + 145,5
R2 = 0,8
NP2
P2
Density (Nb/ha)
Class of diameter (cm)


yNP3 = -91,5Ln(x) + 250,1
R2 = 0,8
yP3 = -74,1Ln(x) + 191,2
R2 = 0,6
NP3
P3
Density (Nb/ha)
Class of diameter (cm)

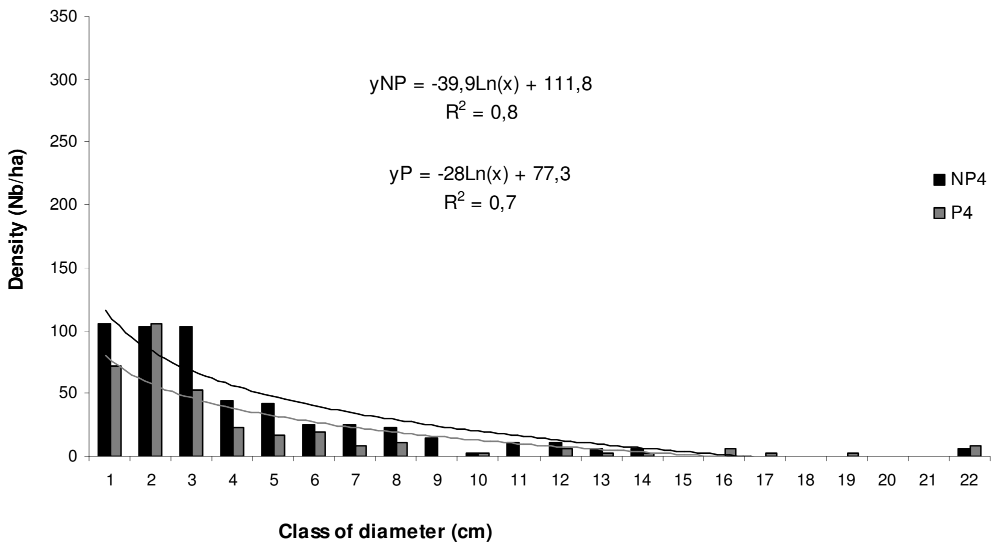


Figure 2. Number of woody plants per class of stem diameter.
1: 10 - 20 cm, 2: 20 - 30 cm, 3: 30 - 40 cm, 4: 40 - 50 cm, 5: 50 - 60 cm, 6: 60 - 70 cm, 7: 70 - 80 cm, 8: 80 - 90 cm, 9: 90 - 100 cm, 10: 100 - 110 cm, 11: 110 - 120 cm, 12: 120 - 130 cm, 13: 130 - 140 cm, 14: 140 - 150 cm, 15: 150 - 160 cm, 16: 160 - 170 cm, 17: 170 - 180 cm, 18: 180 - 190 cm, 19: 190 - 200 cm, 20: 200 - 210 cm, 21: 210 - 220 cm, 22: 220 - 230 cm.
P1; exploited plots for charcoal in Sudanian savanna, **NP1**; unexploited plots for charcoal in Sudanian savanna, **P2**; exploited plots for charcoal In dry forest, **NP2**; unexploited plots for charcoal in dry forest, **P3**; exploited plots for charcoal in Guinean savanna, **NP3**; unexploited plots for charcoal in Guinean savanna, **P4**; exploited plots for charcoal in semi-deciduous forest, **NP4**; unexploited plots for charcoal in semi-deciduous forest.

are observed in both types of regeneration all over the charcoal production areas. Inside Sudanian savanna and dry forest areas, the densities are very high and can double after exploitation. Inside Guinean savanna and semi-deciduous forest, density differences are not so high. After exploitation, coppicing becomes the preferred method of regeneration of the stumps inside all the charcoal production areas. In the Sudanian savanna and dry forest areas, the exploitation lead to suckering which resulted in doubling or tripling of densities (Figure 3). Inside the unexploited areas, the distribution of the regeneration, all methods inclusive, is inconsistent. However, regeneration of preferred species was better than that of species by default and other species in the exploited plots (Figure 4).

In the Sudanian savanna area, seedlings were very frequent inside the unexploited plots than inside the exploited plots (Figure 5a). But in the dry forest and Guinean savanna, seedlings were higher within exploited plots than inside unexploited plots (Figures 5b and 5c). The exploitation of the species for charcoal production favours considerably the regeneration of their stumps in all eco-systems; almost all exploited species showed good regeneration by coppices inside exploited plots (Figures 5a, 5b and 5c). In semi-deciduous forest area, the high presence of pioneer species (*T. orientalis*, *Macaranga barteri* and *H. madagascariensis*) both inside the exploited plots and the unexploited plots proves that they were secondary plant communities that have been studied (Figure 5d).

