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Research Application Summary

Stands structure characterization, health and regeneration status of *Adansonia digitata* L. in agroforestry systems of northwest Benin

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Abstract

The present study characterized the population structure and natural regeneration of stands of baobab in North-Western Benin. Data were collected using linear transects of 2 km x 50 m bands in three communes of the Atacora department. Two villages per commune were chosen based on the visual abundance of baobab feet. In each village three transects were installed. A total of eighteen linear transects were installed. ANOVA followed by Student Newman Keuls test were used to test the differences in morphological traits between systems within categories and districts. The results showed that Cobly was home to the lowest density (15 ± 16.43) of young plants in contrast to Materi (58.33 ± 45.35) and Boukombe (58.33 ± 62.10) which had equal density of baobab trees. In addition, district of Materi had higher density in adult individuals (198.33 ± 74.68) and the district of Cobly the least dense adult baobab individuals (85 ± 22.58). There was also a significant difference between the different density categories (p-value <0.001). The youngest individuals were found in Boukoumbe and the older ones in the commune of Cobly and Materi. The number of individuals less than 5m tall was 8, 13 and 3, in the communes of Materi, Boukombe and Cobly respectively. The results showed that most of the baobab individuals were healthy. However, there were feet mutilated, pruned, attacked by Loranthaceae and some had trunks debarked.

Keywords: *Adansonia digitata*, baobab, North-western Benin, regeneration, transects

Résumé

La présente étude a caractérisé la structure de la population et la régénération naturelle des peuplements de baobab dans le Nord-Ouest du Bénin. Les données ont été collectées à l'aide de transects linéaires de bandes de 2 km sur 50 m dans trois communes du département de l'Atacora. Deux villages par commune ont été choisis en fonction de l'abondance visuelle des pieds de baobab. Dans chaque village, trois transects ont été installés. Au total, dix-huit transects linéaires ont été installés. L'ANOVA suivie du test Student Newman Keuls ont été utilisés pour tester les différences de traits morphologiques entre les systèmes au sein des catégories et des districts. Les résultats ont montré que Cobly abritait la plus faible densité (15 ± 16,43) de jeunes plants contrairement à Materi (58,33 ± 45,35) et Boukombe (58,33 ± 62,10) qui présentaient une densité égale de baobabs. Par ailleurs, le district de Materi présentait la plus forte densité en individus adultes (198,33 ± 74,68) et le district de Cobly la moins forte densité en individus adultes de baobabs (85 ± 22,58). Il y avait également une différence significative entre les différentes catégories de densité (P <0,001). Les individus les plus jeunes ont été trouvés à Boukoumbe et les plus vieux dans la commune de Cobly et Materi. Le nombre d'individus de moins de 5m était de 8, 13 et 3, respectivement dans les communes de Materi, Boukombe et Cobly. Les résultats ont montré que la plupart des individus de

baobab étaient sains. Cependant, il y avait des pieds mutilés, élagués, attaqués par des Loranthaceae et certains avaient des troncs écorcés.

Mots clés : Adansonia digitata, baobab, Nord-Ouest du Bénin, régénération, transects.

Introduction

Adansonia digitata is one of the most widespread and important multipurpose species in Africa, being present in most of sub-Saharan Africa (Sidibe and Williams 2002). *A. digitata* is one of eight species of Adansonia, and is the only native species on the African mainland and Wickens and Lowe (2008) have published an extended review about this species. Baobab tree is a multi purpose tree with a number of medicinal properties, numerous food uses of various plant parts and bark fibers that are used for a variety of applications (Owen, 1970; Von Maydell, 1990; Etkin and Ross, 2000; Van Wyk and Gericke, 2000; Codjia *et al*., 2001; Sidibe and Williams, 2002). In Africa, *A. digitata* is found in Angola, Benin, Botswana, Burkina Faso, Cameroon, Chad, Congo, Eritrea, Ethiopia, Gambia, Ghana, Kenya, Mali, Mozambique, Namibia, Niger, Nigeria, Senegal, Somalia, South Africa, Sudan, Tanzania, Togo, Zambia, and Zimbabwe which are considered as its centres of origin. In time some species were exported and cultivated in India. It is also common in America, India, Sri Lanka, China, Jamaica and Holland (Sidibe and Williams, 2002 ; Assogbadjo, 2005).

