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Population structure and abundance of *Sclerocarya birrea* (A. Rich) Hochst subsp. *birrea* in two contrasting land-use systems in Benin

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The importance of indigenous fruit tree species for people living around protected areas is widely acknowledged. There is then a need to assess their conservation status in the current context of increasing human population and pressure around reserves. We investigated the population structure of *Sclerocarya birrea,* a multiple-use tree species in two land use systems in Northern Benin. Adult density was about nine times higher in the protected area ($p < 0.001$) compared to agroforestry systems (agro-systems). Seedling occurrence was similar in both land use type even though seed germination was best favoured in agro-systems. Saplings and adults with 5 - 20 cm dbh were almost absent in agro-systems. The mean diameter in agroforestry systems was about twice higher than in the protected area. Although a log-linear analysis showed a difference in the size class distributions between land use types ($p < 0.0001$), they were all positively skewed. Green's index showed a clumped distribution in the protected area (0.48) compared to agro-systems (0.05). Population structure variation could mainly be explained by agricultural pressure. Saplings conservation is required in agro-systems to ensure sustainable use.

Key words: Population structure, *Sclerocarya birrea*, land use, agroforestry systems, protected area.

INTRODUCTION

As part of their livelihoods, populations living near natural reserves make use of indigenous fruit tree species which fulfil different roles in their sustenance, and allow them to live with less cash (Vedeld et al., 2007). Most of these local forest populations are farmers with limited livelihood opportunities (Sunderlin et al., 2005) and often characterised by a high growth rate (Wittemyer et al., 2008). This often results in a greatest pressure on land and natural resources around these reserves. It is then important to assess the conservation status of the resource in relation to these impacts so as to know how sustainable it will be through time. Ndangalasia et al. (2007) stressed that plant species level research that comprises inventories, impact studies and monitoring is necessary if plant resources are to be harvested sustainable by human populations living adjacent to protected areas in protected areas in sub-saharan Africa. The ecological parameters which may guide sustainable management of any given species are life cycle characteristics, multiplicity of uses and types of resources produced, abundance in different forest types, and size-class distribution of populations (Peters, 1996). The patterns of abundance, distribution and population structure can be used to help infer key demographic stages or ecological variables that merit special focus when implementing a management scheme (Bruna and Ribeiro, 2005). Since these variables can differ by habitat type (Bruna and Kress, 2002), they should be evaluated for any given species in the multiple habitats or forest types in which it occurs given that comparative studies of biodiversity in alternative land-use scenarios are important to inform policy makers about the potential impacts of changes in land use on both conservation and livelihood goals (Gillison et al., 2004). Moreover, to understand the current status and forecast the future state of tropical diversity, we must understand levels and patterns of biodiversity in landscapes actively managed and modified by humans for a wide variety of

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traditional and commercial purposes and how these patterns are affected by different human practices (Chazdon et al., 2009). Evaluation of anthropogenic impact requires data from exploited sites be compared to undisturbed sites such as protected areas where ecological conditions are as natural as possible. In this paper, we assessed the impact of land use type on the conservation status of *Sclerocarya birrea subsp. birrea.* The objectives of the study were to assess the distribution pattern, the abundance, and the size class structure of *S. birrea* in agroforestry systems in comparison with the protected area and propose management strategies with regard to the species population conservation status in relation to land use practices.

MATERIALS AND METHODS

Study area and species

The W National park of Benin extends from 11°20' - 12°23'N latitudes and 2°04' - 3°05'E longitudes and covers 568 000 ha. It is a component of W transboundary biosphere reserve between Niger, Burkina Faso and Benin (West Africa). The climate is dry with an average annual rainfall of 950 mm in the Sudanian zone (at the southern side) and 600 mm in the Sudano-sahelian zone (northern side). The woody vegetation of the park is dominated by *Acacia ataxacantha*, *Combretum glutinosum*, *Bombax costatum*, *Anogeissus leiocarpa* and *Sclerocarya birrea.* The herbaceous layer is frequently represented by *Loudetia spp*. and *Andropogon spp*. The human population of 47757 inhabitants in the study areas grows at a rate of 3.18%. Farming and cattle rearing are the main source of subsistence for local communities.