DISCUSSION

The limit of this survey is the impossibility to single out, in the context of Togo, the impact of logging for charcoal production with the numerous human activities operated in the natural vegetations. Indeed, there are no natural ecosystems in the country protected against bushfires or grazing. This is why, as far as possible, the unexploited plots have been selected in protected areas inside the supply basins. The idea developed in this survey is to consider, in addition to the disruptions already evoked in the study areas, the supplementary impact caused by charcoal production.

In the conditions specified above, the present survey permitted to record 34 woody species popularly used for charcoal production in Togo. Among these species, 15 are preferred while 19 others are used by default. 2 families (Caesalpiniaceae and Combretaceae) contain 60% of the species used for charcoal production. In areas of Sudanian savanna and dry forest, *A. leiocarpa*, *L. lanceolata, B. africana*, *V. paradoxa* and *P. africana* are by far the most exploited species which provide the best wood for charcoal production. Ouro-Djeri (1994) had already reported all these species from a list of 19 species of fuel

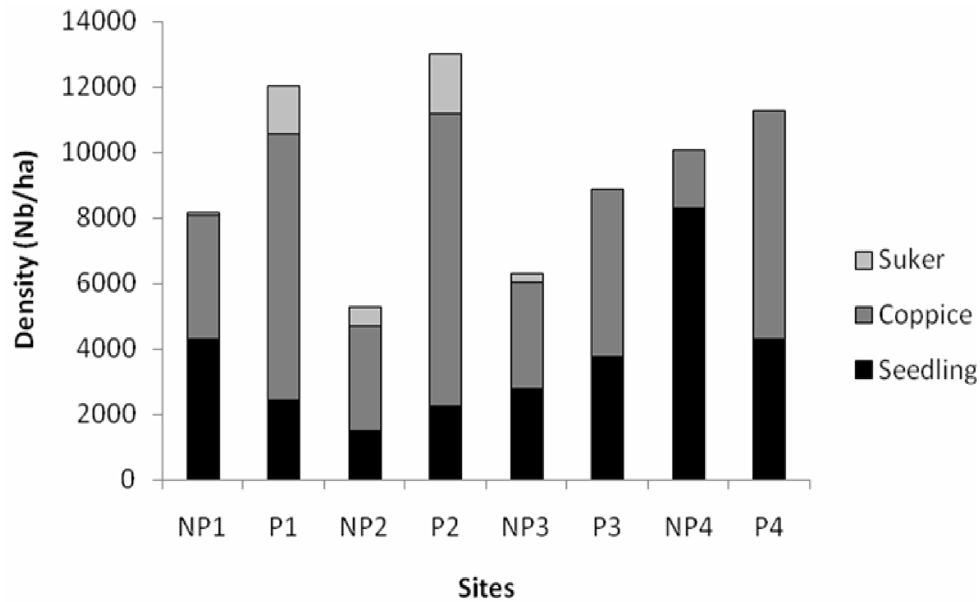


Figure 3. Method and density of regeneration in exploited areas for charcoal production and unexploited areas.
P1: exploited plots for charcoal in Sudanian savanna, NP1: unexploited plots for charcoal in Sudanian savanna; P2: exploited plots for charcoal In dry forest, NP2: unexploited plots for charcoal in dry forest; P3: exploited plots for charcoal in Guinean savanna, NP3: unexploited plots for charcoal in Guinean savanna; P4: exploited plots for charcoal in semi-deciduous forest, NP4: unexploited plots for charcoal in semi-deciduous forest.

