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Impact of land use types on population structure and extent of bark and foliage harvest of *Afzelia africana* and *Pterocarpus erinaceus* in Eastern Burkina Faso

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In the West African Sudanian regions, people depend on natural products, especially on highly valued species as source of income, fuel wood, food, medicine, fodder for livestock etc. However, land-use management coupled with unsustainable uses of highly valued trees might jeopardize the long-term viability of some species' populations. Thus, we compared the population structures of two trees, *Afzelia africana* and *Pterocarpus erinaceus* and the extent of bark and foliage harvesting within two contrasting land-use types using a random stratified design with 45 replication plots for each species. For both species, population structures were stable in the protected area whereas they showed a declining structure in the agroforestry parklands with lower densities of seedlings and adults as well as a total lack of saplings and young mature trees. In addition, both species were over-exploited. More individuals of *A. africana* and *P. erinaceus* were harvested with a weak to severe intensity in the parklands, while only few individuals were harvested in the protected area, with a higher proportion of weak to medium intensity. To ensure conservation of these highly valued species, participatory introduction of juveniles and sensitization for seedling protection are required in the agroforestry parklands.

Key words: Population structure, W National Park, agroforestry parklands, pruning, debarking, West Africa.

INTRODUCTION

In the Sudanian zone people depend heavily on the natural resources and on the services provided by ecosystems and agro-ecological systems (Devineau et al., 2009). Indeed, the majority derives their livelihood from agriculture combined with extensive livestock breeding and the use of a variety of natural products. Among these services, non-timber forest products (NTFPs) play an important role (Lykke, 1998; Cunningham, 2001; Belem et al., 2007). Therefore, the increase of population in these recent years and agricultural intensification (notably cotton cultivation) combined with climate change result in an increasing pressure on natural resources. This ecological crisis is particularly accentuated in West Africa leading to habitat degradation and loss of biodiversity. For example, more than 14.5% of savanna habitats were lost in the peripheral areas of the W-Arly-Pendjari (WAP) protected area complex in the period 1984 to 2002. During this period, the potential capacity of the area to conserve species richness decreased considerably (Clerici et al., 2007).

Afzelia africana (Sm.) or African mahogany (Caesalpiniaceae) and *Pterocarpus erinaceus* Poir or African rosewood (Papillionaceae) are highly valued

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species throughout the Sudanian zone and particularly in the area around the WAP complex (Sieglstetter and Wittig, 2002; Krohmer et al., 2006; Koadima, 2008). Both are known for the good quality of the wood for timber, fuel and charcoal. *A. africana* and *P. erinaceus* also provide medicinal products. The barks, leaves and roots are used by local people in the treatment of diarrhoea, cough, mental illness, gastrointestinal disorders, general pain relief and trypasonomiasis in domestic animals (Arbonnier, 2002; Akinpelu et al., 2008; Ouédraogo-Koné et al., 2008). Leaves are important fodder and nitrogen sources for animals during the dry season in the agrosylvopastoral system (Petit and Mallet, 2001; Ouédraogo-Koné et al., 2008).

Due to the importance of these species, especially for medicinal and fodder purposes, they are very often subject to bark and foliage harvesting in Eastern Burkina Faso, which could affect the long-term viability of their populations. According to Peter (1994) and Delvaux et al. (2009) harvesting of vegetative structures (like stems, leaves and barks) significantly threatens the survival of plant populations. Due to these threats *A. africana* was classified as "Endangered" in the IUCN red list and in the national red list species data base of threatened species in Burkina Faso (Paré et al., 2009). Consequently these species need conservation efforts, which should be based on a detailed knowledge about their current population status.

Two main land-use types characterize the West African ecosystems: protected areas controlled for *in situ* biological conservation goals and agroforestry parklands, exposed to human impact *via* land clearing for agriculture, livestock grazing and/or harvesting of forest products. Thus, studying how strong land-use affects population structures of highly valued species might help to develop effective conservation strategies of the given species in accordance to the needs of local population. Especially understanding species population dynamics under harvesting impact is important for improved conservation. The use of population structures as a tool to investigate the demographic health of harvested populations can be the basis for strong management decisions if it is combined with information related to species specific growth rate, spatial distribution (Fandohan et al., 2010a), patterns of use and harvest (Gouwakinnou et al., 2009; Schumann et al., 2010).

Previous studies on *A. africana* and *P. erinaceus* have focused primarily on regeneration and seedling survival constraints (Bationo et al., 2001; Ouédraogo et al., 2006), characterization of nutritive value, chemical composition (Ouédraogo-Koné et al., 2008) and medicinal properties (Akinpelu et al., 2008). Sinsin et al. (2004) used the dendrometric characteristics as indicators of pressure of *A. africana* to assess the dynamic changes in trees between climatic zones. None of the studies assessed the relationships between bark and leave harvestings and population structures under land-use impact for conservation purposes. Our study will especially emphasize the effect of land-use types on *A. africana* and *P. erinaceus* populations by comparing their populations in a National Park and its surrounding agroforestry parklands under harvesting impact. Thus, it will provide a profound knowledge and information basis for developing management strategies for a more sustainable use and conservation of these species.

