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Analysis of the Structure and Diversity of *Prosopis africana* (G. et Perr.) Taub. Tree Stands in the Southeastern Niger

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Abstract

All parts of *Prosopis africana* are used by rural people in Niger, and this exposes it to degradation and a regeneration problems. The objective of this study was to determine the structure and regeneration of *P. africana* stands in the southern regions of Maradi and Zinder, Niger. Data were collected in plots, following transects after stratified sampling. Trunk diameter of all woody species was recorded in 126 plots. The diversity was analyzed and diameter structure and regeneration rates were determined. *P. africana* was the predominant species in both Maradi and Zinder: frequency = 40.35% and 43.95% of all species, respectively in Maradi and Zinder; importance value index = 40.57% in Maradi and 48.60% in Zinder. The Shannon diversity index was 2.82 in Maradi and 2.40 in Zinder and the Sorensen similarity index between the two regions was 0.73. According to the diameter structure, the stands were degraded in Zinder but regenerating in Maradi. The density of *P. africana* per hectare for trees with trunk diameter $\geq$ 5 cm and < 5 cm, respectively was 16 and 51 in Maradi, and 30 and 12 in Zinder. The regeneration rate of *P. africana* was low compared with the general woody population. These results show the need for reforestation operations, using appropriate techniques, to avoid local extinction of the species.

Keywords: *Prosopis africana*, tree stand, structure, degradation, regeneration, Niger

1. Introduction

In the Sahel in general and in Niger in particular, trees provide many products and services to rural populations (Larwanou et al., 2010; Laouali et al., 2014), which exposes them to high anthropogenic pressure reducing their natural regeneration. As a result, many populations of woody species are in a regressive dynamics characterized by the increasing scarcity or lack of younger individuals (Endress et al., 2006; Bellefontaine et al., 2010; Sanogo et al., 2013). The exploitation and marketing of non-timber forest products in Africa to date are primarily designed to increase gatherers' individual incomes without concern for sustainable management. Sustainable management would require ensuring natural regeneration of the species, and promoting their domestication to reduce the pressure on natural populations (Ouédraogo et al., 2006). *Prosopis africana* is a particularly vulnerable species because all parts of the tree are used by rural communities (Faye et al., 2011). Its wood is dense (Sotelo Montes & Weber, 2009) and highly resistant, so it is used for making construction poles and planks, and mortars and pestles. The wood has a high calorific value (Sotelo Montes et al., 2011), so it is highly valued for charcoal by blacksmiths. The leaves, roots and especially the barkare used in traditional medicine. The leaves and pods are used for fodder and the seeds for food (Larwanou, 1994; Arbonnier, 2000; Agboola, 2004; Larwanou et al., 2012; Laouali et al., 2014). Unfortunately, this species is facing a regeneration problem (Ahoton et al., 2009, Niang-Diop et al., 2010; Laouali et al., 2015) and overexploitation to which are added climatic conditions increasingly difficult due to climate change. This will result in a regression of the species' population or its disappearance if sustainable management precautions are not taken.

In Niger, *P. africana* is represented by scattered individuals with some relic stands in the southern regions of

Dosso, Maradi and Zinder. Little information is available on their structure and regeneration. It is therefore necessary to have reliable data on the current state of these stands for better conservation and sustainable management of the species.

The main objective of this study is to characterize the *P. africana* tree stands in the southeastern Niger on based on the analysis of their structure and diversity.

