Ecological Complexity 13 (2013) 60–68

Contents lists available at SciVerse ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom

Original Research Article

How far a protected area contributes to conserve habitat species composition and population structure of endangered African tree species (Benin, West Africa)

Thierry D. Houehanou [a,*], Achille E. Assogbadjo [a], Romain Glele Kakaï [a], Tina Kyndt [b], Marcel Houinato [a], Brice Sinsin [a]

[a] Laboratory of Applied Ecology, Faculty of Agronomic Science, University of Abomey Calavi, 01 BP 526 Cotonou, Benin
[b] UGent Faculty of Bioscience Engineering, Coupure Links 653, 9000 Ghent, Belgium

ARTICLE INFO

Article history:
Received 1 August 2011
Received in revised form 30 December 2012
Accepted 7 January 2013
Available online 4 February 2013

Key words:
Afzelia africana
Pterocarpus erinaceus
Khaya senegalensis
Species composition
Population structure
Conservation

ABSTRACT

The Pendjari Biosphere Reserve located in the Sudanian zone of Bénin, is a protected area well managed, but mainly aimed at wild animal conservation. This study assessed its effectiveness to conserve habitat species composition and population structure of three endangered African tree species: *Afzelia africana* Sm., *Pterocarpus erinaceus* Poir. and *Khaya senegalensis* (Desv.) A. Juss. We randomly sampled 120 plots in the protected and surrounding unprotected habitats by inventorying plant species. For the three target species, we estimated adult and juvenile densities and recorded size classes. According to floristic composition four habitats groups were recognized in relation to human disturbance, vegetation type, and moisture. These were protected savannas, unprotected savannas, old fallows and gallery forests. The estimated adult densities of *A. africana* were similar between protected (14 ± 1.2 tree/ha) and unprotected savannas (17 ± 0.9 tree/ha) while for *P. erinaceus* the adult density was significantly higher in protected (12 ± 3.7 tree/ha) than in unprotected savannas (5 ± 1.9 tree/ha). Estimated adult density of *K. senegalensis* was also significantly higher in protected gallery forest (40 ± 5.8 tree/ha) than in unprotected one (29 ± 4.8 tree/ha). Juvenile densities of *A. africana, K. senegalensis* and *P. erinaceus* were higher in protected habitats than in unprotected ones but the difference was not significant. Skewness coefficient indicated that populations of investigated trees were declining in their protected habitats. However, in the case of *A. africana* and *K. senegalensis* populations seemed to be mostly threatened in the protected area. We concluded that although the studied protected area is effective to conserve some habitats species compositions, protection is not sufficient to guarantee future conservation of some threatened tree species.

Published by Elsevier B.V.

1. Introduction

In the tropics, increasing demand for timber, fuel and construction and for traditional agriculture, by a rapidly growing population, put high pressure on limited forest resources (Ehui et al., 1990; Scoones, 1995; Glèlè Kakaï and Sinsin, 2009). Under this situation much of tropical biodiversity is unlikely to survive without effective protection and therefore strategies to promote its conservation are needed, for instance by establishing and maintaining protected areas (Bruner et al., 2001). According to Lykke (1998) various human activities have disturbed savanna ecosystems for a long time, as savannas are a resource for food, medicine, timber and livestock breeding (Bellefontaine et al., 2000). The significant effect of human disturbance such as logging, land clearing and/or grazing on species composition of some broad ecosystems, has been highlighted by many studies (Sagar et al., 2003; Banda et al., 2006; Makana and Thomas, 2006; Haugo et al., 2010; Kohyani et al., 2011).

At regional level, approximately 76% of all species are facing extinction risk due to loss and modification of their natural habitats (McNeely, 1996). In Benin, a total of 280 threatened plant species, representing 10% of the national flora, have been reported (Adomou et al., 2009). As the global strategy of plant conservation states that at least 60% of threatened plant species should be within protected areas (Vellak et al., 2009) there is increasing concern about the extent to which protected areas contribute to conserve threatened plant species and their habitat. Several previous studies (Botha et al., 2004; Djossa et al., 2008; Gouwakinnou et al., 2009; Fandohan et al., 2011; Schumann et al., 2010) have emphasized the positive effect of different protected areas to conserve some valuable tree species in Africa using their population structure as an indicator.

Afzelia africana Sm., (Leguminosae-Caesalpinioideae); *Pterocarpus erinaceus* Poir., (Leguminosae-Papilionoideae) and *Khaya senegalensis* (Desv.) A. Juss, (Meliaceae) are three tree species, for which a strong decline has been reported in their native area by

* Corresponding author. Tel.: +229 95 69 35 74.
E-mail address: houehanout@yahoo.fr (T.D. Houehanou).

1476-945X/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.ecocom.2013.01.002

previous international findings (Adomou et al., 2009; IUCN, 2008; Lykke, 1998; Hahn-Hadjali and Thiombiano, 2000). Adomou et al. (2009) reported that they are highly endangered in Benin. This is linked to their multiple uses such as medicine, fuel, craft and fodder (Eyog-Matig et al., 2002; Gautier et al., 2005; Ouédraogo-Koné et al., 2006) and also to land clearing for agriculture.

The Pendjari Biosphere Reserve is a protected area located in the Sudanian zone and is the most managed protected area in Benin (Delvingt et al., 1989). However, management strategies (such as the regular early bush fire, patrols against poaching and others) applied in this protected area aim at conserving wild animals since these latter provide almost all financial resources obtained from the reserve valorization. Thus, plants in general and trees in particular are neglected in these management strategies.

Past studies relating to the conservation of target threatened tree species has focused on seedling survival constraints (Bationo et al., 2001; Ouédraogo et al., 2006), seedling responses to ectomycorrhizal inoculation (Diédhiou et al., 2005), impact of foliage and bark harvesting on population structure (Gaoue and Ticktin, 2007), dynamic changes through climatic zones (Sinsin et al., 2004) and habitat characterization (Bonou et al., 2009). However, the difference in population structure and in habitat-species composition in protected versus unprotected areas is relatively unknown. In the absence of long-term studies, investigations on population structure by density and size class distributions is a relevant way to obtain important data about the status of tree populations (Lykke, 1998; Obiri et al., 2002). This study was carried out to assess the effectiveness of this protected area in the conservation of the three target species and their habitats species composition. Specifically we conducted this research to address the following two questions: (1) Do protected and unprotected habitats of these tree species differ in species composition? (2) Have population structures (expressed by density and size class distribution) of these tree species been positively affected by this protected area?

2. Materials and methods

2.1. Study area

The study was carried out in the Pendjari Biosphere Reserve, a protected area located in the extreme north-western part of Benin (West Africa) and in its surrounding land use areas (Fig. 1). It is geographically located in the Sudanian zone between 10°40′–11°28N and 0°57′–2°10E. The reserve covers an area of about 4666.4 km^2 and is composed of the Pendjari National Park (2660.4 km^2), the Pendjari hunting zone (1750 km^2) and the Konkombri hunting zone (251 km^2). In the protected area anthropogenic activities are strictly prohibited while the surrounding areas are dominated by farmlands, fallows and savannas. The savannas in the surrounding unprotected areas are all subjected to selective logging and cutting of valuable tree species, livestock grazing and/or non timber forest products harvesting.