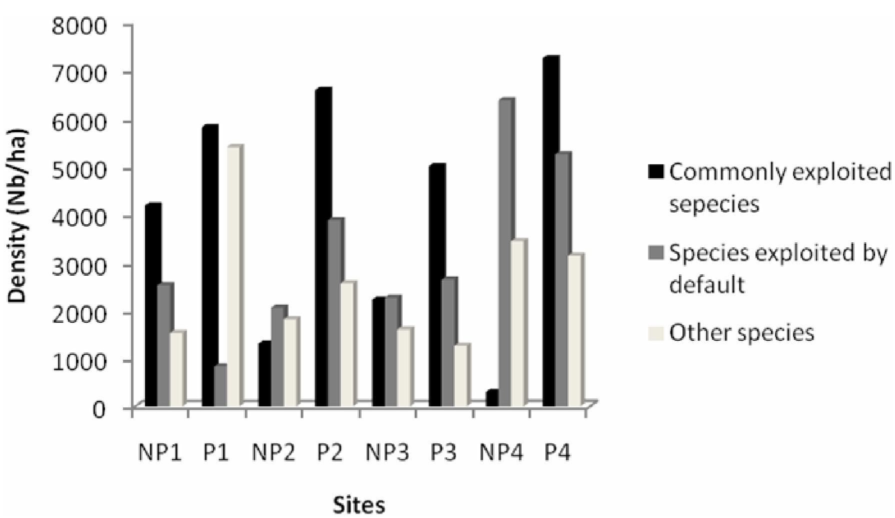


Figure 4. Regeneration of the species per category.
P1: exploited plots for charcoal in Sudanian savanna, NP1: unexploited plots for charcoal in Sudanian savanna; P2: exploited plots for charcoal In dry forest, NP2: unexploited plots for charcoal In dry forest; P3: exploited plots for charcoal in Guinean savanna, NP3: unexploited plots for charcoal in Guinean savanna; P4: exploited plots for charcoal in semi-deciduous forest, NP4: unexploited plots for charcoal in semi-deciduous forest.

wood used in central Togo. In Guinean savanna and semi-deciduous areas, *E. suaveolens* is added to these "key" species. The interest shown in these species is related to the quality of their charcoal, which is highly valued by the consumers in the cities. Apart from these first choice species, others are increasingly being exploi-