2. Material and Methods

2.1 Study Area

The study was conducted in the southern regions of Maradi and Zinder (Figure 1). Relevant administrative departments are Gazaoua in Maradi region, Kantché and Magaria in Zinder region. The human population in the Aguié and Gazaoua departments (which formed the same department) expanded from 172,922 to 406,532 inhabitants or from 57.52 to 135.24 inhabitants / km^2 from 1988 to 2012. The human population in the Kantché and Magaria departments expanded from 518,452 to 976,924 inhabitants or from 82.95 to 156.3 inhabitants / km^2 from 1988 to 2012 (Institut National de la Statistique/Niger [INS], 2014). The socio-economic activities of these populations are dominated by agriculture, livestock, crafts, trade. The climate is sahelo-soudanian. In the south of Maradi, the average annual temperature is around 28 °C. The average annual rainfall from 1981 to 2010 at the Gazaoua station was 446.32 mm. The soils are mainly dunal and the flora is dominated by species in the Mimosaceae family (*Prosopis africana* (Guill. & Perr.) Taub., *Albizia chevalieri* Harms, *Faidherbia albida* (Del.) Chev.…), the Caesalpiniaceae family (*Piliostigma reticulatum* (DC.) Hochst., *Cassia singueana* (Del.) Lock, *Bauhinia rufescens* Lam.…), the Combretaceae family (*Combretum glutinosum* Perr., *Guiera senegalensis* J. F. Gmel, *Anogeissus leiocarpa* (DC.) Guill. & Perr. ...) and the Anacardiaceae family (*Sclerocarya birrea* (A. Rich.) Hochst., *Lannea microcarpa* Engl. & K. Krause …). In the south of Zinder, the average annual rainfall is around 525 mm. The average temperature is 22.5 °C. The soils are mainly sandy, loamy sand and clay loam. The flora is dominated by the Mimosaceae (*Faidherbia albida* (Del.) Chev., *Prosopis africana* (Guill. & Perr.) Taub.) and the Anacardiaceae (*Lanea microcarpa* Engl. & K. Krause) (United States Agency for International Development [USAID], 2006; Laouali et al., 2014). Each of these areas is shared between the central south sahelian and central north soudanian compartments, according to Saadou (1990) phytogeographic subdivisions on the basis of climatic conditions; the vegetation consists of Combretum thickets, steppes, lowland dry forests, gallery forests and savannas.