Mean annual rainfall in the reserve is 1000 mm with 60% falling between July and September (Sinsin et al., 2002). However, the rainfall in the sampled area, falls between 1000 mm and 1020 mm and is equally distributed between land use area and protected area for some given rainfall levels (Fig. 1). The climate is characterized by one rainy season (April/May to October) and one dry season (November to March). Temperature varies from 21 °C during the night up to 40 °C during the day in this zone. Soils are ferruginous in many areas of protected and land use areas (Fig. 1). However, indurate tropical ferruginous soils and swampy tropical ferruginous soils are mainly distributed in sampled area of

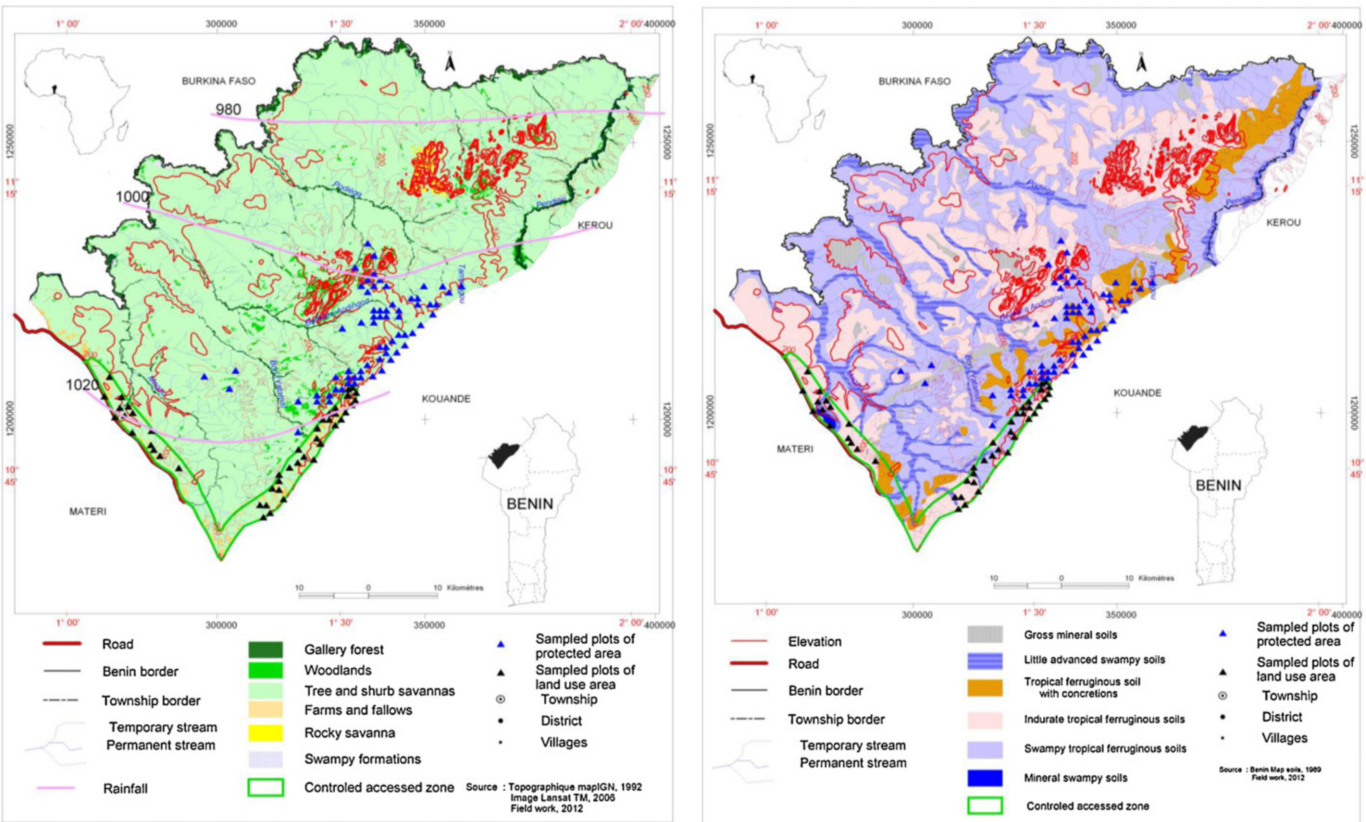

Fig. 1. Map showing the distribution of vegetation formations and rainfall (left picture) and the distribution of soils (right picture) in the Pendjari Biosphere Reserve.

protected and unprotected areas. Vegetation formation is characterized mainly by woodlands and savannas in the protected and land use areas (Fig. 1).

2.2. Study species

The three target species are found in the dry and wet Sudanian regions of Africa (White, 1983). *A. africana* is found in savannas, humid and dry forests and on hills (Akoègninou et al., 2006). It grows up to 35 m height (Arbonnier, 2000) and is a shade-intolerant species dispersed by gravity. Although *A. africana* is an ectomycorrhizal tree species in tropical Africa (Torti and Coley, 1999; Onguene and Kuyper, 2001), it has been established that its seedlings showed little mycorrhiza dependency (Diédhiou et al., 2005). *P. erinaceus* occurs mainly in savanna woodlands (Akoègninou et al., 2006) and it grows up to 15 m height (Arbonnier, 2000). *K. senegalensis* is found generally in savannas and gallery forests (Akoègninou et al., 2006) and grows up to 35 m height. In the Sudanian zone it occurs mainly in gallery forest (Natta, 2003).

2.3. Sampling and data collection

The sample size, N was computed to guarantee a margin error of $d = 10\%$ for the estimation of the mean basal area using the following formula (Dagnelie, 1998):

$$N = \frac{t_1^2 - \alpha/2(\mathrm{CV}^2)}{d^2}$$

where $t_1 - \alpha/2$ ($\alpha = 0.05$) is the critical value of the t-distribution that converges to the normal distribution for a large sample set ($N > 30$) and approximately equal to (1.96); CV = coefficient of variation of the mean basal area. Thirty individual trees were chosen randomly in savannas (protected and unprotected) and the coefficient of variation was calculated to be 55.9%. Considering these values, N equals 120. These 120 plots have been shared between savanna, gallery forest and old fallow and proportionally to their importance in protected and unprotected area (Table 1). These habitats represented the best conditions for species to occur in the study area. The vegetation map of the study area was used to select the number of plots defined per habitat through a random sampling scheme in each habitat. Geographic coordinates of plots were noted and projected on the study area map (Fig. 1).

The plots are rectangular in gallery forest and square in savannas and fallows with a total area of 1000 m^2 and 900 m^2 respectively. A total of 54 plots were sampled in the protected area while 66 plots were established in land use area (Table 1).