In Benin, the baobab is a multipurpose species used for food, medicinal, socio-cultural and economic purposes (Codjia *et al*., 2001). It occupies a prominent place in the Otamari culture, an ethnic group in northern Benin (Fonton-Kiki, 2001). The leaves of *A. digitata* are used either fresh as a cooked vegetable or dried and powdered as an ingredient of soups and sauces and is used on a daily basis. Leaves are especially rich in vitamin A. Leaf collectors look for particular traits including leaf taste, mucilage, leaf availability and height of the tree. Green leaf availability is less important in the humid areas, because of the availability of other products to serve similar purposes. The seeds are used to prepare peanuts and may be used as a coffee substitute. They can be eaten fresh, dried or roasted, or be used to extract oil by boiling and distillation. The fruits are ovoid, spherical or elongated covered with a hard exocarp. The seeds are enclosed by a whitish dry pulp which is very rich in C and B1 vitamins as well as carbohydrates and this pulp is often used to make refreshing and nutritive beverages. There can be a threefold variation in vitamin C content of the pulp. Fermentation of the seed kernels can improve the nutritional value (Sidibe and Williams, 2002). Fibres from the bark are used to make cords, used as rope and string.

A. digitata is also among the ten agroforestry species prioritized according to their availability on the market, the ease of access to their products, by the populations of Benin, Burkina Faso, Mali, Senegal, Niger (Eyog Matig *et al*., 2002, Assogbadjo *et al*., 2017) for their socio-economic development.

Unfortunately, the species is threatened by wildfires, agriculture, cattle grazing and pollution of agroforestry systems by pesticides (Sidibe and Williams, 2002). Thus, agroforestry systems are no longer able to ensure the conservation of the species. The objective of this work was to characterize the structure of baobab populations in northern Benin. Specifically, the study asked the following questions: (i) what is the floristic composition of the agroforestry systems that host baobab trees?, (ii) What is the adult and regeneration density of baobab and how do they vary across communes? What is the health status of *A. digitata* plants?

Materials and methods

Data collection. Data were collected by means of linear transects bands of 2 km by 50 m in three

communes of the Atacora Department in Benin. The walking azimuth of the transect strips was taken using a SUUNTO clinometer. Two villages per commune were to establish the abundance of baobab and in each village three bands of transects were installed there. A total of eighteen bands of linear transects were installed in three different communes of Materi, Cobly and Boukombe. On each transect strip, all the baobab individuals encountered were recorded by their diameter at breast height (dbh), the total height, the diameter of the crowns, the health status of these trees and their phenology. The height and diameter of the crowns were recorded using the clinometer and penta-decameter, respectively. In addition, the heights and dbh of all other adult species encountered in each transect band were also recorded. Figure 1 shows forms of baobab trees recorded.