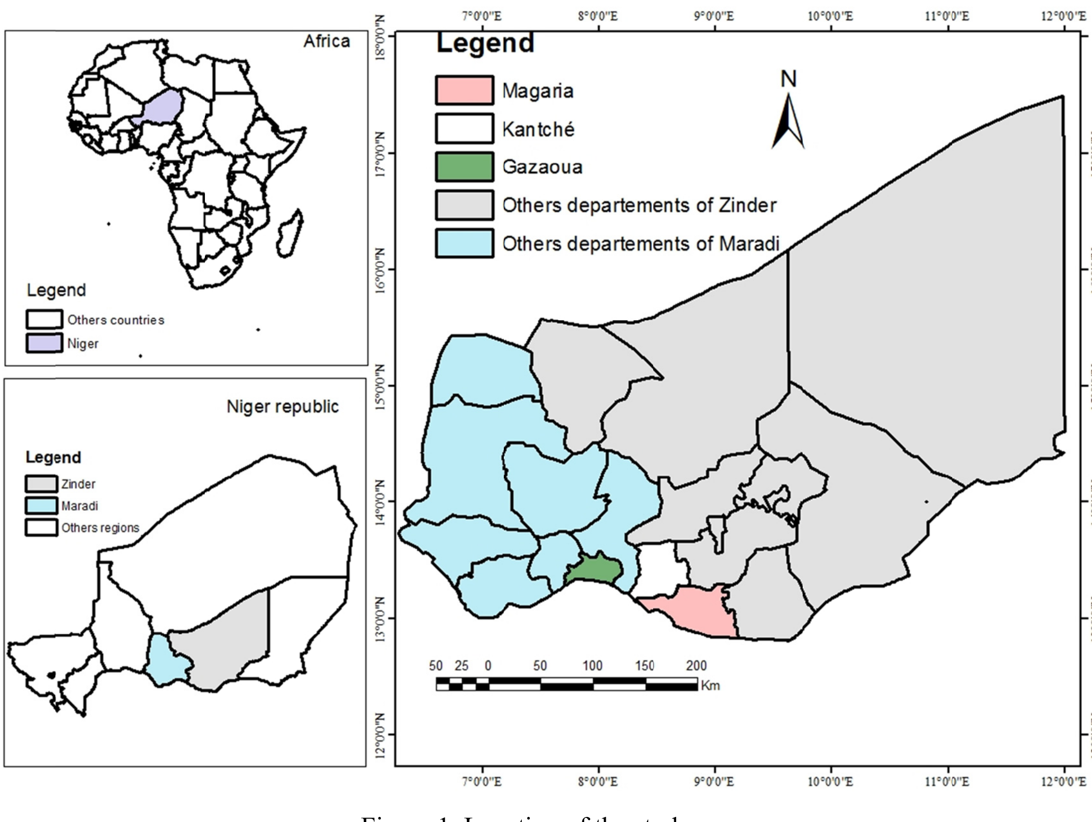

Figure 1. Location of the study area

2.2 Sampling

The sampling, guided by the presence of *P. africana* in the regions and administrative departments, was systematic across transects in the territories of villages. In the Gazaoua administrative department in the Maradi region, sampling was conducted in three villages (Elguéza, Guidan Adamou and Dan Damou). In the Zinder region, the surveys were conducted in eight villages (Bawada, Angoual kirya, Sabar, Gagéré, Kahin baka, Kadeye, Kokotaou and Tsagai) distributed in the Kantché and Magaria administrative departments. The administrative departments were selected after a field visit and a consultation of resource persons which allowed having more information about the presence of the species. Villages were selected following recommendations from the departmental offices of the Ministry of Environment.

The *P. africana* stands were identified prior to sampling. Different sampling schemes were used in the two regions because stand structure differed. In the Maradi region, the only one stand of *P. africana* studied was homogeneous and extended throughout the three village territories. In the Zinder region, there were many stands located in the village territories, and the stands were not contiguous. In the Maradi region, individuate plots (50 x 50 m) were arranged in seven linear and parallel sampling strategies (transects) with a length of 4 km each and separated by one km, individuated using a GPS. In each sampling strategy, there was a distance of 400 m between plots. A total of 62 plots were surveyed, and these covered the entire *P. africana* stand. Plots size is justified by the fact that the studied stands are parklands and the selected layout allowed reaching a sampling rate of 1.8%. In the Zinder region, plots (50 x 50 m) were placed along four sampling strategies (with a length of 1.5 km each) that extended radially in four directions (compass directions) from each village. A total of 64 plots distributed among the eight villages were surveyed.

2.3 Data Collection

Data collected during the inventory are including the number of individuals for each woody species, tree height, crown diameter and stem diameter at breast height. Data were recorded only for individuals with a trunk diameter $\geq$ 5 cm. Trees with trunk diameter <5 cm were considered young natural regeneration: these trees were counted.

2.4 Diversity and Species Importance Value Indices

To analyze the diversity between regions and inside regions, several indices were calculated.

The diversity index of Shannon and Weaver (1949) was calculated to study the Alpha diversity for assessing the weight of the species in land use in each region. This index varies depending on the number of species present. It is higher when there are more species, indicating greater diversity. It is calculated as bits per individual and its formula is:

$$H = -\sum_{i=1}^{s} pi \log_2 pi \qquad (1)$$

S = total number of species and pi = relative frequency of species. Pielou evenness index was also calculated. Its formula is:

$$E = \frac{H}{Hmax} \quad \text{where } Hmax = \log_2 S \qquad (2)$$

S is the total number of species. The Pielou evenness index varies between 0 and 1. It is 0 when there is a phenomenon of dominance and 1 when the distribution of individuals among species is homogenous.

The coefficient of Sorensen (1948) was calculated to assess beta diversity for comparing habitats of the two regions. This index expresses the degree of similarity between two sites and has the formula:

$$Is = \frac{2C}{2C+A+B} \qquad (3)$$

A is the number of species found only in site 1; B is the number of species found only in site 2, and C is the number of species common to both sites. Beta diversity is the importance of species replacement or biotic change along environmental gradients. The interest of its study is to highlight the diversity across the region.

To appreciate the importance of tree species in general and that of *P. africana* in particular at the study regions, the importance value index (IVI) (Curtis & Macintosh, 1951) was calculated. This index is expressed by the formula:

IVI (%) = relative density + relative dominance + relative frequency (for the species) (4)

The relative dominance of one species (relative basal area) is the quotient of its basal area per total basal area of all species. The relative density of a species is the ratio between its absolute density and total absolute densities of all species multiplied by 100. The relative frequency of a species is the ratio between its specific frequency and the total specific frequencies of all the species multiplied by 100.