Within each plot, all plant species of tree and shrub layers were inventoried. The plant species of the herbaceous layer were inventoried in square sub plots of 100 m^2 randomly established in each plot. The diameter of target tree species for individuals with a diameter at breast height (dbh) $\geq$ 2 cm was recorded. Simultaneously, field data on environmental variables were collected. These are the vegetation type, human disturbance signs (collected only in unprotected savannas and fallows), and presence of water, rock and sand. In addition local people were interviewed on availability of target species in land use area. Herbarium specimens were prepared and identified with the help of National flora or at the National Herbarium of Benin. The data were collected during the vegetation period (from July to September) of 2008 and 2009.

Table 1
Distribution of the sampled plots in protected and unprotected areas.

Vegetation type	Protected area	Unprotected area	Total
Gallery forest	16	12	28
Savanna	38	35	73
Old fallow	–	19	19
Total	54	66	120

2.4. Data analysis

2.4.1. Habitat species composition

Presence-absence data of the different species was submitted to Detrended Correspondence Analysis (DCA) (McCunne and Mefford, 1999) through the Bray-Curtis distance measure and the group linkage method of Flexible Beta in PCORD.5 to explore the variation of floristic composition of plots. Floristic composition changes and correlations with environmental parameters were investigated using Canoco 4.5 for Windows (ter Braak and Šmilauer, 2002) by Canonical Correspondence Analysis (CCA). The environmental variables tested were: vegetation type, moisture, sand presence, rock presence, tree density, juvenile density, basal area and human disturbance. Also, the presence of water, sand and rock were recorded during the data collection in the environment of the sampled plots. Tree and juvenile densities as well as basal area were calculated for each sampled plot. Human disturbance gradient was defined as following: fallow (high human disturbance), unprotected savanna and gallery forest (medium human disturbance) and protected savanna and gallery forest (no human disturbance). All qualitative environmental variables were codified.

The CCA model and the significance of the fitted environmental variables were evaluated by the Monte Carlo permutation test with 499 permutations. Monte-Carlo permutation tests were also used to test the significance of the ordination axes (499 permutations under reduced model). A p-value ≤ 0.05 for the first ordination axis was accepted as an indicator for a significant relationship between the items.

Due to the fact that people preferred to cut trees rather than shrubs and woody climbers, we assessed local availability of tree species between habitat groups. The importance value index (IVI) was used to characterize the tree (dbh $\geq$ 10 cm) species composition of each discriminated habitat group and to assess the local availability of tree species in the group (Albuquerque et al., 2009). IVI of a species is defined as: IVI = RtD + RtDo + RtF, with RtD, RtDo and RtF representing species relative dominance (basal area), relative density and relative frequency respectively. When IVI > 10 for a species in a given habitat, it is considered to be ecologically important in that habitat (Reitsma, 1988).

2.4.2. Population structure

The density of adults (dbh $\geq$ 10) and juveniles ($2 \leq$ dbh < 10), expressed as mean $\pm$ standard error, were compared for each target species between protected and unprotected habitats using the non parametric tests of Mann Whitney (in case of two samples) and Kruskal–Wallis (in case of three samples) as data were not normally distributed. These statistical analyses were performed with Statview. Size class distributions were adjusted to 3-parameters (a, b, c) Weibull theoretical distribution (see Bonou et al., 2009) because of its flexibility (Husch et al., 2003). This theoretical distribution has the ability to describe a wide range of unimodal distributions including reversed-J-shaped, exponential and normal frequency distributions (Newton et al., 2005). The threshold parameter (a) has been considered with the value of $a = 2$ cm for adjusting the size class of each target species. Log-linear analysis was performed in SAS (SAS, 2004) to test the adequacy of the observed distribution to Weibull distribution and also to test for significant differences between size class distributions. For size class distribution of each target species the coefficient of skewness (g_1), which is a measure of the relative proportion of small versus large stems (Feeley et al., 2007), was calculated.

3. Results

3.1. Discrimination of habitat groups and tree species composition

Variation in floristic composition indicated four vegetation groups (Fig. 2). The first axis separated old fallows (G4 composed of 19 plots located exclusively in old fallows), unprotected savannas (G3 constituted of 38 plots mostly located in unprotected savannas) and protected savannas (G1 constituted of 38 plots located in protected savannas) according to the anthropogenic gradient. The second axis distinguished gallery forests and temporary flooded plains (G2 composed of 25 plots of which 57% were located in gallery forests and temporary flooded plains of protected area and 43% located in gallery forests of land use area) from other habitats (G1, G3 and G4) and expressed a gradient of humidity.

According to the importance value index (IVI), tree species such as *A. africana*, *Lannea acida*, *Burkea africana*, *Detarium microcarpum*, *Vitellaria paradoxa*, *Ekebergia senegalensis*, *Combretum glutinosum*, *Combretum nigricans* and *Pteleopsis suberosa* are mostly available in G1 and G3 (Table 2). However, IVI values of *A. africana*, *P. erinaceus*, *L. acida*, *Crossopteryx febrifuga*, *Daniellia oliveri*, *B. africana*, *Terminalia macroptera* and *P. suberosa* are higher in protected savannas (G1) than in unprotected ones (G3).

In gallery forest (G2), *K. senegalensis*, *Anogeissus leiocarpa*, *T. macroptera*, *Tamarindus indica*, *C. febrifuga*, *D. oliveri*, *Terminalia laxiflora*, *Pericopsis laxiflora*, *Piliostigma thonninguii* and *Syzygium guineense* are the most available species (Table 2).

In fallows (G4), the tree layer is characterized by the highest availability of *Combretum collinum*, *Combretum fragrans*, *Azadirachta indica*, *Parkia biglobosa*, *Terminalia avicennoides* and *Ximenia americana*.

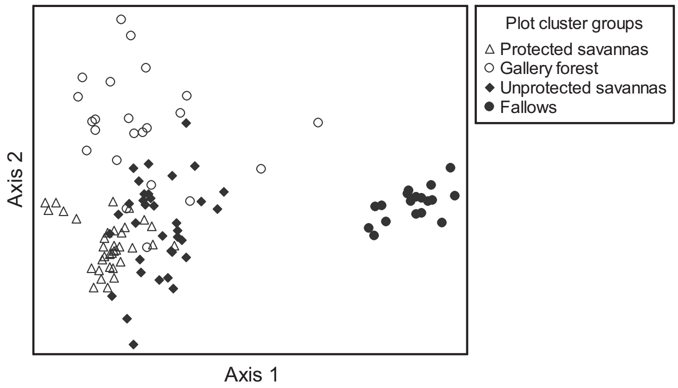

Fig. 2. Detrended Correspondence Analysis (DCA) showing discrimination of plots by species composition.