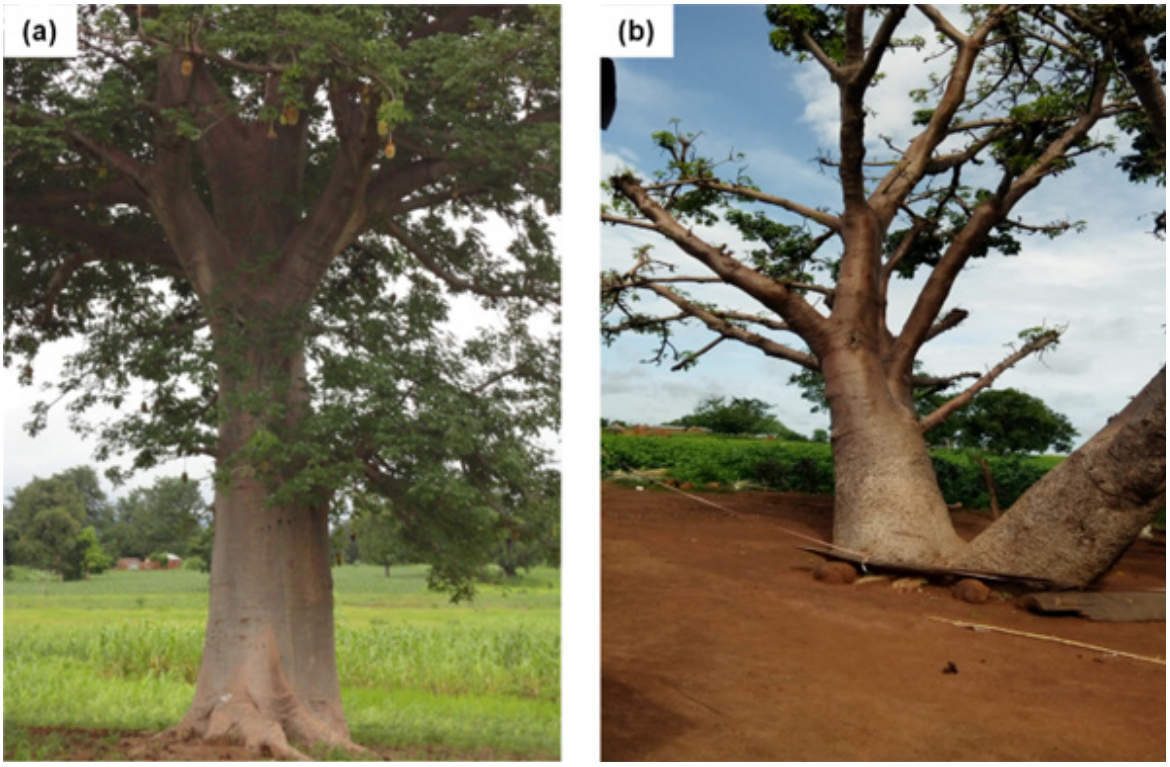

Figure 1. Forms of baobab feet, a. Right; b. Leaning (Agbohessou, 2018).

The differents health status, forms and phenology of baobab tree according to site were also recorded.

Data analysis. In order to know the different species associated with baobab and their importance in each commune, the Cottam and Curtis (1956) species importance value index (IVI) was calculated. This index is given by the formula:

$$IVI = Frel + Drel + Dorel$$

Fret= Relative frequency
Drel = Relative density
Dorel= Relative dominance

The average density of baobab populations and their morphological characteristics were determined by commune, by diameter class and height. ANOVA followed by Student Newman Keuls test were used to test the differences in morphological traits between systems within categories and districts. The average values were calculated for the morphological traits (diameter, basal area, total height and crown diameter).

$$\text{Basal area} = \sum_{i=1}^{s} \left(\frac{ni(ni-1)}{N(N-1)} \right)$$

d. the diameter (in cm) of the i-th tree of the plot; s = 0.25 ha.

The Pearson Chi-square test was applied to compare the average health status, forms and phenology by districts. The rate of recruitment were also calculated. All statistical analyzes were performed in the R Statistical software 3.5.0 (R Development Core Team, 2018).