Basal area was calculated using the following formula:

$$G\ (m^2/ha) = \frac{\pi}{40000s}\sum_{i=1}^{n} di^2 \quad (5)$$

d is the trunk diameter (cm) of the tree i in the plot and s the area of the plot (ha). The trees were then divided into 18 diameter classes of 5 cm. Furthermore, to better analyze the data, the observed structure was modeled using the parameters of the theoretical Weibull distribution whose probability density function is (Rondeux, 1999):

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} exp\left[-(\frac{x-a}{b})^{c}\right] \quad (6)$$

x is the trunk diameter of the tree; $f(x)$ is the probability density value at point x. a is the position parameter: it is 0 if all categories of trees are considered (from plantlets to the seed trees) during the inventory; it is not null if the trees have a diameter $\geq a$ (a = 5 in this study). b is the scale parameter, linked to the central value of the probability distribution of variable x = diameter. c is the shape parameter related to the diameter structure. A value of $c < 1$, distribution "inverted J" is characteristic of multispecies or uneven-aged stands, while $c > 3.6$ is characteristic of predominantly aged individuals stands. Moreover, $1 < c < 3.6$ means stands with predominance of young individuals or small diameter. Minitab 16 software was used for this purpose. To test the adjustment of the structure observed in the Weibull distribution, a log-linear analysis was applied with the R 2.15.3 software. This structure determination concerns the total woody population on one hand and *P. africana* the other hand. To appreciate the regeneration, the density of adult trees and that of the young individuals were calculated for both the total woody population and *P. africana*, which were used to calculate the regeneration rates. The results were compared through a FISHER test performed with the Minitab 16 software. Thus, the regeneration rate of *P. africana* and that of the woody population were compared in each region. A comparison was also made between *P. africana* regeneration rates of the two regions and between the woody population regeneration rates of the two regions.

3. Results

3.1 Diversity Analysis

Values for Shannon diversity index (H), maximum diversity (H max) and Pielou evenness index (E) in the two regions are listed in Table 1.Diversity was relatively low compared to the maximum diversity at both regions. There was no significant difference in diversity and evenness between the Maradi and Zinder regions ($P > 0.05$). The value of the Sorensen similarity index is 0.73.

Table 1. Diversity and equitability indexes values

Region	**H**	**Hmax**	**E**
Maradi	2.82	4.70	0.60
Zinder	2.40	4.52	0.53

3.2 Dendrometric Characteristics and Regeneration

The inventories included 26 woody species in Maradi (Table 2) and 23 woody species in Zinder (Table 3). *P. africana* had the largest IVI at both regions: 121.72% (40.57% of the total IVI) in Maradi, and 145.79% (48.60% of the total IVI) in Zinder.

Table 2. Dendrometric parameters of species recorded in the Maradi region

Species	**RF (%)**	**RDs (%)**	**RDm (%)**	**IVI (%)**
Prosopis africana (Guill. & Perr.) Taub.	40.35	40.35	41.02	121.72
Piliostigma reticulatum (DC.) Hochst.	22.65	22.65	26.28	71.59
Faidherbia albida (Del.) Chev.	14.08	14.08	14.94	43.09
Albizia chevalieri Harms	1.88	1.88	3.66	7.41
Bauhinia rufescens Lam.	3.35	3.35	0.42	7.12
Dichrostachys cinerea (L.) Wight & Arn.	2.95	2.95	0.27	6.17
Diospyros mespiliformis Hochst. ex A. Rich.	1.34	1.34	2.62	5.31
Hyphaene thebaica (L.) Mart.	1.74	1.74	1.70	5.19
Lannea microcarpa Engl. & K. Krause	0.94	0.94	2.26	4.14
Balanites aegyptiaca (L.) Del.	1.61	1.61	0.71	3.93
Azadirachta indica A. Juss.	1.61	1.61	0.53	3.75
Tamarindus indica L.	0.40	0.40	2.47	3.28
Annona senegalensis Pers.	1.47	1.47	0.03	2.98
Pterocarpus erinaceus Poir.	0.40	0.40	2.04	2.85
Acacia nilotica (L.) Willd. ex Del. subsp. Nilotica	0.94	0.94	0.64	2.52
Guiera senegalensis J. F. Gmel	0.94	0.94	0.02	1.90
Combretum glutinosum Perr.	0.67	0.67	0.03	1.37
Cassia singueana (Del.) Lock	0.54	0.54	0.00	1.08
Strychnos innocua Del.	0.40	0.40	0.18	0.99
Maerua oblongifolia (Forssk.) A. Rich.	0.40	0.40	0.01	0.81
Moringa oleifera Lam.	0.40	0.40	0.00	0.81
Sclerocarya birrea (A. Rich.) Hochst.	0.27	0.27	0.07	0.60
Calotropis procera (Ait.) Ait. f.	0.27	0.27	0.00	0.54
Vitex doniana Sweet	0.13	0.13	0.07	0.34
Maerua angolensis DC.	0.13	0.13	0.00	0.27
Ziziphus mauritiana Lam.	0.13	0.13	0.00	0.27
Total: 26	**100**	**100**	**100**	**300**

Note. RF = Relative frequency; RDs = Relative density; RDm = Relative dominance; IVI = Importance value index.