3.2. Discriminated habitat group in relation to environmental variables

The CCA explained 16.48% of the total inertia. It selected height significant ($p < 0.005$ for the first five and $p < 0.05$ for the last three) environmental variables that explained the variation in floristic composition. In decreasing order of significance, these variables are: human disturbance, vegetation type, rocky soil, moisture, official protection status, basal area, juvenile density and tree density. Monte Carlo test results revealed that the first canonical axis is significant ($F = 2.53$, $p = 0.002$). Table 3 shows the correlation of environmental variables with the first two canonical axes. Human disturbance, official protection status and vegetation type correlate best with the first axis whereas moisture correlates with the second axis. The environmental variables are projected in the first two axes as well as the discriminated habitat groups (Fig. 3). The pattern of these variables confirmed effectively that the first axis showed an anthropogenic gradient whereas the second axis revealed a moisture degree.

Table 2
Tree species composition of each habitat group according to species importance value index (IVI), IVI ≥ 10.

Species	Protected savanna (G1)	Gallery forest (G2)	Unprotected savanna (G3)	Fallows (G4)
Afzelia africana	90.49	24.93	84.91	
Pterocarpus erinaceus	88.20	10.13	69.53	81.36
Vitellaria paradoxa	97.90	11.40	116.58	178.97
Lannea acida	47.51	24.75	24.70	
Crossopteryx febrifuga	41.35	121.06	35.71	29.16
Daniellia oliveri	33.27	62.36	16.79	
Burkea africana	24.69	10.22	21.68	
Terminalia macroptera	18.26	169.96		
Pteleopsis suberosa	17.09			
Detarium microcarpum	14.36		17.63	
Combretum collinum	13.50		13.58	60.50
Piliostigma thonningii	10.21	14.32		
Khaya senegalensis		251.52	36.60	
Anogeissus leiocarpa		170.23	17.75	
Tamarindus indica		129.51	10.86	
Terminalia laxiflora		57.03		
Syzygium guineense		54.23	13.26	
Sarcocephalus latifolius		43.07		
Pericopsis laxiflora		38.46	17.18	
Ficus exasperata		24.34		
Mitragyna inermis		15.08		
Pseudocedrela Kotschyii		14.68		
Combretum nigicans			26.88	
Combretum fragrans			11.23	46.32
Acacia gourmaensis			26.45	
Azadirachta indica				36.20
Parkia biglobosa				29.27
Terminalia avicennoides				20.19
Ximenia americana				19.22

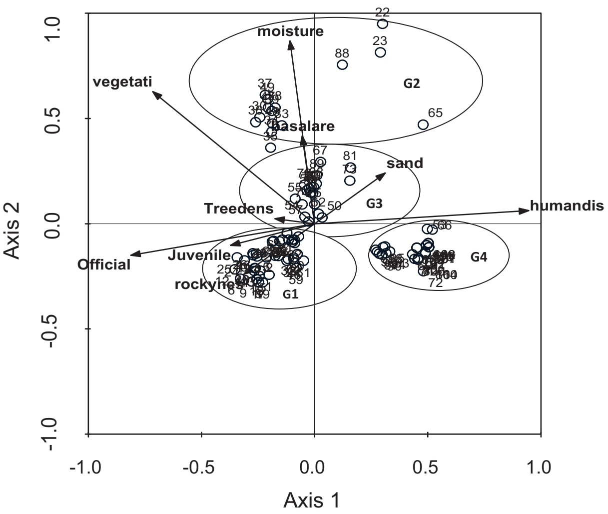

Fig. 3. Canonical Correspondence Analysis (CCA) diagram representing the first two axes that explained 61.1% (Axis 1: 48.1% and Axis 2: 13%) of all variance explained by the CCA. Empty circle designate the plots scores in each discriminated habitat group by species composition: G4: fallows, G2: Gallery forests, G3: Unprotected savannas and G1: Protected savannas. Environmental variables are represented by vectors that determine additional arrowed axes in the diagram. These variables are: Official (Official protection), juvenile (juvenile density), Treedens (tree density), Rocky (presence of rocks), Humandis (human disturbance), Vegetati (Vegetation type); Basalare (basal area), Moisture (moisture), Sand (presence of sand).

3.3. *Density of adults and juveniles (seedlings and saplings) of* A. africana, K. senegalensis *and* P. erinaceus *in relation with habitat protection*

The estimated adult density of *A. africana* was similar in protected savanna and unprotected one, with respectively 14 ± 1.2 and 17 ± 0.9 trees/ha. Juvenile density was slightly higher in protected savanna (2 ± 0.7 stems/ha) than unprotected savanna (1 ± 0.6 stems/ha), although these differences were not statistically significant.

The estimated density of *P. erinaceus* adults is significantly different ($H = 25.54$, $p < 0.0001$) between protected savanna (12 ± 3.7 tree/ha), unprotected savanna (5 ± 1.9 tree/ha) and fallow (17 ± 2.1 tree/ha), while the juvenile density did not show significant differences ($H = 0.69$ $p = 0.709$) and are respectively 5 ± 0.9 stems/ha, 3 ± 1.1 stems/ha and 0.00 ± 0.0 stems/ha.

As far as *K. senegalensis* is concerned, its adult density is significantly different ($w = 143.00$, $p = 0.031$) between protected (40 ± 5.8 tree/ha) and unprotected stands (29 ± 4.8 tree/ha). Juveniles were estimated at 1 ± 0.8 stem/ha and 0.00 ± 0.0 stem/ha

Table 3
Correlation of environmental variables with ordination axes of CCA. Only values > 0.5 contribute substantially to the axis.

Variables	Axis 1	Axis 2
Moisture	−0.093	0.775
Rocky	−0.266	−0.215
Sand	0.266	0.215
Human disturbance	0.807	0.056
Tree density	−0.150	0.021
Basal area	−0.046	0.371
Juvenile density	−0.317	−0.092
Vegetation type	−0.611	0.560
Official protection status	−0.693	−0.133

respectively in protected and unprotected gallery forest and were not significantly different.

3.4. *Size class distribution of* A. africana, K. senegalensis *and* P. erinaceus *in relation with habitat protection*

The size class distributions of the target species were analyzed only in the vegetation types where the species is mostly represented and when all its observed distributions presented a good fitting to Weibull distribution ($p > 0.05$).

Size class distributions of *A. africana* (Fig. 4) are constructed within protected and unprotected savannas. In both savanna types the species has a c-value comprised between 1 and 3.6, highlighting the predominance of small stems. The 22–42 cm dbh classes are the most represented in both habitat types. Juveniles represented 7% and 9% respectively in protected and unprotected savannas. Individuals of large diameter classes (dbh > 52 cm) are scarce in unprotected compared with protected habitats for this species. The size class distributions were not significantly different between the two savanna types ($G = 1.11$, $p = 0.99$) and the coefficients of Skewness ($g_1 > 0$), indicated relatively few small stems versus many large stems in both habitats.

As far as *P. erinaceus* is concerned, size class distributions (Fig. 5) were built for this species in protected and unprotected savannas and in fallow. In all habitats the *c*-value is comprised between 1 and 3.6. Although the size class distributions did not reveal significant difference between habitats ($G = 1.69$, $p = 0.99$) it was right-skewed ($g_1 < 0$) in unprotected savanna and in fallow while it was left-skewed ($g_1 > 0$) in protected savanna. Individuals of dbh > 52 cm are less present in unprotected than in protected savannas. However, size class distribution holds few classes of dbh (only three classes of dbh) in fallow. The others classes are absent. Juveniles account for 33%, 42% and 0% respectively in protected savanna, unprotected savanna and in fallow.