The aim of this study is to (i) assess the population structure of *Afzelia africana* and *Pterocarpus erinaceus* by comparing populations of two land-use types: parklands *versus* a protected area and (ii) identify the harvesting patterns of *Afzelia africana* and *Pterocarpus erinaceus* products. We draw on our results to provide recommendations for better conservation strategies for the species populations in the West African savannas.

MATERIALS AND METHODS

Study site

The study was undertaken in two different land-use types namely protected and agroforestry parklands located in Eastern Burkina Faso. The protected area comprises the W National Park (WNP) and its adjacent hunting zones. WNP is a component of a transfrontalier biosphere reserve (1 023 000 ha) shared between three countries: Benin, Burkina Faso and Niger (Figure 1). The protected area is managed through prescribed annual early fires (October or November) (Clerici et al., 2007). Grazing and fuel wood extractions are prohibited inside, while exploitation of baobab fruits and straw by neighbouring local communities is authorized and regulated. The vegetation is composed of a mosaic of various types of woodland and riparian forests where *Afzelia africana* and *Pterocarpus erinaceus* characterize two main vegetation communities namely the *Afzelia africana-Tamarindus indica* and the *Isoberlinia doka-Pterocarpus erinaceus* associations (Mahamane, 2005).

The agroforestry parklands are characterized by farming systems with alternating cycles of cultivation and fallows. Also heavy and extensive livestock grazing, uncontrolled fires as well as wood and NTFP collection for daily subsistences (legume, fodder, medicinal products, domestic uses like traditional hives and pestles, etc.) takes place (Belem et al., 2007). *Vitellaria paradoxa* Gaertn. C. F., *Parkia biglobosa* (Jacq.) R.Br. ex G.Don, *Piliostigma thonningii* (Schumach.) Milne-Redh., *Guiera senegalensis* J.F. Gmel., *Combretum collinum* Fresen., *Pterocarpus erinaceus* and *Afzelia africana* trees are commonly found in this area.

The average annual rainfall in the study area ranges from 750 to 950 mm and the dry season lasts 6 to 7 months which corresponds to the Sudanian phytogeographical sector (Fontès and Guinko, 1995). The main soil types are luvisols, lixisols and leptosols. Human population density bordering the WNP in Burkina Faso is about 16 inhabitants per km² (INSD, 2007). The largest ethnic groups are Gourmantché, Fulani and Djerma who are farmers and cattle-breeders. Livestock density (mainly cattle, sheep and goats) in the province Tapoa is about 50.28 per km² (ENEC, 2003).

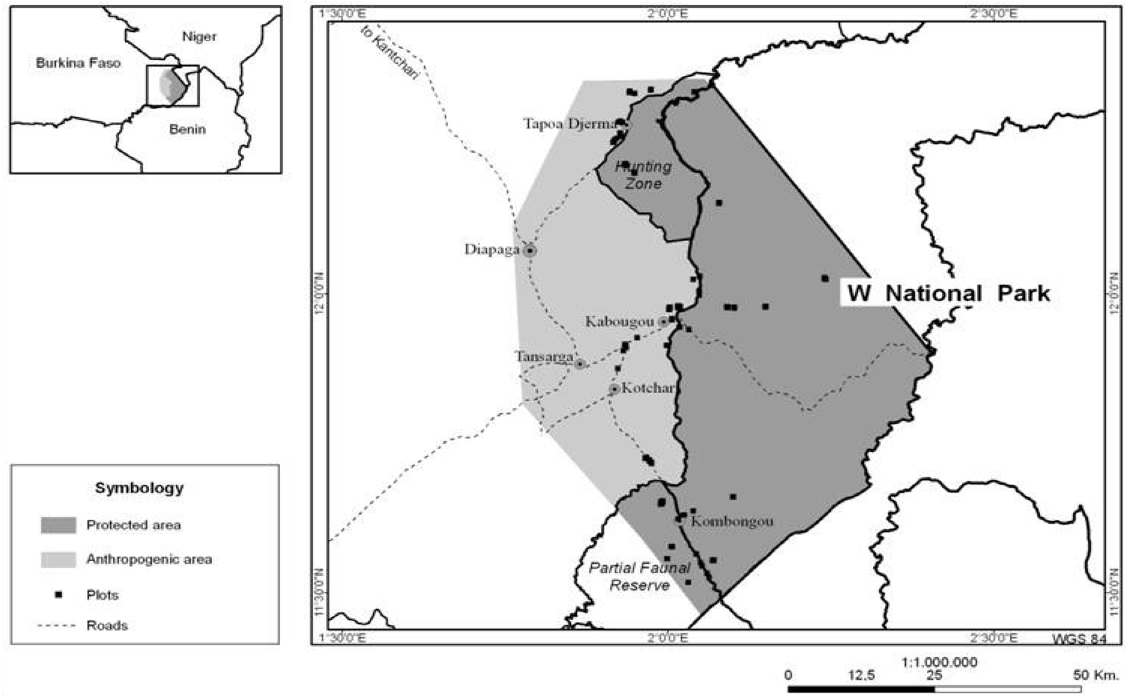

Figure 1. Location of the study area with the position of the plots (UTM zone 31 North, WGS 84).