Results

Diversity of co-occurring species ofAdansonia digitata and their importance value. A total of 58 different species were encountered in the three study communes. The 10 different species primarily companions of the baobab by district and their importance value are summarized in Table 1. In the district of Materi 34 species were encountered in our transects. The ten most important were: *Lannea acida* (IVI = 143.15), B*orassus aethiopum, Azadirachta indica, Hyphaene thebaica, Parkia biglobosa, Ficus sycomorus, Vitex doniana, Khaya senegalensis, Anogeissus leiocarpa* and *Diospiros mespiliformis* (I V1= 69.99), In the district of Boukombe, the specific diversity is higher with 38 species encountered. In addition, *Parkia biglobosa* ([VI =148.81), *Vitellaria paradoxa, Borassus aethiopum, Mangifera indica, Lannea acida, Vitex doniana, Ficus sycomorus, Diospyros mespiliformis Tectona grandis* and *Azachdirata indica* (IVI = 84.99) were the 10 most common. At Cobly, 37 different species were recorded, of which the ten most common were: *Parkia biglobosa* (IVI = 167.8), *Lannea acida, Ficus sycomorus, Cassia sieberiana, Prosopis africana, Borassus aethiopum, Azachdirata indica, Vitellaria paradoxa, Mangifera indica* and *Terminalia macroptera* (IVI = 77.36). Five species were common in all three districts (Tablel).

Density and morphological characteristic of baobab according to the study sites

Density. Baobab trees were found in all of the three districts with different densities and morphological characteristics of the life stage considered. In terms of density at the level of young trees Cobly had low density (15 ± 16.43) versus (58.33 ± 45.35) and (58.33 ± 62.10) respectively in Materi and Boukombe. In addition, the district of Materi had higher density in adult individuals (198.33 ± 74.68) and the district of Cobly the least dense adult baobab individuals (85 ± 22.58). There was significant difference between the different density categories (P-value <0.001).

Morphologic characteristics. The different morphological characteristics summarized in Table 2 show that the largest young individuals in diameter were found respectively in Materi (24.41 ± 24.41) and in Cobly (19.94 ± 15.07), and the smallest were recorded in Boukombe (18.93 ± 16.14). In contrast, larger adult individuals were found in Cobly (163.99 ± 58.14) and smaller individuals in Materi (148.31 f 74.45). In terms of height, the tallest young individuals were found in Materi (5.40 ± 3.08) and the shortest in Cobly (4.68 ± 2.64). The adults were found in Materi (13.78 ± 4.50) tallest and the shortest in Boukombe (12.48 ± 2.92). The young individuals and adults of Boukombe had the largest crown diameters, respectively (4.78 ± 2.46) and (16.55 ± 5.81). In contrast, the smallest crown diameters in young people were recorded in Cobly (2.27 + 1.58) and the smallest crown diameters in adults in Materi (12.80 ± 5.65). No significant differences existed between the categories, from one morphological characteristic to another (P> 0.05).