S. birrea belongs to the Anacardiaceae family and has been described by many authors under different names, *Sclerocarya caffra* Sond. (1850), *Poupartia caffra* (Sond.) H. Perrier (1944), *Poupartia birrea* (A. Rich.) Aubrév. (1950). It is a dioecious fast growing tree species. Flowering takes place in the dry season when the trees are leafless. The major pollinators (or flower visitors) of *S. birrea* are honey bees (Chirwa and Akinnifesi, 2008). The tree bears plum-sized stone fruits with a thick yellow peel and translucent white flesh. They are eaten fresh and can be processed into things such as beverages, jams and jellies. The juice contains as much as four times the vitamin C of orange juice (National Research Council, 2008). The kernels are eaten or the oil extracted; the leaves are browsed by livestock and have medicinal uses, as does the bark. The wood is carved into spoons, plates and decorative animal figures (Shackleton, 2002; Gouwakinnou 2008).

Sampling and data collection

Ten households were randomly selected in each of the 18 villages around the park to investigate the species' presence/absence in the areas. Two to three farmers were chosen in each village and their farms were visited for field measurements. The entire farm of a given sampled farmer was considered as a plot and its area was calculated for tree density estimation (Nghitoolwa et al., 2003; Shackleton et al., 2003). A total of forty plots were established in agroforestry systems. In the protected area, thirty-four 0.2 ha plots were established. In each plot, we collected data on vegetation type and the abundance, height and diameter at breast height (dbh) of each of *S. birrea* tree. All stems were measured for multi-stemmed trees. Each species other than *S. birrea* with dbh greater than 5 cm and the number of trees per species were also recorded within each plot. Presence and abundance of *S. birrea* saplings were also recorded within plots and seedling presence or absence was recorded beneath adult trees and in 4 subplots of 5 × 5 m nested at the corner of each plot. Any plant from germination to basal diameter (at ground level) less than 1 cm were considered as seedlings. Plants with stem greater than 1 cm basal diameter or more than 1 m height and less than 5 cm dbh and/or less than 1.5 m height was considered as saplings. Indeed, field exploration showed that plant with basal diameter superior to 1 cm are those who have survived to fire and other environmental factors and may recruit to adult stages.

Data analysis

Shannon Wiener entropy index H and true diversity D (Jost, 2006) was used to characterize each land use type.

$$H = -\sum_{i=1}^{S} \frac{n_i}{n} \log_2 \frac{n_i}{n} \qquad (1)$$

$$D = 2^H \qquad (2)$$

Where; ni is the number of trees of species i, n is the overall number of trees inventoried in a considered plot and S is the number of species recorded in the plot.

Pielou evenness index Eq was calculated to measure the entropy degree of the plot compared with the possible maximal entropy H_{max}:

$$Eq = \frac{H}{\log_2 S} \qquad (3)$$

Where; $\log_2 S$ is the maximal entropy (H_{max}).

Using dbh as a measure of tree size, we assessed *S. birrea* population structure and calculated the density per land use type. T test of Student was used to test whether tree density significantly differed between land-use types.

We used Green's Index (GI) (Jayaraman, 1999) to appreciate the distribution of the species in each land use type.

$$GI = \frac{\left(\frac{\sigma^2}{\bar{x}} - 1\right) - 1}{n - 1} \qquad (4)$$

Where; σ^2 is the variance of the density, $\bar{x}$ is the mean density, and n is the sample size. GI varies between 0 (for random) and 1 (for maximum clumping).

For each multi-stemmed tree with y stems, the quadratic diameter d_q was used. It was computed as follow from each stem diameter d_i

$$d_q = \left(\sum_{i=1}^{y} d_i^2\right)^{1/2} \qquad (5)$$

The number of individuals per hectare was plotted against class midpoint per land use type and we used the coefficient of skewness (Feeley et al., 2007) to assess intra-population trends in population

Table 1. Ecological parameters describing the characteristics of both land use types.

Land use type / Parameters	Agroforestry park	Protected area
Shannon entropy index (± SE, bits)	1.59 ± 0.10	1.79 ± 0.11
D (± SE, species)	3.01 ± 1.07	3.46 ± 1.07
Pielou evenness index (± SE)	0.58 ± 0.04	0.58 ± 0.03
Overall species richness	30	33

structure. This coefficient describes the evenness of truncated distributions (Condit et al., 1998; Feeley et al., 2007) and is defined as follow:

$$g = \frac{n \sum_i \left(x_i - \overline{x}\right)^3}{(n-1)(n-2)\sigma^3} \quad (6)$$

Where; n is the number of stems and x_i, $\overline{x}$ and *are* diameter at breast height (dbh) of stem i, the mean of x_i, and the standard deviation of x_i respectively.