Table 3. Dendrometric parameters of species recorded in the Zinder region

Species	RF (%)	RDs (%)	RDm (%)	IVI (%)
Prosopis africana (Guill. & Perr.) Taub.	43.95	43.95	57.89	145.79
Faidherbia albida (Del.) Chev.	32.58	32.58	22.69	87.86
Sclerocarya birrea (A. Rich.) Hochst.	4.24	4.24	4.88	13.37
Tamarindus indica L.	2.80	2.80	3.61	9.20
Combretum glutinosum Perr.	2.62	2.62	0.66	5.90
Annona senegalensis Pers.	2.62	2.62	0.12	5.35
Lannea microcarpa Engl. & K. Krause	1.71	1.71	1.58	5.01
Parkia biglobosa (Jacq.) R. Br. Ex G. Don	1.08	1.08	2.82	4.98
Albizia chevalieri Harms	1.71	1.71	1.51	4.94
Guiera senegalensis J. F. Gmel	2.17	2.17	0.01	4.34
Dichrostachys cinerea (L.) Wight & Arn.	1.17	1.17	0.32	2.67
Piliostigma reticulatum (DC.) Hochst.	0.81	0.81	0.59	2.21
Adansonia digitata L.	0.27	0.27	0.84	1.38
Daniellia oliveri (Rolfe) Hutch. & Dalz.	0.18	0.18	0.76	1.12
Terminalia avicennioides Guill. & Perr.	0.36	0.36	0.33	1.05
Balanites aegyptiaca (L.) Del.	0.27	0.27	0.35	0.89
Ficus platyphylla Del.	0.09	0.09	0.63	0.81
Ziziphus mauritiana Lam.	0.36	0.36	0.07	0.79
Bauhinia rufescens Lam.	0.27	0.27	0.02	0.56
Azadirachta indica A. Juss.	0.18	0.18	0.19	0.55
Cassia singueana (Del.) Lock	0.27	0.27	0.00	0.54
Hyphaene thebaica (L.) Mart.	0.18	0.18	0.10	0.46
Acacia nilotica (L.) Willd. Ex Del. Subsp. Nilotica	0.09	0.09	0.03	0.21
Total: 23	**100**	**100**	**100**	**300**

The density was higher in Zinder than Maradi for trees ≥ 5 cm in trunk diameter. Trees < 5 cm in trunk diameter were more common in Maradi (Table 4). This concerns woody population one hand and *P. africana* on the other hand.

Tableau 4. Woody population and *P. africana* density at both regions for trees ≥ 5 cm and < 5 cm in trunk diameter

Regions	Density (trees/ha)					
	Woody population			*P. africana*		
	≥ 5 cm	< 5 cm	Total	≥ 5 cm	< 5 cm	Total
Maradi	41	143	184	16	51	67
Zinder	65	77	142	30	12	42

Assuming that trees with trunk diameter ≤ 5 cm reflect relatively recent natural regeneration, the regeneration rate was significantly higher in Maradi than in Zinder ($P < 0.05$), for both the woody population and for *P. africana*. For the regions separately, the regeneration rate of *P. africana* was significantly lower than that of woody population in Zinder ($P < 0.05$), but these two rates were not significantly different in Maradi ($P = 0.209$) (Figure 2).