Table 1. Description of the four levels of intensity of harvesting based on Cunningham (2001).

Percentage of harvesting	Intensity of harvesting
Individual without damage (without branch neither cut nor mutilated trunk)	Null
Individual with 0–25% of their crown pruned or trunk debarked	Weak
Individual with 25–50% of their crown pruned or trunk debarked	Medium
Iindividual with >50 % of their crown pruned or trunk debarked	Severe

Studied species

Afzelia africana is a fire-tolerant tree species (Stark, 1986) occurring in sub-Saharan Africa between the Guinean and the Sudano-guinean bioclimatic zone. The species is mostly found on deep sandy and alluvious soils. While *Pterocarpus erinaceus* is widely distributed in West African savanna regions on diverse types of soil. The later occurs in the Sudano-guinean bioclimatic zone (Arbonnier, 2002). Both species colonise woodland savannas and dry or open forests. They attain a height up to 25 to 35 m (*A. africana)* and 8 to 15 m (*P. erinaceus)*. In Burkina Faso *A. africana* is found between the latitude 12 to 13°N and *P. erinaceus* below the latitude 13°N (Terrible, 1984).

Sampling and data collection

Trees and other sapling populations of *A. africana* and *P. erinaceus* were sampled following a random stratified (protected and parklands) design with 45 replication plots (30 x 30 m) for each species. Individuals with a diameter between 5 to 10 cm at breast height (dbh) were considered as saplings, whereas those with dbh >10 cm were recorded as trees. Seedling populations (dbh <5 cm) were sampled in one random subplot (10 x 10 m) within each plot.

The parameters measured for each individual of tree and sapling populations were dbh, height, the percentage of debarked trunk and pruned branches. The adapted scale of human pressure on trees from Cunningham (2001) is used to estimate separately for each individual the percentage of trunk debarking as well as the percentage of pruned branches. Four levels of disturbance pressure were thus considered as shown in Table 1. All these data were coupled with informal talks and interviews with farmers in order to know the reasons of harvests.

Data analysis

To assess the impact of land-use on the two high value species we compared variables of population structure (density, height, dbh and the height/dbh ratio) following development stages between the land-use types using the Mann-Whitney non parametric test since the data were not normally distributed.

Table 2. Comparison of seedling, sapling and tree densities (mean individuals ha-1 ± SE) of *A. africana* and *P. erinaceus* in protected and parklands.

Species	Diameter by developmental stage	Protected area	Parklands	Z score	p-value
	Seedlings (0-5)	2466.67 ± 369.62	4.44 ± 4.44	Z = -8.048	p = 0.000
A. africana	Saplings (5-10)	3.46 ± 1.05	0	Z = -3.516	p = 0.000
	Trees (>10)	52.10 ± 4.16	21.48 ± 1.95	Z = -6.091	p = 0.000
	Seedlings (0-5)	244.44 ± 101.98	6.67 ± 6.67	Z = -3.280	p = 0.001
P. erinaceus	Saplings (5-10)	3.95 ± 1.28	0	Z = -3.514	p = 0.000
	Trees (>10)	43.46 ± 3.70	20.25 ± 1.94	Z = -5.312	p = 0.000

The significance of land use differences were tested using a Wilcoxon matched pairs test; z values and significance level are given.

The proportions of trees ranging by bark and foliage harvests intensities were calculated for the two land-use types; and the comparison of the extent between land-use types was assessed using Kruskal-Wallis test.

To test if the proportion of trees harvested (pruned or debarked) is dbh or species dependent we used the Fisher's exact test (two-tailed) instead of a chi-square test, because some cells of our contingency table had frequencies less than five.

The dbh was used as a measure of tree size, since this parameter is strongly correlated with the height (Spermann's rho = 0.670, p = 0.000 and rho = 0.583, p = 0.000 respectively for *A. africana* and *P. erinaceus*).

The trend of *A. africana* and *P. erinaceus* populations in both land-use types was analyzed through size class diameters (SCD) using the method proposed by Condit et al. (1998) and Lykke (1998). Ten diameter classes were used: [0 to 5], [5 to10], [10 to 20], [20 to 30], [30 to 45], [45 to 60], [60 to 70], [70 to 80], [80 to 90] and [90 to 100 cm]. Square linear regression was calculated with size class median as the independent variable and the average number of individuals in that class (Ni) as the dependant variable. The size class variable was logarithmically-transformed (ln) and the average number of individuals was transformed by ln (Ni+1), because some classes were without individuals. SCD slopes were used as indicators of population structure and their interpretation was based on the type of SCD described by Everard et al. (1995) and Lykke (1998). All statistical analyses were performed by PASW Statistic 18.0.0 (IBM).