When $g > 0$, the size distributions shows relatively few small stems and many large stems; $g < 0$ indicate distributions with relatively few large stems and many small sized stems.

Log-linear analysis was used to test if adults' size-classes distribution differed with land use. The effects of land use on sapling density, tree heights and diameter were tested using Mann-Whitney non parametric test. Seedling occurrence (expressed in term of proportion of number of plot containing seedlings out of the total number of plot) was compared between the two land use types using the two-sample test of proportions while Fisher exact test was used to compare sapling proportions.

Major axis (MA) regression (Legendre, 2001) and an analysis of covariance (ANCOVA) were used to test whether relationship between height and diameter are significantly different between land use type

RESULTS

Distribution and habitat characteristics

All farmers recognized the occurrence of *S. birrea* in agroforestry parklands and in wild within the study area. About 79% of farmers hold on farm at least one individual of the species. In the agroforestry systems, *S. birrea* was associated with others indigenous fruit tree species such as *Vitellaria paradoxa, Balanites aegyptiaca* and *Tamarindus indica*. In the protected area, the species occurs mainly in open savannah where its companion species were *Combretum nigricans, Grewia bicolor, Guiera senegalensis, Anogeissus leiocarpa, Balanites aegyptiaca, Combretum glutinosum, Mimosa pigra.* The ecological parameters calculated for both land use types are presented in (Table 1).These companion species except *A. leiocarpa* and *B. aegyptiaca* were often found under the canopy of large *S. birrea* individuals. The density of these woody species (dbh > 5 cm) was 9.61 stems/ha in agroforestry systems and 112.35 stems/ha in the protected area. *S. birrea* was found on various types of soil ranging from less degraded soil to the most degraded ones. However it was not found in permanent or quasi-permanent flooded areas or on hydromorphic soil.

Green's index (GI) used as an index of dispersion showed that the species had a clumped distribution in the protected area (0.45) than in the agroforestry systems (0.05) where the distribution was quasi random.

Seedlings and saplings densities and occurrence

Only 6% of the sampled plots in agroforestry systems contained saplings whereas 33% of them in the protected area contained saplings. In contrast, the occurrence of seedlings did not significantly differ between the two type of land use (Proportion test, $Z = -1.93$; $p = 0.054$). Sapling density was significantly higher in the protected area (34.54 stems/ha) than in the agroforestry systems (1 stem/ha) (Fisher exact test, $P = 0.008$; Figure 1).

Adult trees abundance and population structure

The density of adults *S. birrea* was ca 9 times higher in the protected area than in agroforestry systems (27.6 ± 3.8 trees/ha vs 3.4 ± 0.6 trees/ha) ($t = 13.30$; $df = 69$; $p < 0,001$). The diameter size class distribution significantly differed between the two land use systems (Log-linear analysis, $G^2 = 555.26$; $p < 0.0001$) (Figure 2). However, these distributions were all right-skewed ($g = 0.83$ for agroforestry systems and $g = 0.68$ for protected area) indicating a relatively higher proportion of smaller trees than larger ones. About 58% of individuals in the protected area were represented in 10-30cm dbh class while in agroforestry systems 50% were in 30 - 50 cm dbh class (Figure 2). The mean dbh of trees in agroforestry systems is about twice greater (46.61 ± 1.40 cm; Mean ± SE) than in the protected area (26.74 ± 1.23 cm; $W = 19197.5$; $p= 0.000$), indicating that the largest individuals of *S. birrea* were found in agroforestry systems (Highest dbh: 106 cm in AS *vs* 65cm in PA) while the smallest were found in the protected area (Lowest dbh: 5 cm in PA vs 20.6 cm in AS).