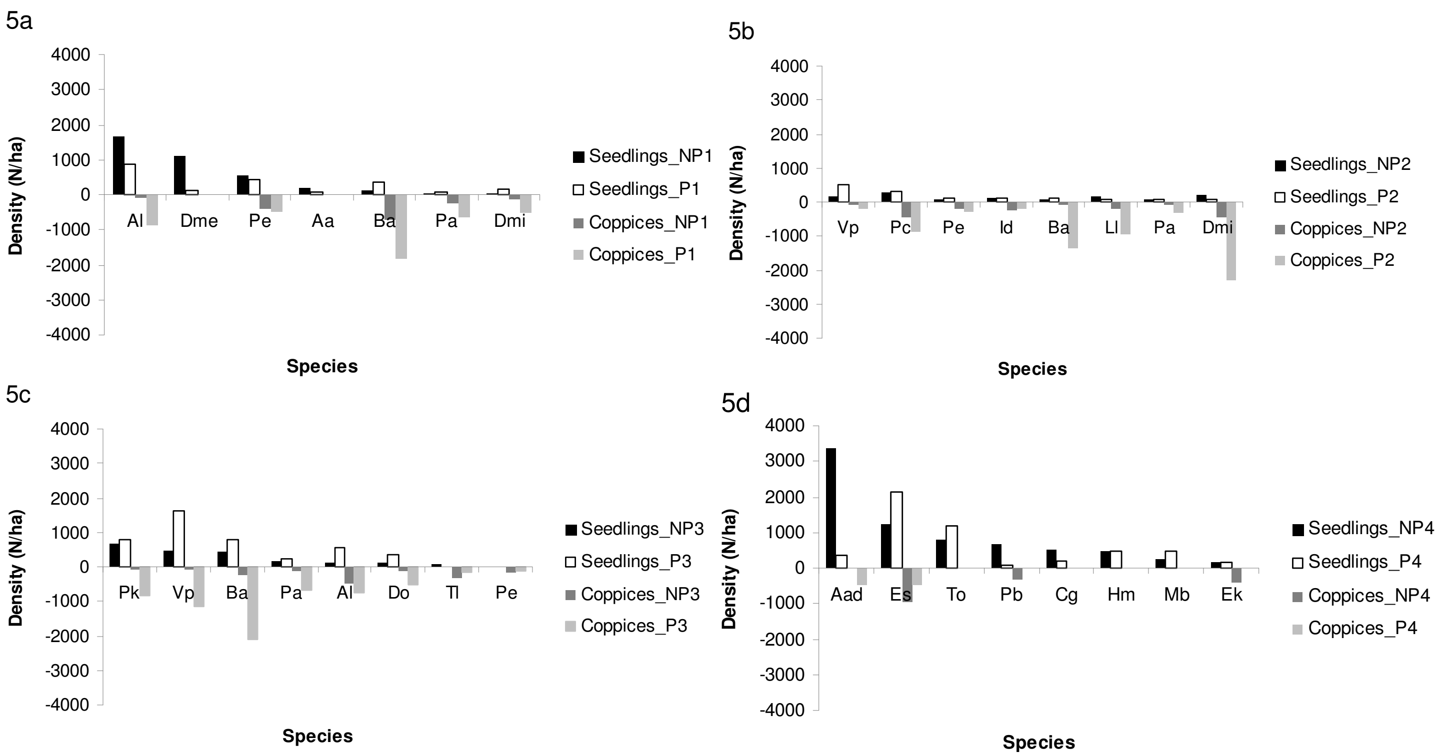


Figure 5. Regeneration by seedlings and coppices in exploited and unexploited plots for charcoal production.
Seedlings are on the positive side of Y axis, coppices on the negative side.
P1; exploited plots for charcoal in Sudanian savanna, **NP1**; unexploited plots for charcoal in Sudanian savanna, **P2**; exploited plots for charcoal in dry forest, **NP2**; unexploited plots for charcoal in dry forest. P3: exploited plots for charcoal in Guinean savanna, **NP3**; unexploited plots for charcoal in Guinean savanna, **P4**; exploited plots for charcoal in semi-deciduous forest, **NP4**; unexploited plots for charcoal in semi-deciduous forest. **Al** ; *A. leiocarpa*, **Dme**; *D. mespiliformis*, **Pe**; *P. erinaceus*, **Aa**; *A. africana*, **Ba**; *B. africana*, **Pa**; *P. africana*, **Dmi**; *D. microcarpum*. **Vp**; *V. paradoxa*, **Pc**; *P. curatellifolia*, **Id**; *I. doka*, ***Ll****;* *L. lanceolata*, **Pk** ; *Pseudocedrela kotschyi*, **Do**; *D. oliveri,* **Tl**; *T. laxiflora,* **Aad**; *A. adianthifolia*, **Es**; *E. suaveolens*, **To**; *T. orientalis*, **Pb**; *P. butyracea*, **Cg**; *Cola gigantea*, **Hm**; *Harungana madagascariensis*, **Mb**; *.M barteri*, **Ek**; *E. kerstingii.*

exploited because of their availability. This is the case of certain preferred species, but mainly the species by default, which a decade ago were not used in charcoal production in Togo. The use of these species of the second category, mainly those used in reforestation such as teak, is an alternative towards the reduction of the current pressure on natural vegetation. The choice of the resource is not only related to the energy quality but also to the availability.

Plant diversity and the dendrometric characteristics are major indicators of trends of progress in qualitative and quantitative flora (Tews et al., 2006). These two parameters reveal not only human pressure but also the climatic conditions (Oosterhoom and Kapelle, 2000). In this study, in addition to the already heavy pressure of human activities on ecosystems of Togo, the negative impact of charcoal production has resulted in the reduction of the biodiversity. Naughton-Treves et al. (2007) also highlighted the negative impact of the intensive woody species exploitation in a national park in Ougadan through the production and marketing of charcoal. In fact, inside the unexploited plots, the diversity index (Species Richness, Shannon index and Evennness) are higher than those inside the exploited plots. The comparison of dendrometric characteristics also reveals that the production of charcoal has a greater impact on the biomass of savanna and dry forest than in semi-deciduous forest. Thus, the tree densities inside the exploited plots are considerably lower than those inside the unexploited plots ($p = 0.001$). The average diameter between exploited plots and unexploited plots were considerably greater inside the dry forest ($p = 0.023$) but no difference was noted inside the other production areas. Like the average diameters, the average heights varied very little among the plant communities in both the exploited plots and unexploited plots. Basal area was considerably lower ($p = 0.002$) inside the exploited plots, except in semi-deciduous forest where the difference was not important. The abundance of some unexploited or less exploited species apparently veils the impact of this activity on the structure of exploited plant communities.

The distribution of diameter classes shows that exploitation pressures are centred on classes between 25 and 65 cm diameter. Woody species of middle class ranging from 25 to 45 cm undergo more pressure in savanna while classes from 45 to 65 cm are mostly wanted in the forest. These results support the findings of Guédou (2005) in the protected forest of Ouémé Boukou in Benin. This author also stresses that the selective exploitation affects plant communities through the depletion of some "key" species, mainly belonging to preferred species, such as *A. leiocarpa*, *E. suaveolens*, *L. lanceolata, P. africana, P. erinaceus*, *V. paradoxa*. Other studies have similarly reported this selected exploitation due to the value for fuel wood (Oribi et al., 2001; Luoga et al., 2004; Neke et al., 2006). The effect of this selected exploitation varies according to the type of plant community. It leads to in more structural changes in savanna plant community where logging for charcoal production seems to be worsened by bushfires and grazing than it is in the forest. Indeed, the outstanding degradation due to the exploitation and the creation of kilns in savanna areas favours the growth of grass and a greater exposure to the sun. These predispositions render bushfires impacts more severe, mainly when they are late.