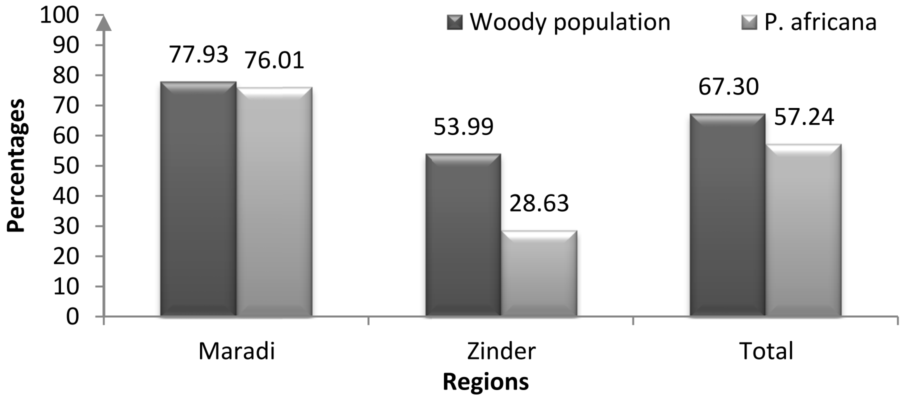

Figure 2. Regeneration rates of woody population and *P. africana* in Maradi, Zinder and both regions

3.3 Structure of Woody Population

The mean trunk diameter of *P. africana* was significantly higher in Zinder (38.13 ± 8.78 cm) than in Maradi (17.8 ± 13.6) ($P < 0.001$).The distribution of trees in diameter classes in Maradi had a "reversed J" shape. It fit the theoretical Weibull distribution with shape parameter c = 0.93 for woody population and c = 0.82 for *P. africana* (Figure 3a and 3b). In Zinder, the distribution of trees in diameter classes had a bell-shape. It fit the theoretical Weibull distribution with shape parameter c = 2.96 for woody population and c = 3.88 for *P. africana* (Figure 3c and 3d). The results of the log-linear analysis indicate a good fit of the data to the Weibull distribution for both regions ($P > 0.05$).