RESULTS

Impact of land-use on species population structures

The seedlings, saplings and trees of *A. africana* and *P. erinaceus* differed significantly between the two sites (Table 2).

For both species stem density of adult trees and density of seedlings was significantly higher in the protected area compared to the parklands. Saplings and adults densities were two to three times higher in the protected area than in the parklands. However, for both species, the densities of saplings were very low in the protected area and totally absent in the parklands. Comparing the mean dbh between the land-use systems, no significant difference was observed for both species. However the species showed a significantly higher mean height in the protected area than in the parklands (Table 3). Moreover, the height/dbh ratio was significantly higher in the protected area compared to the parklands for both species.

Impact of land-use on species diameter (dbh) class distribution

Based on slope values and regression coefficients, the structure of the species populations showed different trends according to the two land-use types (Table 4).

In the protected area the population structure of *A. africana* and *P. erinaceus* showed strong negative slopes (respectively -1.30 and -0.95) and high coefficients of SCD regressions (0.73 and 0.85) with a typical inverse-J-shaped distribution. In contrast, the population structure of *A. africana* and *P. erinaceus* in the parklands deviated from J-shaped distribution (Figures 2a and 2b). In this area, slopes and regression coefficient of SCD were not significant. Moreover, these slopes were flat (respectively -0.088 and -0.141).

Furthermore, regardless of the overall population structure, young mature trees and some of the large size-classes were totally absent for both species in the sample plots of parklands. For *A. africana* individuals with a dbh of 5 to 10, 15 to 20 and 70 to 80 cm only occurred in the protected area. Similarly, *P. erinaceus* individuals with a dbh of 5 to 15 cm and 55 to 60 cm were only found (Figure 2).

Extent and degree of bark and foliage harvest

The extent of trees bark and foliage harvests of *A. africana* and *P. erinaceus* differed significantly between land-use types (Figures 3 and 4). In the parklands 95.51 ± 2.21% of individuals of *A. africana* and 96.34 ± 2.09% of individuals of *P. erinaceus* were pruned from weak

Table 3. Comparison of mean dbh (cm), height (m) and ratio (m) (mean ± SE) of *A. africana* and *P. erinaceus* within protected and parklands.

Species	Parameters measured	Protected area	Parklands	Z score	p-value
A. africana	Dbh (cm)	36.81 ± 1.19	40.42 ± 1.43	Z = -1.628	p = 0.104
	Height (m)	9.22 ± 0.19	7.19 ± 0.23	Z = -5.757	p = 0.000
	height/dbh Ratio (m)	30.17 ± 0.95	18.34 ± 0.47	Z = -9.068	p = 0.000
P. erinaceus	Dbh (cm)	28.56 ± 0.94	30.76 ± 1.17	Z = -1.299	p = 0.194
	Height (m)	8.71 ± 0.25	6.11 ± 0.22	Z = -6.119	p = 0.000
	height/dbh Ratio (m)	34.32 ± 1.06	20.68 ± 0.66	Z = -8.552	p = 0.000

The significance of land use differences were tested using a Wilcoxon matched pairs test; z values and significance level are given.

Table 4. Regression slope and coefficients values of *A. africana* and *P. erinaceus* following the land use regime.

Land-se types	Regression parameters	*A. africana*	*P. erinaceus*
Protected area	Slope	- 1.30	- 0.95
	r^2	0.73	0.85
	p	0.002	0.001
Parklands	Slope	- 0.09	- 0.14
	r^2	0.13	0.20
	p	0.301	0.266

The significant level is 0.05.

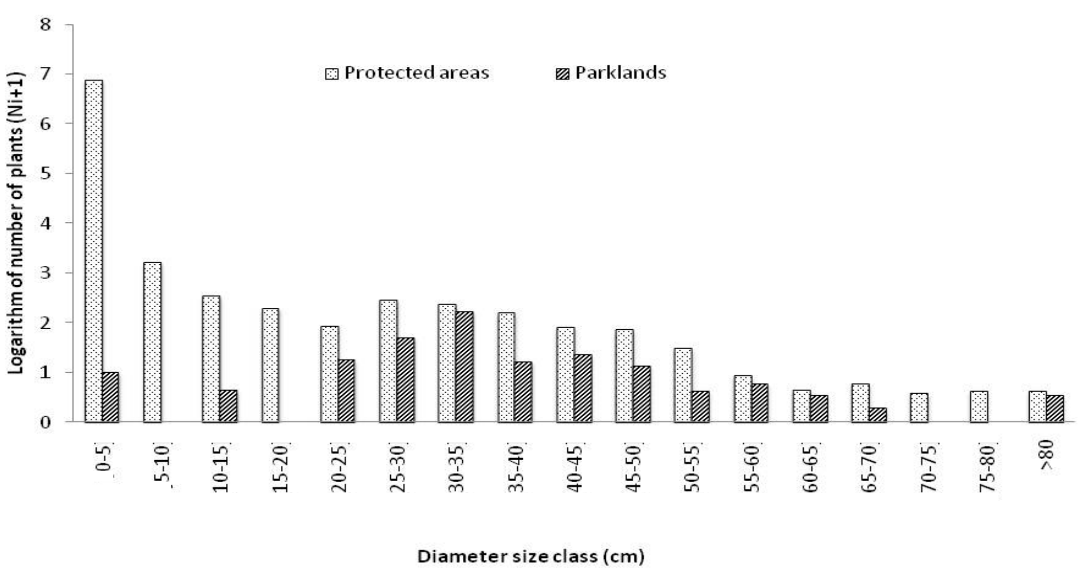

Figure 2a. Dbh class distribution of *A. africana* in the protected and parklands.