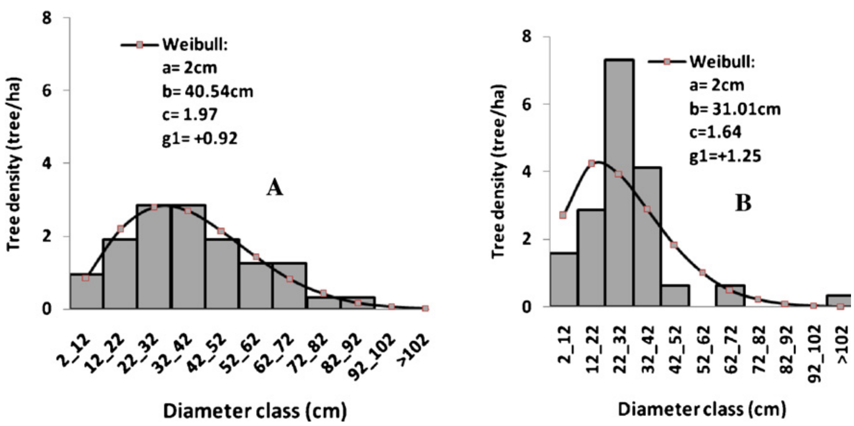

Fig. 4. Size class distribution of *Afzelia africana* in protected savanna (A) and unprotected savanna (B).

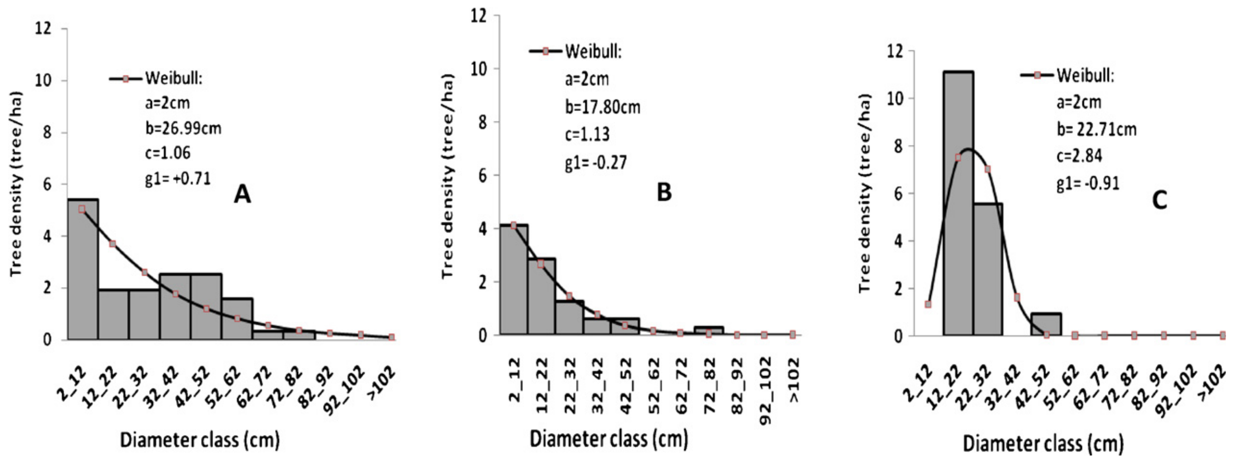

Fig. 5. Size class distribution of *Pterocarpus erinaceus* in protected savanna (A), unprotected savanna (B) and in fallows (C).

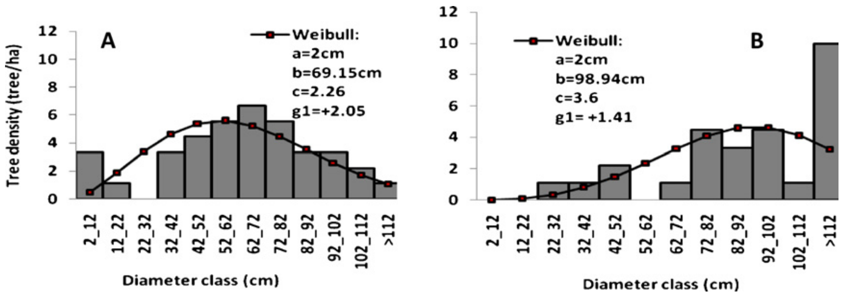

Fig. 6. Size class distribution of *Khaya senegalensis* in protected gallery forest (A) and unprotected gallery forest (B).

Size class distributions (Fig. 6) of *K. senegalensis* were made in protected and unprotected gallery forest habitats and revealed a *c*-value that is respectively smaller than 3.6 and close to 3.6. The two size distributions were not significantly different ($G = 2.67$, $p = 0.53$) and values of skewness indicated left-skewed ($g_1 > 0$) populations in both habitats. The dbh classes that are comprised between 32 and 82 cm hold more individuals in protected gallery forest than in unprotected gallery forest. However, highest dbh classes (dbh > 112 cm) were more present in unprotected than in protected habitats. Juveniles represented 2.78% and 0.00% respectively in protected and unprotected gallery forest.

4. Discussion and conclusion

4.1. Human disturbance in relation to species composition of habitats

This study showed that the floristic species composition is different in protected savanna habitats versus unprotected savanna. The protected gallery forest on the other hand has a similar floristic composition as the unprotected gallery forest. This suggests that human disturbance affects savanna species composition more than gallery forest. In that respect, gallery forest can be a mean to conserve many of its common plant species such as *K. senegalensis, A. leiocarpa, T. indica, C. febrifuga, D. oliveri, T. laxiflora* and *S. guineense*. This is in accordance with the theory saying that gallery forests are refuge areas for many plants and animals in dry regions (Porembski, 2001). If species composition of gallery forests is not significantly modified by human disturbance, this may suggest low human pressure on gallery forests in the study area or may depend on the accessibility or disturbance threshold in this habitat. Indeed, in surrounding areas of the reserve, tree cutting for firewood, is less done in gallery forest compared to savanna. This may be due to the fact that gallery forests are sometimes considered as sacrifice sites by local people. Also, logging and livestock grazing are minimal in gallery forest of land use area. However, with increasing demographic pressure, gallery forests species composition of the current study area can also become significantly affected.

The differences in species composition observed between protected and unprotected savannas may be explained mostly by a combined effect of selective logging and cutting, and livestock grazing. Surrounding unprotected savannas are highly subjected to these latter human disturbances. Mainly larger individuals of valuable tree species are selected for logging and cutting; and this involves modification of microclimate that leads to a species composition change of these habitats. Moreover, it has been argued that human disturbance such as logging usually causes an immediate decline in biodiversity followed by a recovery not necessarily of the same species (Noble and Dirzo, 1997; Sagar et al., 2003). Some species may tolerate disturbance while others may disappear.