The height class distribution statistically depended on the type of land use system ($G^2 = 212.43$; $p < 0.0001$)

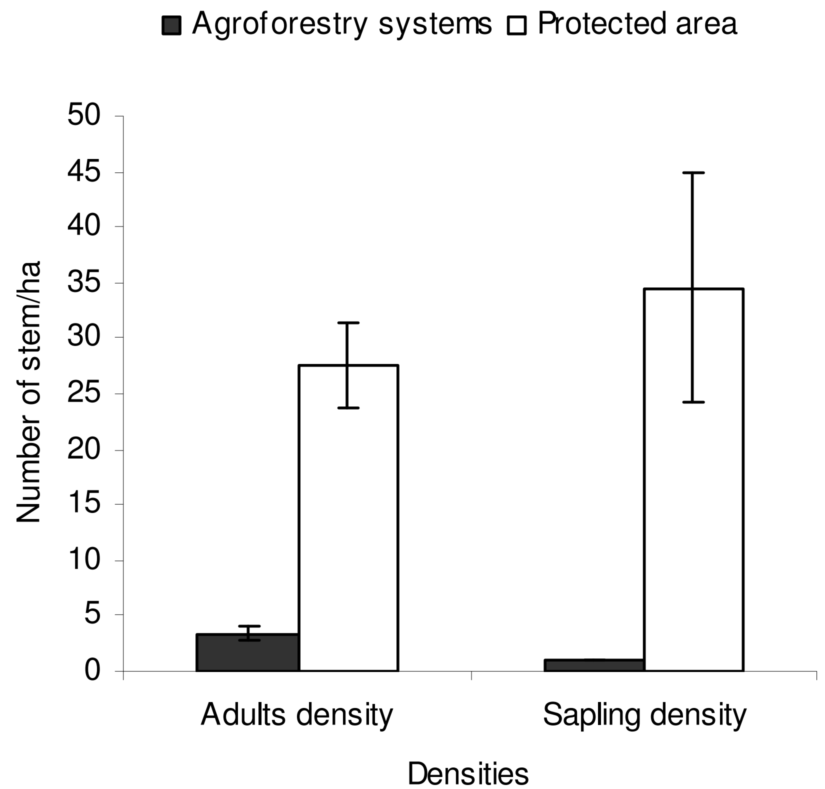

Figure 1. Adults and saplings total stem density in both habitats Northern Benin (Karimama). Means ± 1 SE.

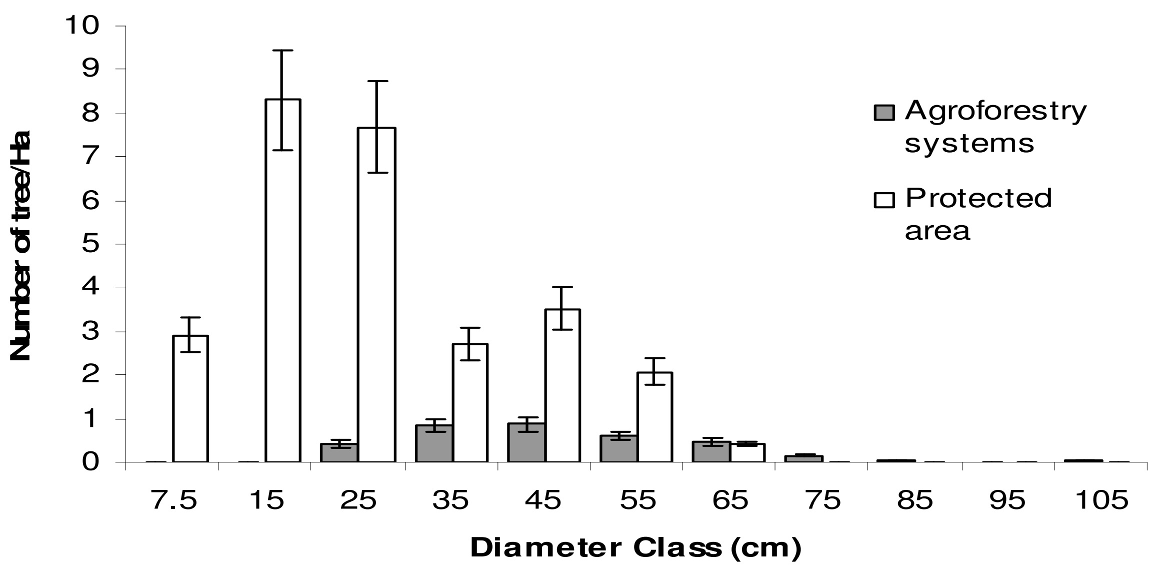

Figure 2. Size-class distribution (dbh) of *S. birrea* trees in protected area versus agroforestry systems in Northern Benin (Karimama). Means ± 1 SE.