(between 0 to 25%) to severe intensity (>50%), while only 0.99 ± 0.76 and 0.74 ± 0.42% of individuals of *A. africana* and *P. erinaceus* respectively were not pruned (Figures 3a and 4a). Similarly, 83.15 ± 3.99 and 87.80 ± 3.64% individuals of *A. africana* and *P. erinaceus* respectively were debarked following the same levels. However, more

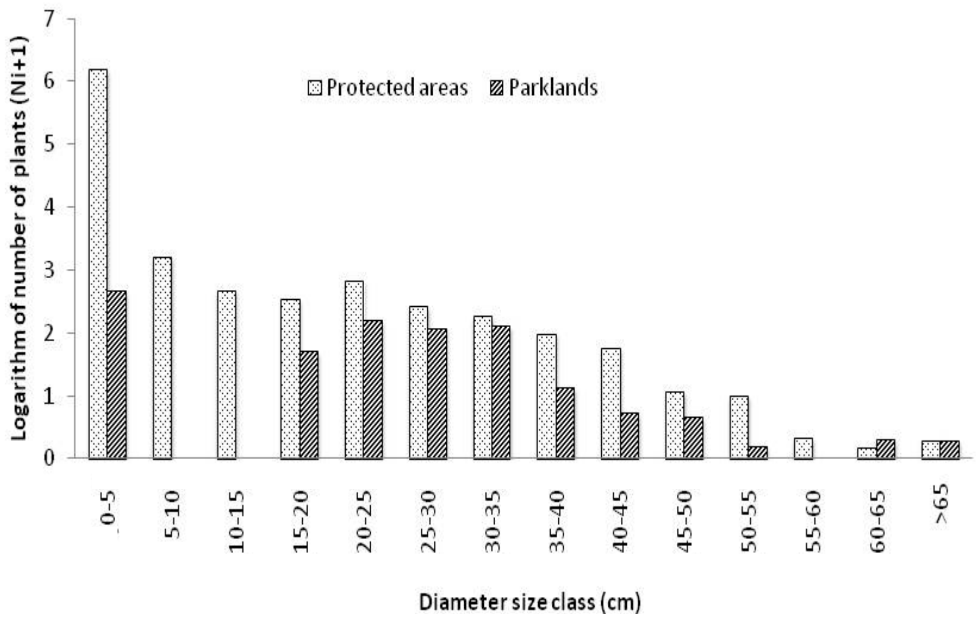

Figure 2b. Dbh class distribution of *P. erinaceus* in the protected and parklands.

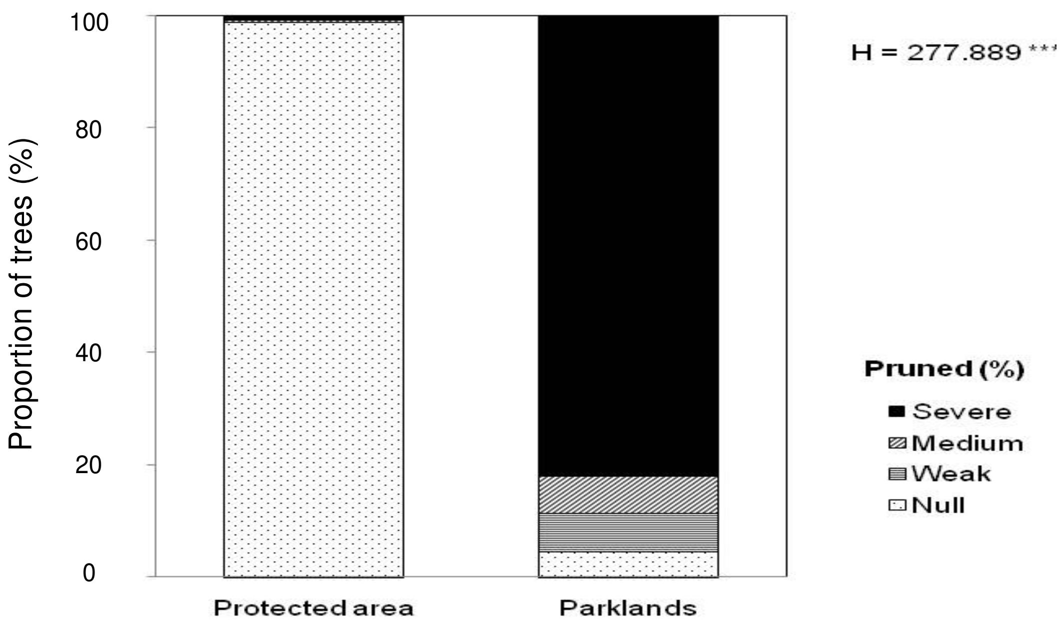

Figure 3a. Proportion of *A. africana* individuals foliage harvest within protected and parklands. *** p<0.001.

individuals were not debarked compared to pruning (3.70 ± 1.12 and 2.96 ± 0.74% for *A. africana* and *P. erinaceus* respectively).