Table 1. Species Importance Value Index per district

Communes /species	Families	Frel	Drel	Dorel	IVI
Materi					
Lannea acida A.Rich. s.l.	Anacardiaceae	100	20.54	22.61	143.15
Borassus aethiopum Mart..	Areacaceae	100	13.24	11.62	124.87
Azadirachta indica A.Juss.	Meliaceae	100	8.48	5.03	113.51
Hyphaene thebaica (L.) Mart.	Areacaceae	83.33	12.65	17.03	111.08
Parkia biglobosa (Jacq.) R.Br. ex Benth.	Mimosoideae	83.33	10.71	4.86	100.84
Ficus sycomorus L.	Moraceae	83.33	2.83	2.98	89.14
Vitex doniana Sweet.	Verbenaceae	83.33	2.83	2.24	88.4
Khaya senegalensis (Desr.) A.Juss..	Meliaceae	66.67	1.79	4.40	72.86
Anogeissus leiocarpa (DC.) Guill. & Perr..	Combretaceae	66.67	1.19	3.81	71.66
Diospyros mespiliformis L..	Ebenaceae	66.67	1.19	1.51	69.99
Boukombé					
Parkia biglobosa (Jacq.) R.Br. ex Benth.,	Mimosoideae	100	17.17	31.64	148.81
Vitellaria paradoxa C.F.Gaertn. ssp. paradoxa,	Sapotaceae	100	16.28	14.52	130.81
Borassus aethiopum Mart.,	Areacaceae	100	14.69	12.92	127.61
Mangifera indica L.,	Anacardiaceae	100	7.08	17.15	124.23
Lannea acida A.Rich. s.l.,	Anacardiaceae	100	5.66	2.48	108.15
Vitex doniana Sweet,	Verbenaceae	100	4.60	3.00	107.60
Ficus sycomorus L.,	Moraceae	100	3.54	3.23	106.77
Diospyros mespiliformis L.,	Ebenaceae	83.33	7.08	2.51	92.92
Tectona grandis L.f.,	Verbenaceae	83.33	3.89	0.75	87.98
Azadirachta indica A.Juss.,	Meliaceae	83.33	1.42	0.24	84.99
Cobly					
Parkia biglobosa (Jacq.) R.Br. ex Benth.,	Mimosoideae	100	28.11	39.7	167.8
Lannea acida A.Rich. s.l.	Anacardiaceae	100	16.44	15.23	131.8
Ficus sycomorus L.,	Moraceae	100	7.07	10.98	118.05
Cassia sieberiana DC.,	Leguminosae-Caesalpinioideae	100	3.63	0.93	104.56
Prosopis africana (Guill. & Perr.) Taub.,	Mimosoideae	100	2.29	1.83	104.13
Borassus aethiopum Mart.,	Areacaceae	83.33	6.88	5.27	95.48
Azadirachta indica A.Juss.,	Meliaceae	83.33	4.21	4.72	92.26
Vitellaria paradoxa C.F.Gaertn. ssp. paradoxa,	Sapotaceae	83.33	2.68	2.40	88.41
Mangifera indica L.,	Anacardiaceae	83.33	1.34	2.02	88.69
Terminalia macroptera Guill. & Perr.,	Combretaceae	66.67	7.65	3.03	77.36

Table 2. Population density (mean ± standard deviation) of A. digitata in the study sites

Study sites		Density (stem.ktri')		Diameter (cm)		Total height (m)		Crown (m)	diameter
		Young	Adult	Young	Adult	Young	Adult	Young	Adult
Materi	M	58.33a	198.33a	24.41 a	148.31a	5.40a	13.78a	2.87a	12.80 a
	Sd	45.35	74.68	24.41	74.45	3.08	4.50	2.31	5.65
Boukombe	M	58.33a	165b	18.93a	160.26a	5.20a	12.48a	4.78a	16.55 a
	Sd	62.10	80.93	16.14	88.03	3.24	2.92	2.46	5.81
Cobly	M	15a	85c	19.94a	163.99a	4.68a	13.77a	2.27a	15.75 a
	Sd	16.43	22.58	15.07	58.14	2.64	2.67	1.58	4.18
P-value		<0.001	<0.001	0.461	0.968	0.538	0.358	0.257	0.22

- young (0- 50 cm dbh generally not yet producing fruit)
- adult (>50cm dbh)

The densities by diameter class (Table 3) and by height class (Table 4) as well as the number and type of regenerations (Table 5) are presented by commune. The 50-99 cm diameter individuals (7.50 ± 8.41) and height 12-14.99 m (5.50 ± 3.15) were the most abundant in Materi. In Boukombe, it was the 0-49 cm diameter (5.83 t 6.21) being the most abundant class, and the individuals of height between 9-11.99 m (5.17 ± 3.49) and 15-17.99 m (5.17 ± 4.91) the more abundant. In the commune of Cobly, the abundant classes in diameter and in height were respectively 150-199 cm (2.83 ± 2.48) and 15-17.99 m (3.83 ± 2.04).

The number of individuals with <3 m height was highest in Boukombe (13) with a mean collar diameter of 13.32 cm with 92% seedlings and 7.69% stump rejection; at Materi, 8 individuals were recorded with 62.50% seedlings, 37.50% stump rejects, and an average neck diameter of 13.20. The commune of Cobly had only 3 individuals, all seedlings with an average collar diameter of 12.31 cm.