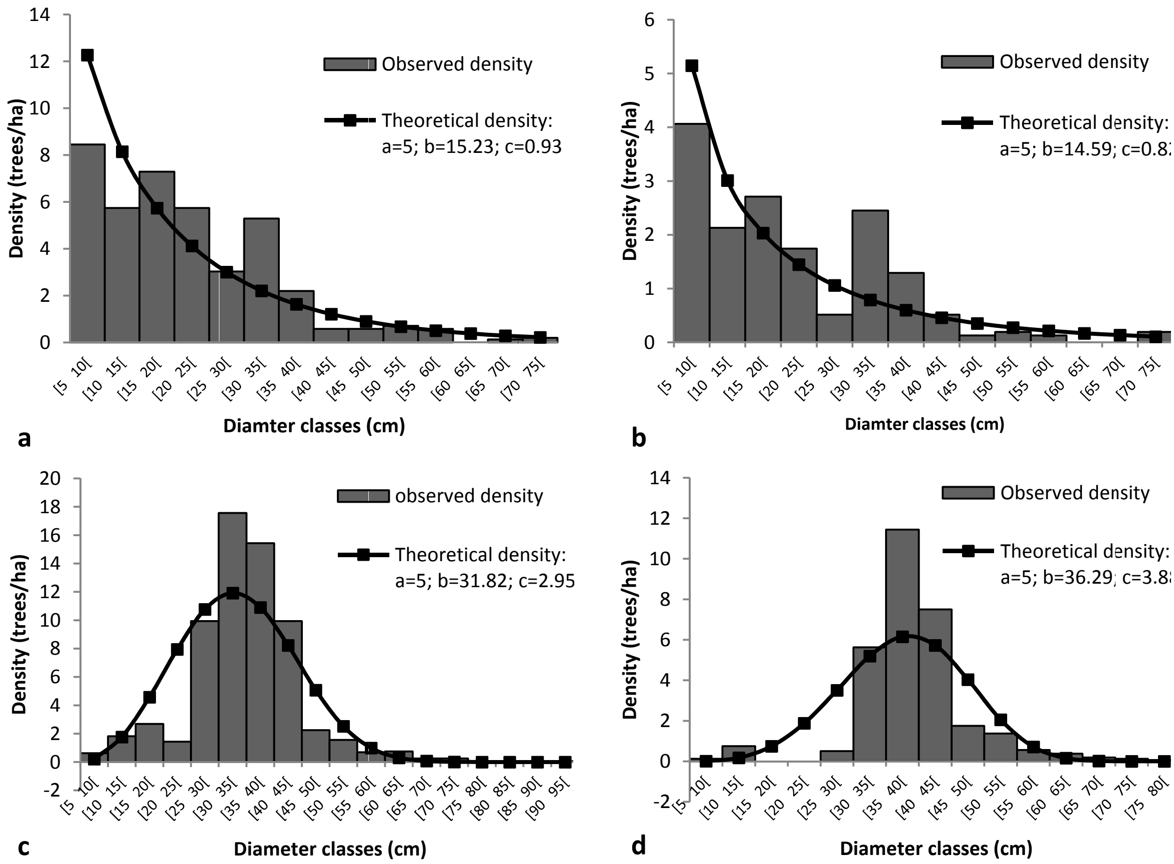

Figure 3. Structure of trunk diameter classes of (a) all woody species and (b) *P. africana* in the Maradi, and (c) all woody species and (d) *P. africana* (d) in Zinder

4. Discussion

Prosopis africana was the most common species in the two regions. This is linked to the importance given to the species by the local population. In fact, the population would have favored the conservation of this species in previous years, while the climatic conditions were more favorable and the demographic pressure lowest. Indeed, in practice, farmers agree to keep a tree in their fields if they can have a crop production gain or if the crop yield decrease can be compensated by the economic gains due to the presence of the tree (Pierre et al., 1992). This could also explain the relatively low species diversity. The relatively high similarity between the two regions can be explained by climatic conditions and socioeconomic activities, including agricultural practices, which are essentially the same.

The distribution of trees in diameter classes with a shape of "J reversed" observed in Maradi (Figures 3a and 3b) with the shape parameter c = 0.82 (< 1) for *P. africana* is characteristic of a fast regenerating stand. These results are similar to those found by others in vegetation study in Niger (Dan Guimbo et al., 2010; Abdourahamane et al., 2013; Boubacar et al., 2013).

The low proportion of *P. africana* trees in the large diameter classes in Maradi is due to a particularly important use of wood of this species. The wood of *P. africana* is strong and hard, so it is used as poles to support barns, houses, etc. and for mortars and pestles. For these uses, the wood of *P. africana* is preferred over the other species in this region (Laouali et al., 2014).

According to Ajonou et al. (2009), the bell shape distribution of trunk diameter reflects an unstable population characterized by an absence or very small proportion of individuals in one or more diameter classes. This is the situation in Zinder. The majority of *P. africana* trees were in the average diameter class (30 to 50 cm), and individuals in the smaller and larger diameter classes were poorly represented. This could be explained by systematic cutting of large diameter trees (as in Maradi) and the vulnerability of small diameter trees to browsing animals and farmers seeking fodder. The regeneration of a natural stand is more certain if it has a lot of trees in the smaller diameter classes (Morou, 2010), so regeneration of *P. africana* is more threatened in Zinder than in Maradi.

The difference in diameter found between the two regions could be related to rainfall which is slightly higher in Zinder, although overall, the climatic conditions are essentially similar. The low regeneration of of *P. africana* compared with the total woody population could be explained by its relatively poor seed germination (Ahoton et al., 2009, Niang-Diop et al., 2010; Laouali et al., 2015). The fact that regeneration was better in Maradi than Zinder could be explained by the promotion of assisted natural regeneration by several research projects. This started to be adopted by farmers in the southern part of Maradi in the late 1980s, while in the Zinder region, the adoption started later (USAID, 2006; Larwanou et al., 2010).

Not enough of previous studies on this topic in the same area was an obstacle in the discussion of the results but makes this study more interesting. Based on this study, we can say that in the still extant *P. africana* stands, the regeneration rate of the species is lower than that of other species, especially in the Zinder region, even though development projects have promoted awareness campaigns and the practice of assisted natural regeneration. This confirms that *P. africana* is threatened with local extinction. Given these results and the socio-economic importance of this species, restoration operations through reforestation campaigns should be considered in areas with suitable habitat for the species. Growth and survival of trees are better for *P. africana* provenances from drier locations in Niger (Weber et al., 2008), and this probably is due to a higher root/shoot ratio in these provenances (Weber et al., 2015). The climate is becoming hotter and drier and with variable rainfall in the West African Sahel (Buontempo, 2010), so it would be advisable to use seed from drier locations for the reforestation campaigns. In addition, monitoring forestry extension services should provide technical assistance to rural communities for all steps in the reforestation process (seed collection, germination, planting, maintenance, monitoring and evaluation).

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