In contrast, in the protected area 99.80 ± 0.001% of *A. africana* and 97.7 ± 0.01% individuals of *P. erinaceus* were not pruned, whereas, only 1.33 ± 0.76% individuals of *A. africana* were pruned at severe intensity and 4.17 ± 1.62% individuals of *P. erinaceus* were pruned at weak and severe intensity (Figures 3a and 4a). Similarly, 97.70 ± 0.001% of individuals of *A. africana* and 95.40 ± 0.01% of individuals of *P. erinaceus* were not debarked, while 1.77 ± 0.88% of *A. africana* were debarked at weak

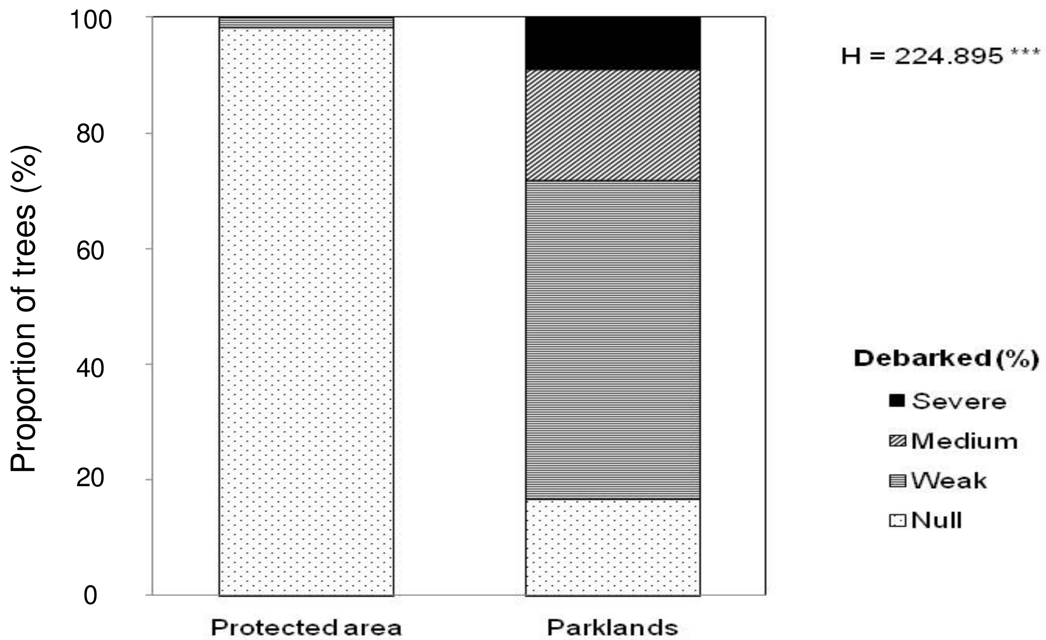

Figure 3b. Proportion of *A. africana* individuals bark harvest within protected and parklands. *** p<0.001.

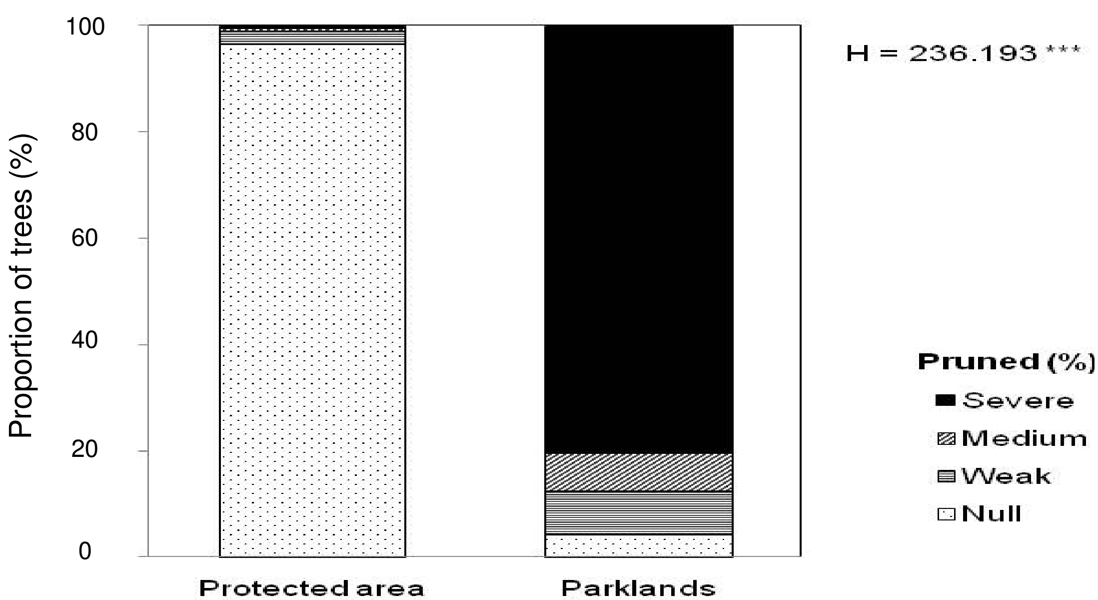

Figure 4a. Proportion of *P. erinaceus* individuals foliage harvest within protected and parklands. *** p<0.001.