The results suggested that the commune of Cobly has limited baobab stands and the few individuals present were mostly old while Boukombe was richer in young individuals. It conserves the baobab better than other communes.

Table 3. Population density (mean standard deviation) among the size classes

Diameter size-class (cm)	Density (trees/km')		
	Materi	Boukombe	Cobly
0-49	5.17a±4.35	5.83 a +6.21	1.50 a +1.64
50-99	7.50 a +8.41	5.67 a +4.63	1.33 a+1.37
100-149	4.00 a ±2.76	4.33 a +3.26	2.00 a ±1.26
150-199	2.83 a ±2.93	3.17 a +1.17	2.83 a ±2.48
200-249	3.50 a ±3.56	1.50 a +0.84	1.33 a +1.97
250-299	1.67 a ±0.52	1.17 a+1.47	1.00 a +0.89
300-349	0.00±0.00	0.33±0.82	0.00±0.00
? 350	0.50 a +0.55	0.33 a +0.52	0.00 a ±0.00

Means with different letters denote significant differences ($P < 0.05$) among sites

Table 4. Population density (mean standard deviation) among the height size- classes

Height size classes (m)	Density (trees/km')		
	Materi	Boukombe	Cobly
0-2.99	1.67 a +1.63	2.50 a ±2.07	0.50 a ±0.55
3-5.99	1.83 a ±2.71	0.83 a ±1.60	0.67 a +1.21
6-8.99	4.17 a ±3.54	4.17 a ±3.66	0.67 a +1.033
9-11.99	3.83 a ±4.66	5.17 a +3.49	1.00 a +1.55
12-14.99	5.50 a ±3.15	4.50 a +2.26	3.00 a +1.41
15-17.99	4.33 a ±1.75	5.17 a+4.91	3.83 a ±2.04
18-20.99	2.33 a ±2.62	0.00+0.00	0.33 a ±0.82
≥ 21	1.50+2.81	0.00+0.00	0.00±0.00

Means with different letters denote significant differences ($P < 0.05$) among sites

Variation in health status, forms and phenology of baobab according to sites. The different health status, forms and phenology encountered are presented Table 6. At Materi and Boukombe, the most dominant health status was the healthy status with 11.33 and 14.5, respectively, while in Cobly, the disabled status was the most abundant. In the three communes, the baobab trees encountered were mostly straight and in fruitification. However, there was no significant variation between health status ($F = 16.249$, $P = 0.1801$) and phenology ($F = 0.007$, $P = 0.9963$) of baobab individuals in the three different study districts. Figures 4, 5, 6, 7 and 8 present differents phenology and health status encountered.

Table 5. Individuals with less than 3 m height

Communes	Number	Collar diameter (cm)	Type (%)	
			Seedling	Stump recruitment
Materi	8.00	13.32	62.50	37.50
Boukombe	13.00	13.20	92.31	7.69
Cobly	3.00	12.31	100.00	0.00

Figure 2. Photo of African baobab seedling at Boukombé (Agbohessou, 2018)

Figure 3. Phenology stage encoutered. a. Flowering; b. Flowering and fruiting (Agbohessou, 2018)

Table 6. Health status, forms and phenologyof baobab in the different locations in Benin

	Mated	Boukombe	Cobly	Khi - p-value
Health status				
Healthy	11.33	14.5	04.00	16.249 - 0.1801
Disabled	10.00	00.50	04.33	
Barked	05.83	01.33	01.00	
Pruned	00.17	01.00	00.00	
Trunk rot	00.00	01.33	00.00	
Burned trunk	01.17	0.33	00.5	
Loranthaceae	00.50	01.17	00.00	
Forms				
Right Standing	23.00	18.33	08.33	
Leaning	00.50	1.33	01.00	
Layer	00.00	00.00	00.00	
Phenology				
Fructification	17.00	16.67	07.83	00.007 - 0.9963
Flowering	17.17	16.5	07.50	

Figure 4. State of health of the baobab feet encountered, burnt trunk

Figure 5. Baobab trunk barked.