The high penetration of light due to the selective logging for charcoal production favours the germination of seed stock. These observations are consistent with those of Ouédraogo et al. (2006) in Sudanian savanna and those of Neke et al. (2006) in South Africa, which revealed that the large numbers of seedlings may be due to a response to the thinning of the woodland and the opening up of the canopy through harvesting. However, further works (Gijsbers et al., 1994; Boussim et al., 1998) indicated that regeneration by seedlings in these plant communities is related to soil and climatic factors. Comparing the regeneration capacities of the preferred species and species by default inside the different charcoal production areas, the situation varies from one species to another. *A. leiocarpa* offers poor germination capacities in Guinean savanna but regenerates better in the Sudanian savanna. Adonsou (1993) and Traore (1998) showed that the regeneration by seedling of both *Anogeissus leiocarpa* and *Pterocarpus erinaceus* is generally difficult. The germination capacities of *V. paradoxa* are higher in Guinean savanna than in Sudanian savanna and in the dry forest. But their coppices capacities are the same inside the three charcoal production areas where the species grows naturally. The regeneration by seedling of *B. africana*, *P. africana* and *P. kotschyi* is higher in Guinean zones than in Sudanian savanna and in dry forest. In dry forest, *P. curatellifolia* and *L. lanceolata* present good regeneration capacities both by seedling and coppices. *A. africana* offers the best germination capacities in Sudanian zones. In addition, *D. microcarpum*, *I. doka*, *I. tomentosa*, *P. suberosa* show greater suckering capacities than coppices through the stumps. Bellefontaine (2005) also demonstrated the vegetative propagation capacities of these species in tropical arid and semi-arid zones. *D. microcarpum* regenerates well both by suckers and sprouts. The extraordinary regeneration capacity of certain species, particularly *I. doka* and *D. microcarpum* enable them to withstand pressures from human activity. These findings confirm those of Devred (1998), which indicate that *D. microcarpum* supports cutting. Woody species such as *C. collinum*, *C. glutinosum* and *C. fragrans*, *T. glaucescens*, *T. avicennioides*, *T. macroptera*, *S. kunthianum*, *C. febrifuga* show good regeneration capacities. This is consistent with the works of Traoré (1998) that indicate that the species of shrub stratum which the majority of species mentioned above belong to generally have better regeneration capacities contrary to those of the tree stratum. In semi-deciduous forest, regeneration capacities of *Albizia* spp. are higher in unexploited areas than in exploited areas. The trends are reversed with *E. suaveolens*, which is the most exploited species in these forests germinating abundantly in the gaps (Akpamou, 2003). It seems that after exploitation, coppices become the major pathway for regeneration of individuals inside the SB's. The new seedlings from natural seeds are more vulnerable than sprouts from roots or stumps (Dickinson et al., 2000). The majority of seedlings died at the beginning of the dry season while bushfires destroyed the survivors. However, the vitality of the sprouts that determine the health state and the age of the logs contribute to their survival.

Conclusion

This study has identified 34 woody species for charcoal production in Togo. Out of these species, 15 are considered the most exploited while 19 are exploited by default. *A. leiocarpa*, *P. erinaceus*, *L. lanceolata B. africana*, *V. paradoxa and P. africana* are by far the most wanted in both dry forest and Sudanian savanna areas while in Guinean savanna and semi-deciduous forest, *E. suaveolens* is mostly exploited. The families of Caesalpiniaceae and Combretaceae include 60% of those species. The negative effect of charcoal production on ecosystems results in the depletion of the biodiversity and dendrometric characteristics (density, height and diameter of the stands, basal area...). It also has a greater consequence in the savannas and dry forest biomass than in the semi-deciduous forest. The exploita-tion is centred on the classes of circumference ranging to 25 and 45 cm in the savannas and 45 to 65 cm in forests. These results indicate that the use of wood for charcoal production is selective and affects the plant communities through the depletion of some "key" species mostly belonging to preferred species. If such practices continue, Togo's natural remnant ecosystems will soon be exhausted. This will also affect supply of other vital resources such as water, medicinal plants and forest services needed in general by local populations. To protect forest resources from over-exploitation for energy, policy makers should target charcoal production. An approach of solution is the development of alternative energies. The monitoring of the parcels exploited for charcoal production must be promoted because of their high potentialities of natural regeneration. The current study mentionnes that in such exploited parcels, coppicing is the preferred method and the species of first choice are mostly represented in the regeneration.

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