intensity and 8.33 ± 2.13% of individuals and *P. erinaceus* were debarked at weak and medium intensity (Figures 3b and 4b).

In addition following the harvesting type (pruning or debarking), the severe intensities occurred with pruning type (88.15% of species) compared to bark harvest (50.36% of species). However, the proportion of tree foliage harvest was similar within the two species (Fisher's Exact: p = 0.99). Conversely, the proportion of trees debarked differed significantly between the species (Fisher's Exact: p = 0.0389). Higher proportions of *P. erinaceus* trees (74.07 ± 15.39%) were severely

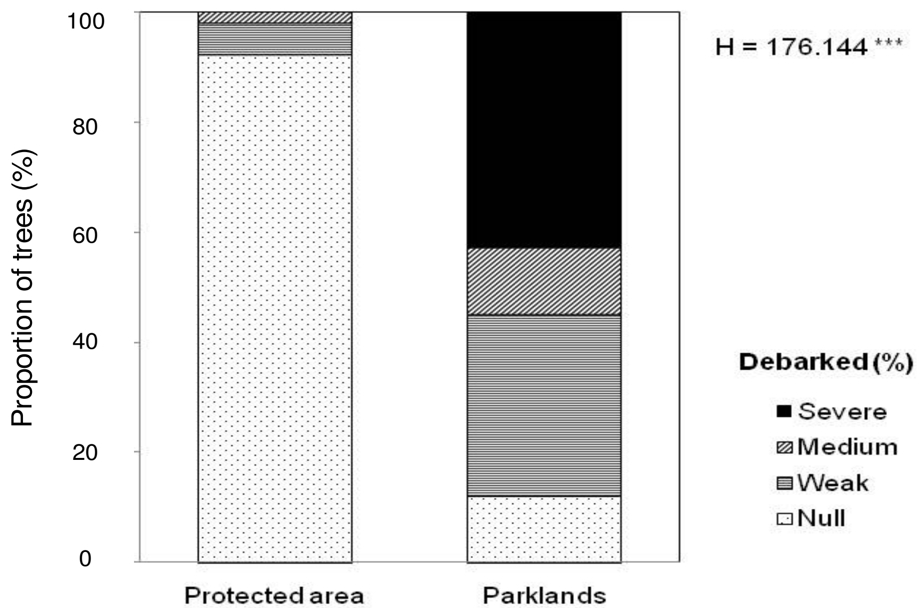

Figure 4b. Proportion of *P. erinaceus* individuals bark harvest within protected and parklands. *** p<0.001.

debarked compared to *A. africana* (9.88 ± 4.77%). Furthermore, following the dbh size class distribution, the intensity of pruning (Fisher's Exact: p = 0.3132 for *A. afri*cana and p = 0.7866 for *P. erinaceus*) and debarking (Fisher's Exact: p = 0.7484 for *A. afri*cana and p = 0.1993 for *P. erinaceus*) did not vary significantly within the size classes (small, medium and large).

DISCUSSION

Impact of land use on species population structures

The differences in species population structures observed between the protected and the parklands are principally related to the land-use types. In the protected area, the inverse J- shape of the curve indicated a stable population structure, with abundant individuals in small diameter size classes and a progressive decrease of individuals in upper size classes. In opposite, the shape of the populations of both species in the parklands indicated an unstable population structure suggesting important perturbations affecting population structures. This might be due to the combined effects of human impact such as land clearing for agriculture, livestock grazing and/or harvesting of fodder and medicinal products. Thus, the absence of protection measures led to the unstable structure. In regard to seedlings recruitment, herbivore pressures through seeds and seedlings consumption (Bationo et al., 2001; Ouédraogo-Koné et al., 2008) and trampling (Onana and Duvineau, 2002) could hinder the regeneration process. Similarly, land clearing and tree density reduction for agricultural purposes may be detrimental to seedling establishment and, hence threaten the species (Fandohan et al., 2010b). The shoots are cut during the rainy season in order to reduce their adverse effects (shade, moisture competition) on crops (Gijsbers et al., 1994) and also on the more preferred fruit-trees like *Vitellaria paradoxa* (Djossa et al., 2008). These findings are consistent with recent studies on other Sudanian trees (*Acacia* spp, *Sclerocarya birrea* (A. Rich.), *Tamarindus indica* L., *Adansonia digitata* L.) which have shown that land-use types and habitats effect differently the population structures of highly valued trees (Traoré et al., 2008; Gouwakinnou et al., 2009; Fandohan et al., 2010b; Schumann et al., 2010). Protection might efficiently provide better conditions for seedling regeneration, favour the recruitment and conserve trees densities (Figures 2 and 3 and Table 2).