(Figure 3). The average height of *S. birrea* in agroforestry systems (13.96 ± 0.37 m) was significantly higher 11.09 ± 0.40 m) than protected area (W = 13824, $p < 0.0001$).

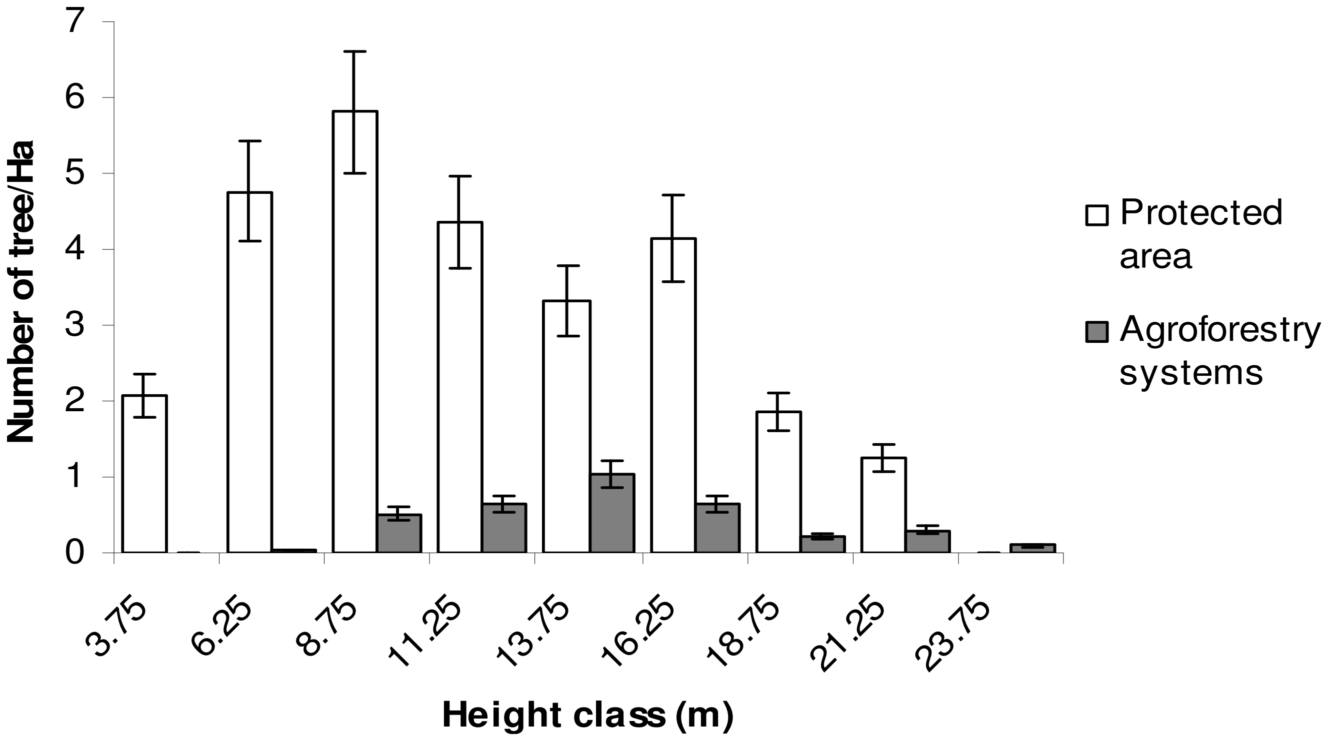

Figure 3. Height class distribution of *S. birrea* trees in protected area versus agroforestry systems in Northern Benin (Karimama). Means ± SE

Height-diameter relationship within *S. birrea* trees

Regardless of the type of land use system, tree height was highly and positively correlated with dbh (Spearman's rho = 0.767, p < 0.001). The allometric relationship between height (m) and the diameter (cm) (model II regression, major axis) for both land use are summarized below

Protected area: *Ln (H) =* 0.87 *Ln* (dbh) - 0.44;
Agroforestry systems: *Ln (H) =* 0.82 *Ln* (dbh) - 0.5;

The 95% confidence interval built around the slope of the regressions are [0.66; 1.14] for the protected area and [0.2; 2.4] for agroforestry systems. In both case, the bounds of the confidence interval have the same sign (positive sign) indicating a significant relationship between both regression variables (Jolicoeur, 1990).