4.2. Effect of protection on population density of target species

The study showed that estimated adult densities of *A. africana* are similar in protected and unprotected savannas. This is justified by the fact that in open access lands, many individuals of *A. africana*, characterized by $20 \leq \text{dbh} \leq 40$ cm are encountered although they are severely pruned. Individuals of large diameter (dbh ≥ 50 cm) are selected for logging and are hence scarce. As far as *P. erinaceus* is concerned, significantly more adults have been found in protected than in unprotected savanna, suggesting significant effect of human pressure. Local residents use *P. erinaceus* mostly for firewood (Houehanou et al., 2011) and this leads to cutting of many adult individuals (generally dbh ≥ 20 cm) in land use areas. Human disturbance in the form of fuel wood extraction is known to reduce adult individuals of preferred woody species in Africa (Pote et al., 2006; Furukawa et al., 2011).

The significant higher adult density of *K. senegalensis* observed in protected than in unprotected gallery forests may be also explained by the effect of human disturbance such as selective logging and cutting for firewood. Indeed, it has been shown previously (Houehanou et al., 2011) in this area that *K. senegalensis* was mostly used as fuel wood by local communities and partially as craft by some local people.

The estimated densities of juveniles for *A. africana*, *K. senegalensis* and *P. erinaceus* revealed higher values in protected habitats compared to unprotected ones although the difference was not statically significant. This means firstly that protection is effective to preserve more juveniles of *A. africana, K. senegalensis* and *P. erinaceus*. Secondly, a similar juvenile density of valuable trees species between protected and unprotected habitats suggests that savannas and gallery forest in land use area may have high potential for conservation of threatened tree species if they are subjected to specific management actions. The estimated juvenile density (2 stem/ha) obtained in this study for *A. africana* in protected savanna was lower than the one (21.5 stem/ha) found by Bonou et al. (2009) in non-degraded dense forest of the Lama Forest reserve (Guinean zone, South Benin). This difference may be due to different climatic conditions and may suggest that populations of *A. africana* better regenerate in the Guinean than in the Sudanian zone. This supposes a possible effect of climate variability on *A. africana* fecundity or regeneration rate. Moreover, many studies at local (Gaoue and Ticktin, 2007; Djossa et al., 2008; Fandohan et al., 2011) as well as at international level (Shaankar et al., 2001; Shahabuddin and Prasad, 2004; Anitha et al., 2010; Schumann et al., 2010), pointed out that a low seedling and sapling density of some valuable tree species in human dominated areas compared to areas where human pressure is minimum.

4.3. Impact of protection on size class distributions of target tree species

The size class distribution of tree species has been described to be affected by many factors (Condit et al., 1998) such as human disturbance or protection effect (Bhuyan et al., 2003; Gaoue and Ticktin, 2007; Fandohan et al., 2011; Schumann et al., 2010). In this study we found that the *c*-values of Weibull distributions were comprised between 1 and 3.6 or close to 1 in all size class distributions, suggesting a predominance of individuals with small diameter in the populations of the target tree species (Husch et al., 2003). However, various skewness coefficient values were obtained and this would suggest a human disturbance effect on the population structure of our target species. The coefficient of skewness showed that *A. africana* populations tend to hold few juveniles and many large stems (Feeley et al., 2007) either in the protected area or in land use area. The regular bush fire practiced in the protected area may justify such trend in this area as fire has been proven to be the main mortality factor of *A. africana* in the earlier life stages (small seedlings) (Bationo et al., 2001), making the transition from earlier to advanced life stage difficult. Also the current status observed for *A. africana* may be explained by the fact that seeds germinate in the proximity of reproductive individuals and consequently seedlings are subjected to their shade, which compromises their viability.

The study also showed that protection is efficient for maintaining large trees of *A. africana* and these large trees would be expected to be able to participate in reproduction of the species. However, regeneration in this protected area seems to be challenging for these populations. The lower number of large trees observed in land use area compared with the protected area may be explained by logging, which is most extensive on individuals of large diameter. Indeed, *A. africana* is preferred by local communities mostly for crafting use (Houehanou et al., 2011).

As far as *P. erinaceus* is concerned, the coefficient of skewness indicated that the protected populations are declining. However, its conservation may be not strongly compromised; regarding the relatively high juvenile proportion (33%).Savanna protection has been proven to be effective for maintaining large individuals of *P. erinaceus*. In our study, individuals of diameter higher than 52 cm were missing in unprotected savanna and this may be due to cutting for fuel wood and/or logging. Although *P. erinaceus* was also observed in fallows, its size class distribution exacerbated high human disturbance as revealed by the absence of many diameter classes. Farmers cut many individuals for fuel wood use during soil preparation for agriculture, and preserve few individuals (generally sub adults: 12 cm $\leq$ dbh $\leq$ 32 cm) for fodder use. These last individuals are those that occur at present in fallow and are highly pruned. Consequently, although the skewness coefficient ($g_1 < 0$) did not indicate a declining population, *P. erinaceus* will probably not be able to sustain its population level in fallow.

As far as *K. senegalensis* is concerned, the coefficient of skewness indicated few small stems versus many large in both populations (protected and unprotected gallery forest), suggesting a declining population. Since *K. senegalensis* populations are protected against human disturbance in the protected gallery forest, this suggests effect of other factors that compromise its viability. For instance, Gaoue and Ticktin (2007) argued that hemi-parasites load; soil type, presence of rocks and habitat type were significantly correlated with variation in seedling and adult density of *K. senegalensis*. Moreover, in gallery forest, viability of *K. senegalensis* seeds or seedlings may also be compromised by an excess of water in the protected area. Seeds that stay in the water for a long time and germinate there die prematurely (pers. Observation).

Size class distribution revealed that individuals of highest dbh (dbh > 112 cm) were more present in unprotected than in protected gallery forest. This fact may be due to debarking disturbance that occurs mostly on *K. senegalensis* in the unprotected zone. Indeed, individuals of *K. senegalensis* that are debarked, present a great trunk after recovering from their wounds.

4.4. Assessing the methodology

Since it is critical to understand the responses of tree species to ongoing anthropogenic disturbances, combined with the fact that appropriate long-term demographic data are scarce (Feeley et al., 2007), we used the shape parameter c of Weibull and the coefficient of skewness for analyzing size distributions. The *c* value indicated in all cases that studied populations were regenerating whereas the coefficient of skewness showed declining populations in some cases. In these latter cases, the results seem to be contrasted using the shape parameter c and the coefficient of skewness. The weibull distribution, due to its flexibility (Husch et al., 2003) to be fitted to a large wide range of distributions, loses ability to detect the declining populations and to appreciate the population status of trees. Consistent with the findings of Feeley et al. (2007) who showed that the coefficient of skewness was a useful tool for predicting future trends in population change, we advise the use of this coefficient to assess population status of trees. Nevertheless, it is required to consider skewness coefficient values together with anthropogenic specific-species pressure data.