However, the observed low number of seedlings in this area could also be due to other biotic and abiotic stresses (Bognounou et al., 2009), such as shade. This emphasizes the partial positive effect of protected areas in conserving highly valued plant species (Fandohan et al., 2010a). In addition, the differences in tree heights between the sites could be explained by high intra- and inter-specific competitions (Shackleton, 2002) for light (Scholes and Archer, 1997). This might lead to faster growth in height than in diameter in the protected area, where vegetation stands are denser.

The non-significant difference of mean diameter between the two sites may be due to the effect of the higher number of individuals in small size class in the protected area. Moreover, the high densities of seedlings and the low density of saplings found in the protected area indicated the high ability of species to regenerate. This confirmed the assumption that regeneration potential of *A. africana* and *P. erinaceus* species exists but the main challenge is the establishment as well as the development of saplings in land-use areas (Gijsbers et al., 1994; Bationo et al., 2001; Ouédraogo et al., 2006) (Figures 2 and 3).

Furthermore, the absence of the larger diameter size classes in the sample plots of the agroforestry parklands indicate other types of pressure such as commercial loggings besides bark and foliage harvests. Especially, large trunks of *A. africana* are used to make large mortars (personal observation) which are sold on the local markets.

To summarize, the stable population structures of *Afzelia africana* and *Pterocarpus erinaceus* observed in the protected area was due to better regeneration conditions and less disturbance of the species in this site because of the protection status. In the parklands, the gap created by the lack of regeneration and the total absence of saplings in combination with traditional agricultural practices, over grazing, seed predators and commercial loggings lead to a declining structure. This result corroborated the findings of Ouédraogo et al. (2006) for the same species and Lykke (1998) for other exploited species in West African savannas.

Extent and degree of harvests

The high proportions of harvested *A. africana* and *P. erinaceus* trees show that these species are used and appreciated particularly by helders of livestock (Petit and Maillet, 2001; Ouédraogo-Koné et al., 2008) and by local populations for the use as medicine (Akinpelu et al., 2008; Delvaux et al., 2009). This emphasizes their role as high value species in the Sudanian zone.

Nevertheless, the designation as protected area could be the best option to protect highly valued species in the over-exploitation context. The higher proportions of severe harvests intensity and the non-size dependant harvests conditions observed in the parklands, coupled with the highest extent of non-harvested individuals, and to the lowest proportion of severe harvestings in the protected area support this assumption. This shows the importance of protected area in preserving the highly valued species.

Furthermore, the non-size class specific harvest conditions (even the smallest diameter sizes) on the parklands, shows that harvesters seem to have no preference about size class. In contrast to Gaoue et al. (2007) on *Khaya senegalensis* and Schumann et al. (2010) on baobab, neither pruning nor debarking on *A. africana* and *P. erinaceus* was size specific. The higher pressures to which species are face might explain this result comparing to the others. Indeed, for species which is highly exploited for its bark, debarked trees of all sizes were found (Stewart, 2003). We also noticed that *A. africana* was subjected to harvest for magico-religious rituals (personal observation) by local people, especially Gourmantché community. For this ethnic group, some *A. africana* trees were sacred, so they were regularly debarked for sacrifices in order to pray to God for good health and protection of families. The sacred trees were debarked and the wound caused by this harvest was recovered with blood and feathers. Moreover, the higher pruning pressure is due to the higher density of livestock in the WNP area, especially in the dry season. Highest livestock densities may be explained by the transhumance activity (Convers et al., 2007) and by the positive effect of cotton culture, which allows farmers to spend money gained for livestock buying (Petit and Maillet, 2001). This result also supported the fact that species were more involved for pruning than debarking (Figures 4 and 5).

In addition, two main reasons might explain the different debarking rates between the two species in the parklands: the higher demand for *P. erinaceus* bark and the fact that *A. africana* does not recover well from debarking (Delvaux et al., 2009). However, according to later authors, harvesting disrupts the tree physiological functioning and stimulated a higher hormonal activity in order to close the wound quickly.

To conclude, the assessment of the population structure and the harvesting patterns of the highly valued species *Afzelia africana* and *Pterocarpus erinaceus* in two different land-use areas showed that both species are severely over-exploited in the parklands due to bark and foliage harvests combined with agricultural practices. However, both species were more affected by pruning than by debarking. To ensure more sustainable use of these highly valued species further research as well as participatory actions with local communities is required: In a participatory way introduction of juveniles and sensitization for seedlings protection should be carried out in the agroforestry parklands. For this purpose, best tree individuals for seed production for the nursery (seedlings production for planting) should be selected and protected for current and future use. The impact of bark and foliage harvests on both species fruit production should be assessed in order to provide indications on the harvesting tolerance.

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