The covariance analysis revealed that the slopes of the regression lines are not significantly different between the type of land use system (F = 1.73; p =0.1896). The Y-intercepts however are significantly different (F = 18.58; p <.0001), indicating that a tree of a given diameter in protected area is taller than in agroforestry systems.

DISCUSSION

We studied the population structure of *S. birrea* in relation to land use impact. Our results indicated a higher abundance of adults and saplings in the protected area than in agroforestry systems where the biggest individuals with a quasi random distribution were found. There was a marked difference in the population structure of the species according to land uses. However the occurrence of seedlings was not affected.

Distribution and habitat characteristics

The density of companion species of *S. birrea* in the protected area is about twelve times higher than in agroforestry systems. This pattern shows the effect of clearing as the impact of land use on *S. birrea* habitat. Farmers control tree species' densities and presence and hence the species diversity on farms, depending on their preferences and individual species use needs. The non-used or non-preferred trees species are cut down while the most useful ones are saved. This selective clearing is often done considering the composition of the original tree population, the ecological conditions, the know-how, the requirements of farmers and their socio-economic environment (Okullo and Waithum, 2007). The index of Green used as indicator of the degree of clumping shows that *S. birrea* is more or less clumped in the protected area while it has a quasi random distribution in agro-forestry systems. Because of the relatively high mass of the fruit of *S.birrea,* it has, on its own, very limited dispersal ability. Thus, the type of distribution pattern found in the protected area is partly due to dispersal limitation. Moreover, the aptitude of the species to reproduce vegetatively from roots, thus increasing local density could also partly explain the found pattern in the protected area. The quasi random distribution in agroforestry systems is an indicator of human pressure on the species' population in this type of land use

Seedlings and saplings densities and occurrence

There was no significant statistical difference in seedlings occurrence with regard to land use. However, opposed to the protected area where seed germination was very scant, there were plenty of seedlings in agroforestry systems mainly beneath adult trees. This bulk germination in agroforestry systems occurs after *S. birrea* fruits which fall down on the ground are buried during farming activities. In the protected area, on the other hand, the low seedling germination can be explained by the lack of favourable germination conditions likely induced by factors such as competition from grass species and probable animals attack on seeds such as damage caused by rodents and squirrels on the kernels as we observed and previously reported by Diallo et al. (2006). Moreover, the lack of seedling or regeneration of this species in the protected area could be related to fire and drought effects. Indeed, wild fire, in some conditions, could dangerously affect seed survival (Zida et al., 2007) and could lead to a negative effect on woody plant density. Alternatively, greater level in fruit production in agroforestry systems at individual level (Shackleton et al., 2003; personal observation) may explain difference in seedling recruitment (Crawley, 1990). However this is to be confirmed by further study on level of fruit production according to land use.

Although there was a high abundance of seedlings in agroforestry systems, we noticed an almost absence of saplings in this land use system while there was a greater sapling density in the protected area. This absence of saplings is due to human impact on seedlings mainly during farming activities. To reduce the adverse effects (shade, moisture competition) on crops in agroforestry systems, farmers regularly remove seedlings and cut down shoots of woody species (Gijsbers et al., 1994) which leads to a gap in seedling transition to adult individuals. Although there were fewer seedlings in the protected area, they appeared more stable than in agroforestry systems as shown by the density of saplings in the protected area (Figure 1). However, the majority of these saplings were multi-stemmed as a results of fire (that is, death of the aerial biomass), which may have activated dormant buds to produce more root suckers or sprouts (Jacobs and Biggs, 2001; Zida et al., 2007). These findings suggest, similarly to previous works (e.g., Luoga et al., 2004; Zida et al., 2007) that most savannah tree species go through a prolonged period of die back of shoots at the juvenile stage of their development.

Abundance, diameter and height class distributions of adult individuals

There was about nine times reduction in adult density from the protected area to agroforestry systems. This is likely induced by human activities. Farmers believe that the shade of adult trees generally hinders crop in their development. Hence, they use many destruction techniques such as burning, ring-barking and felling to reduce tree density in agroforestry systems. This finding corroborates the results of Shackleton et al. (2003) who noticed an increasing in *S. birrea* subsp *caffra* density with increasing distance from villages to protected area. Moreover, results are comparable to those obtained by the same authors who found that the density of adult individuals with circumference at 30 cm greater than 40 cm (ca dbh > 13 cm) was about 4.21 stems/ha in agricultural fields while it was about 13.37 stems/ha in protected areas.