4.5. Conclusion and management implications

Our study revealed specific-habitat species composition change and specific-species population structure in relation to specific anthropogenic disturbance. The protected savanna habitats are different from unprotected ones in terms of species composition, while this was not the case for gallery forests. The protected area was found effective to conserve juvenile density of targeted species. The study revealed that the protected populations of *A. africana, K. senegalensis* and *P. erinaceus* showed, in their investigated habitat, a declining population. Then, protection would not be always a sufficient action to conserve some threatened tree species. Nevertheless, protection is effective to maintain large trees of these target species.

In the protected area, conservation of *A. africana* and *K. senegalensis* deserves particular attention when defining management strategies. Permanent plots must be established in this protected area for monitoring their juveniles and to study the demography of its populations. Moreover, their assisted seedlings establishment should be promoted in the reserve.

Biodiversity conservation is also needed in surrounding unprotected areas as this will help to achieve its effective conservation in the protected area. Thus, the local use of some valuable tree species must be regularized in unprotected savannas as savanna habitats are mostly vulnerable to species composition change and degradation. Controlling fuel wood collection and logging will be a key task involving preventive disturbance and restoration in unprotected savanna ecosystems. The promotion of rapid growth species planting for fuel use in unprotected areas should also be developed.

Generalization of our results should be limited due to the lack of replications of investigated ecosystems in other areas. Also, different vegetations interact with different land use forms and might result in different species compositions and population structure responses.

Acknowledgements

We thank the BIOTA (Biodiversity Monitoring Transect Analysis) project for financial support, Linoce Fagnissey for field work assistance, Dr. Julien Djègo and Laurent Houessou for multivariate analysis assistance of vegetation data.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecocom.2013.01.002.

References

Adomou, A.C., Sinsin, B., Akoégninou, A.A., Van der Maesen, J., 2009. Plant species and ecosystems with high conservation priority in Benin. In: van der Burgt, X., van derMaesen, J.,Onana, .J.-M. (Eds.),Systematics and Conservation of African Plants. Royal Botanic Gardens, Kew, pp. 427–441.

Akoègninou, A., Van der Burg, W.J., Van der Maesen, L.J.G., 2006. Flore analytique du Bénin. Backhuys Publishers, Leiden, The Netherlands.

Albuquerque, U.P., Araujo, T.A.S., Ramos, M.A., do Nascimento, V.T., de Lucena, R.F.P., Monteiro, J.M., Alencar, N.L., de, L., Araujo, E., 2009. How ethnobotany can aid biodiversity conservation: reflections on investigations in the semi-arid region of NE, Brazil. Biodiversity and Conservation 18, 127–150.

Anitha, K., Joseph, S., Chandran, R.J., Ramasamy, E.V., Narendra Prasad, S., 2010. Tree species diversity and community composition in a human-dominated tropical forest of Western Ghats biodiversity hotspot, India. Ecological Complexity 7, 217–224.

Arbonnier, M., 2000. Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest, 2nd ed. CIRAD, France.

Banda, T., Schwartz, M.W., Caro, T., 2006. Woody vegetation structure and composition along a protection gradient in a miombo ecosystem of western Tanzania. Forest Ecology and Management 230, 179–185.

Bationo, B.A., Ouédraogo, S.J., Guinko, S., 2001. Seed longevity and stress survival of seedlings of *Afzelia africana* Sm. in savannah woodland in Burkina Faso. Annales des Sciences Forestières 58, 69–75.

Bellefontaine, R., Gaston, A., Petrucci, Y., 2000. Management of natural forests of dry tropical zones. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, p. 318.

Bhuyan, P., Khan, M.L., Tripathi, R.S., 2003. Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. Biodiversity and Conservation 12, 1753–1773.

Bonou, W., Glele Kakaï, R., Assogbadjo, A.E., Fonton, H.N., Sinsin, B., 2009. Characterisation of *Afzelia africana* sm. Habitat in the lama forest reserve of Benin. Forest Ecology and Management 258, 1084–1092.

Botha, J., Witkowski, E.T.F., Shackleton, C.M., 2004. The impact of commercial harvesting on Waburgia salutaris ('pepper-bark tree') in Mpumalanga South Africa. Biodiversity and Conservation 13 (9), 1675–1698.

Bruner, A.G., Gullison, R.E., Rice, R.E., da Fonseca, G.A.B., 2001. Effectiveness of parks in protecting tropical biodiversity. Science 291, 125–128.

Condit, R., Sukumar, R., Hubbell, S.P., Foster, R.B., 1998. Prediction population trends from size distributions: a direct test in a tropical tree community. The American Naturalist 152, 495–509.

Dagnelie, P., 1998. Statistique Théorique et Appliquée, vol. 2. De Boeck et Larcier, Belgique, Paris.

Delvingt, W., Heymans, J.C., Sinsin, B., 1989. Guide du parc national de la Pendjari. Commission des communautés Européennes. Coordination AGGREF, Bruxelle, p. 119.

Diédhiou, A.G., Guèye, O., Diabate, M., Prin, Y., Duponnois, R., Dreyfus, B., Ba, A.M., 2005. Contrasting responses to ectomycorrhizal inoculation in seedlings of six tropical African tree species. Mycorrhiza 16, 11–17.

Djossa, B.A., Fahr, J., Wiegand, T., Ayihouénou, B.E., Kalko, E.E., Sinsin, B.A., 2008. Land use impact on *Vitellaria paradoxa* C.F. Gaerten stand structure and distribution patterns: a comparison of Biosphere Reserve of Pendjari in Atacora district in Benin. Agroforest System 72, 205–220.

Ehui, K.S., Hertez, W.T., Preckez, P., 1990. Forest resources depletion, soils dynamics and agricultural productivity in the tropics. Journal of Environmental Economics and Management 18, 136–154.

Eyog-Matig, O., Gaoué, O.G., Obel-Lawson, E., 2002. Development of Appropriate Conservation Strategies for African Forest Trees Identified As Priority Species by SAFORGEN member countries. IPGRI, Nairobi.

Fandohan, A.B., Assogbadjo, A.E., Glèlè Kakaï, R.L., Sinsin, B., 2011. Effectiveness of a protected areas network in the conservation of *Tamarindus indica* (Leguminosea-Caesalpinioideae) in Benin. African Journal of Ecology 49, 40–50.

Feeley, J.K., Davies, S.J., Nur Supardi Noor, M.D., Kassim, A.R., Tan, S., 2007. Do current stem size distributions predict future population changes? An empirical test of intraspecific patterns in tropical trees at two spatial scales. Journal of Tropical Ecology 23, 191–198.

Furukawa, T., Fujiwara, K., Kiboi, S.K., Chalo Mutiso, P.B., 2011. Threshold change in forest understory vegetation as a result of selective fuelwood extraction in Nairobi, Kenya. Forest Ecology and Management 262, 962–969.

Gaoue, O.G., Ticktin, T., 2007. Patterns of harvesting foliage and bark from the multipurpose tree *Khaya senegalensis* in Benin: variation across ecological regions and its impacts on population structure. Biological Conservation 137, 424–436.