Figure 6. Trunk of Baobab rotten (Agbohessou, 2018)

Figure 7. Baobab tree attacked by Loranthaceae (Agbohessou, 2018)

Discussion

The present study made it possible to characterize the structure of the regeneration of Baobab populations in the communes of Materi, Cobly and Boukombe in Benin. The data were collected by means of linear transects. This methodology is most appropriate in the description of tree regeneration (Bahl and Brandli, 2007). The distribution of plants in space is an important feature of ecological communities (Jayaraman, 1999). Indeed, the majority of baobab feet studied were found in fields, fallows or houses. This finding is reinforced by the work of Kelly *et al*. (2004) in Mali, which showed that agricultural activities influence the distribution of shea. It was noticed that the distribution of Shea trees was declining in the forests and that the species was more common in the fields. Data collection were done using linear transects. The absence of aggregative distribution of baobab stands in the communes of Materi, Cobly and Boukombe is consistent with the report of Djossa *et al*. (2008) on the distribution of shea feet in the Pendjari region of northwestern Benin. The low density of the individuals observed could be the result of human activities.

The results showed that the baobab stands encountered in the three communes were adults and the largest individuals in diameter were found in Materi and Cobly. In addition, the density of baobab encountered in the commune of Cobly was lower than that recorded in Mated and in Boukombe. This could be explained by the fact that the pressure exerted by agriculture appeared greator at Cobly. As a result, farmers do not keep the species in their field because it affects negatively their yield because of the shading on crops. Thus,farmers often cut baobab feet and suppress the regeneration of baobab that grow in their fields so as not to allow them to grow. This is sconsistent with the work of Gbemavo *et al*. (2010) who showed the reducing effect of Shea shade on capsular production of cotton. The conservation of the few remaining feet in the commune of Cobly in time is therefore doubtful. Younger individuals translated by regeneration were more common in the commune of Boukombe. Indeed, Venter and Witkowski (2013) showed that baobab produced sufficient viable seeds, but the absence of favorable climatic conditions for their development is the main factor for the low recruitment observed. It thus appears that the edaphic and climatic conditions of the commune of Boukombe was more favorable to the regeneration of the species. Data collection was done in the month of September. The individuals encountered during the collection of our data were mostly in fruit or in bloom or in fruit and flowers. This is confirmed by Assogbadjo (2005) which showed that the flowering and the fructification of the baobab are seasonal and can be observed in the Sudanese and Sudano-Guinean areas of Benin from July to the

end of July- end of September. Most of the individuals encountered were in good health and this would reflect the baobab's resistance to attack by pests. In addition, burnt individuals were victims of the consequences of farm fires used by farmers. Indeed, agriculture remains the main cause of destruction of natural habitats, thus posing a great threat to the conservation of biodiversity (SCBD, 2002 ; Venter *et al*., 2006). Faced with these situations, it will be necessary to make farmers aware of the attributes of the Baobab tree in order to encourage them to conserve the species in their fields, especially the young ones in order to ensure the perenniality of the species. Moreover, considering that the reproductive cycle is really long, it will be necessary to think of generating the species in a vegetative way to reducefor baobab very long cycle.

Conclusion

Baobab tree is a species found in the communes of the Atacora department in Benin. Two villages per commune were chosen per commune in view of their abundance in baobab feet and in each village three bands of transects were installed there. A total of eighteen bands of linear transects were installed. The results showed that the town of Cobly is home to the lowest density of the species unlike the communes of Materi and Boukombe which had equal density of the species. The youngest individuals were found in Boukoumbe and the older ones in the commune of Cobly and Materi. The results showed that most of the baobab individuals were healthy. However, there were feet mutilated, pruned, attacked by Loranthaceae, and many had their trunks debarked. There was almost no regeneration. We suggest using vegetative propagation in order not only to make the species available but also to ensure its conservation in the wild.

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