The size class distribution showed that the largest individuals were found in agroforestry systems. However both distributions were right-skewed giving evidence of relatively large proportion of smallest individuals. According to Condit et al. (1998), many factors are susceptible to affect size_class distribution of a given plant species. Some of these factors recently described include pattern of use and harvest (Bitariho and McNeilage, 2007; Gaoue and Ticktin, 2007) and land use type (Klimas et al., 2007; Djossa et al., 2008). The comparatively big-sized individuals found in agroforestry systems versus protected area could be due to many factors. One such a factor is the level of intra and interspecific competition (Shackleton et al., 2003; Monzeglio and Stoll, 2008). In the protected area, *S. birrea* occurs most frequently in stands of high density and with others woody species. The intra and interspecific competition for light might have lead to greater growth in height against the diameter. Nyandoi (2005) found similar results on *Tamarindus indica* and assumed trees in agroforestry systems to be older than in woodlands. This assumption nevertheless is not supported in our findings as trees in agroforestry systems result from a selective human effect on the original vegetation. Trees in agroforestry systems benefit from management actions (weeding and fertilization of land) consented to crops. Moreover other environmental factors such as wild fire could also affect the growth of the species. Another factor which could partly explain the found size class structure, even not evident in this data set, is the illegal logging that target large individuals for carving purposes.

The height class distribution depended on the land use type. The tallest individuals were also found in agroforestry systems. However, trees in the protected area were taller than in agroforestry systems at identical diameter. (cf. regression equation). In both land use types, *S. birrea* tree appears to be canopy dominant as most of West African savannah tree rarely reach 10 m height (Shorrocks, 2007). It, plays then an important ecological role serving as host for other plant species which grow under its canopy as well as for birds.

Conservation status of *S. birrea* and implication for management

Even thought it cannot be concluded that size class distribution alone is a good predictor of future population change, this tool has been widely used toward this end as it is a shortcut in the absence of direct estimates of population size through time (Condit et al., 1998; Feeley et al., 2007). Determining the structure of a population is a first step that, when combined with demographic data, such as size-specific growth rate (Condit et al., 1998), spatial distribution (Klimas et al., 2007; Djossa et al., 2008; Glèlè-Kakaï and Sinsin 2009) and pattern of use and harvest (Bitariho and McNeilage, 2007; Gaoue and Tictin, 2007), can be the basis for strong management decisions.

When compared to the overall density of trees in agroforestry systems (36.52%) and the results of other authors (Nghitoolwa et al., 2003; Shackleton et al., 2005), the current adult density of *S. birrea* (3.4 ± 0.6 trees/ha) does not seems alarming. However, the increasing rate of rural population and the subsequent request of land for agriculture will certainly negatively impact more and more the species density in agroforestry systems or even in protected area as the fates of biodiversity in protected areas and surrounding landscapes are inextricably linked (Harvey et al., 2008). Moreover, the diameter size class distribution revealed a lack of 5 - 20 cm dbh individual and some individuals with dbh more than 100 cm could be found giving evidence of an ageing population in agroforestry systems. This tendency ecologically implies that the population of *S. birrea* may not be self-sustaining and would decline if management decisions were not taken. Such management decisions would not be sound if some points remain unclear as about the species biology and ecology. For instance, given that the species is commonly recognised as dioecious (but see Diallo et al., 2006) it is important to fully make distinction between male and female individuals and to assess the sex ratio within populations. This will give information on the balance between male and female individuals and will permit to know if tree removal could be orientated toward male trees. However, further investigations including the mating mechanism are needed. Taking in account the capacity of the species to regenerate via grafting (Soloviev et al., 2004), this type of regeneration could be developed for the propagation in agroforestry systems and *ex situ* conservation of *S. birrea* and also for the selection of varieties with interesting criteria such as high yield and fruit quality, and rusticity.

Although it is recognised that protected areas are under land pressure (land clearing, logging, hunting, grazing), findings of this study demonstrated that they remain an important means of biodiversity preservation and can really play a key role in supporting habitat conservation policies as stressed by Bruner et al. (2001). However, S *birrea* somehow is subject to environmental influences such as annual wildfire, and drought due to climate change which directly or indirectly impact its regeneration and likely explain the pattern of seedling occurrence and regeneration found in the protected area.

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