Gautier, D., Bonnerat, A., Njoya, A., 2005. The relationship between herders and trees in space and time in northern Cameroon. Geography Journal 171, 324–339.

Glèlè Kakaï, R., Sinsin, B., 2009. Structural description of two *Isoberlinia* dominated communities in the Wari-Maro forest reserve (Benin). South African Journal of Botany 75 (1), 43–51.

Gouwakinnou, G.N., Kindomihou, V., Assogbadjo, A.E., Sinsin, B., 2009. Population structure and abundance of *Sclerocarya birrea* (A. Rich) Hochst subsp. birrea in two contrasting land-use systems in Benin. International Journal of Biodiversity and Conservation 6, 194–201.

Hahn-Hadjali, K., Thiombiano, A., 2000. Perception des espèces en voie de disparition en milieu gourmantche (Est du Burkina Faso). Berichte des Sonderforschungsbereichs 268, 285–297.

Haugo, R.D., Hall, S.A., Gray, E.M., Gonzalez, P., Bakker, J.D., 2010. Influences of climate, fire, grazing, and logging on woody species composition along an elevation gradient in the eastern Cascades, Washington. Forest Ecology and Management 260, 2204–2213.

Houehanou, T.D., Assogbadjo, A.E., Glèlè Kakaï, R., Houinato, M., Sinsin, B., 2011. Valuation of local preferred uses and traditional ecological knowledge in relation to three multipurpose tree species in Benin (West Africa). Forest Policy and Economics 13, 554–562.

Husch, B., Beers, T., Kershaw, J., 2003. Forest Mensuration, 4th ed. Ronald Press Company, London.

IUCN, 2008. List of tropical Woods Used and Sold for Woodturning and their Endangerment Status. http://www.bradturnsgreen.com/Wood%20Status%20List.pdf.

Kohyani, P.T., Bossuyt, B., Bonte, D., Hoffmann, M., 2011. Grazing impact on plant spatial distribution and community composition. Plant Ecology and Evolution 144 (1), 19–28.

Lykke, A.M., 1998. Assessment of species composition change in savanna vegetation by means of woody plants' size class distributions and local information. Biodiversity and Conservation 7, 1261–1275.

Makana, J.-R., Thomas, S.C., 2006. Impacts of selective logging and agricultural clearing on forest structure, floristic composition and diversity, and timber tree regeneration in the Ituri Forest, Democratic Republic of Congo. Biodiversity and Conservation 15, 1375–1397.

McCunne, B., Mefford, M.J., 1999. Multivariate Analysis of Ecological Data Ver: 4. 14. MjM Software, Oregon, U.S.A.

McNeely, J.A., 1996. Conservation and Future: Trends and Options Toward the year 2025. A Discussion Paper. IUCN, Gland Switzerland

Natta, A.K., 2003. Ecological assessment of riparian forests in Benin. Phytodiversity, phytosociology and spatial distribution of tree species. Ph.D. thesis, Wageningen University, The Netherlands.

Newton, P.F., Lei, Y., Zhang, S.Y., 2005. Stand-level diameter distribution yield model for black spruce plantations. Forest Ecology and Management 209, 181–192.

Noble, I.R., Dirzo, R., 1997. Forests as human-dominated ecosystems. Science 277, 522–525.

Obiri, J., Lawes, M., Mukolwe, M., 2002. The dynamics and sustainable use of high value tree species of the coastal Pondoland forests of the Eastern Cape Province, South Africa. Forest Ecology Management 166, 131–148.

Onguene, N.A., Kuyper, T.W., 2001. Mycorrhizal associations in the rain forest of South Cameroon. Forest Ecology and Management 140, 277–287.

Ouédraogo, A., Thiombiano, A., Hahn-hadjali, K., Guinko, S., 2006. Diagnostic de l'état de dégradation des peuplements de quatre espèces ligneuses en zone soudanienne du Burkina Faso. Sécheressse 17 (4), 485–491.

Ouédraogo-Koné, S., Kaboré-Zoungrana, C.Y., Ledin, I., 2006. Behaviour of goats, sheep and cattle on natural pasture in the sub-humid zone of West Africa. Livestock Science 105, 244–252.

Porembski, S., 2001. Phytodiversity and structure of the comoé River Gallery forest (NE Ivory-Coast). Life forms and dynamics in Tropical Forests. Dissertationes Botanicae 346, 1–10.

Pote, J., Shackleton, C., Cocks, M., Lubke, R., 2006. Fuelwood harvesting and selection in Valley Thicket, South Africa. Journal of Arid Environments 67, 270–287.

Reitsma, J.M., 1988. Forest Vegetation in Gabon. Tropenbos Technical Series 1. Tropenbos Foundation, The Netherlands, p. 142.

Sagar, R., Raghubanshi, A.S., Singh, J.S., 2003. Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. Forest Ecology and Management 186, 61–71.

SAS Institute Inc., 2004. SAS Online Doc 9.1. SAS Institute Inc., Cary.

Schumann, K., Wittig, R., Thiombiano, A., Becker, U., Hahn, K., 2010. Impact of land-use type and bark- and leaf-harvesting on population structure and fruit production of the baobab tree (*Adansonia digitata* L.) in a semi-arid savanna, West Africa. Forest Ecology and Management 260, 2035–2044.

Scoones, I., 1995. Living with Uncertainty: New Directions in Pastoral Development in Africa. SRP, Exeter, London.

Shahabuddin, G., Prasad, S., 2004. Assessing ecological sustainability of non-timber forest produce extraction: the Indian scenario. Conservation and Society 2, 235–250.

Shaankar, R.U., Ganeshaiah, K.N., Rao, M.N., 2001. Genetic diversity of medicinal plant species in a deciduous forest of Southern India: impact of harvesting and other anthropogenic pressures. Journal of Plant Biology 28, 91–97.

Sinsin, B., Tehou, A.C., Daouda, I., Saidou, A., 2002. Abundance and species richness of larger mammals in Pendjari National Park in Benin. Mammalia 66 (3), 369–380.

ter Braak, C.J.F., Šmilauer, P., 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5) Microcomputer Power, Ithaca NY, USA, p. 500.

Sinsin, B., Eyog Matig, O., Assogbadjo, A.E., Gaoue, G.O., Siandouwirou, T., 2004. Dendrometric characteristics as indicators of pression of *Afzelia africana* Sm. Dynamic changes in trees found in different climatic zones of Benin. Biodiversity and Conservation 13, 1555–1570.

Torti, S.D., Coley, P.D., 1999. Tropical monodominance: a preliminary test of the ectomycorrhizal hypothesis. Biotropica 31, 220–228.

Vellak, A., Tuvi, E., Reier, U., Kalamees, R., Roosaluste, E., Zobel, M., Pärtel, M., 2009. Past and present effectiveness of protected areas for conservation of naturally and anthropogenically rare plant species. Conservation Biology 23 (3), 750–757.

White, F., 1983. The vegetation of Africa, a descriptive memoir to accompany the UNESCO/AETFAT/UNSO. UNESCO. Natural Resources Research 20, 1–356.