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Structural description of two *Isoberlinia* dominated vegetation types in the Wari–Maro Forest Reserve (Benin)

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Abstract

An tree-inventory of *Isoberlinia* natural mixed stands was carried out in the tree-savannas and woodlands of the Wari–Maro Forest Reserve (Republic of Benin) to serve as basis to improve existing management strategies. Measurements were done in 96 rectangular plots of 30 × 50 m with a cumulative area of 14.4 ha. The two vegetation types were mainly distinguished by the overall tree-density (225.2 stems/ha in tree-savannah against 202.8 stems/ha in woodland), the overall mean height of the stands (13.1 and 14.6 m, respectively) and the mean height of *Isoberlinia* trees (14.1 and 16.8 m respectively). The other parameters (mean diameter, basal area, basal area contribution of *Isoberlinia* trees, bark thickness, tree-density of *Isoberlinia* trees as well as the Shannon diversity index and Pielou evenness index) had essentially the same values for the two vegetation types. The stem diameter structure of *Isoberlinia* stands in the two vegetation types had an "inverse-J" shape for the whole stand and the "I" shape for *Isoberlinia* trees. The stem diameter of *Isoberlinia* decreased on average 1.9 cm/m tree-height. *Isoberlinia* seedlings were more abundant below the canopy of mature trees than further away. The main dispersal mode of the species consisted of dropping the seeds from pods under the mother tree, and suckering which resulted in the observed aggregated distribution of the trees. These results were used to propose management strategies for the two vegetation types.
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Keywords: Dominance; *Isoberlinia* spp.; Structure; Vegetation type; Wari–Maro

1. Introduction

Benin is a sparsely-forested country located in the 'Dahomey Gap', which is breaking the West African rainforest belt between Nigeria and Ghana. The vegetation cover was estimated at 2,538,000 ha (FAO, 2001), representing 23% of the total area of the country. Increasing demand by a rapidly growing population for wood for fuel and construction, cropland for traditional agriculture, mostly under shifting cultivation (Ehui et al., 1990) put high pressure on these limited forest resources. Between 1995 and 2000, more than 60,000 ha of natural vegetation were destroyed in Benin — an annual vegetation loss of 1.2% (FAO, 1999).

One of the evident consequences of this increasing pressure on the natural resources in Benin is the shortage of valuable species such as *Khaya senegalensis* and *Afzelia africana* (Sinsin et al., 2004), which were well represented in forests in the past. With their disappearance, people living adjacent to the forests make massive use of other wood species such as *Isoberlinia* spp., considered in the past as not valuable. Forest inventories of most forests of Benin (Fonton, 1997) showed the quantitative importance of natural stands that are mainly composed of *Isoberlinia* spp. in the woodlands and tree-savannas, which now suffer more and more from deforestation and uncontrolled logging (Yorou et al., 2001).

Isoberlinia (Fabaceae, Caesalpinioidea) is an African tree genus growing mainly in woodlands and tree-savannas. Two species are found in Benin namely *Isoberlinia doka*, on clay and well-drained soils and *Isoberlinia tomentosa*, on stony and sloping soils (Yorou et al., 2001).

The Wari–Maro Forest Reserve is partly composed of woodlands and tree-savannas with *Isoberlinia* natural stands. To prevent the decline of these stands, as was the case for *K. senegalensis* and *A. africana*, a sustainable management strategy should be applied, with special attention to *Isoberlinia*

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spp. This requires better knowledge of the structure of the stands. The present study is aimed at describing and analysing the structure of *Isoberlinia* dominated stands in woodlands and tree-savannas for the purpose of designing suitable management strategies. The specific objectives were to determine dendrometric and ecological features of the two *Isoberlinia*-dominated vegetation types in the Wari–Maro Forest Reserve, in particular their stem diameter structure and spatial distribution patterns of the seedlings and saplings.

2. Methods

2.1. Study area

The inventory of *Isoberlinia* natural stands was done in the Wari–Maro Forest Reserve, central region of the Republic of Benin, between 8°80–9°10′ N and 1°55′–2°25′ E (Fig. 1).

The Wari–Maro Forest Reserve covers an area of about 120,686 ha with 50,057 ha of woodland and 56,088 ha of tree-

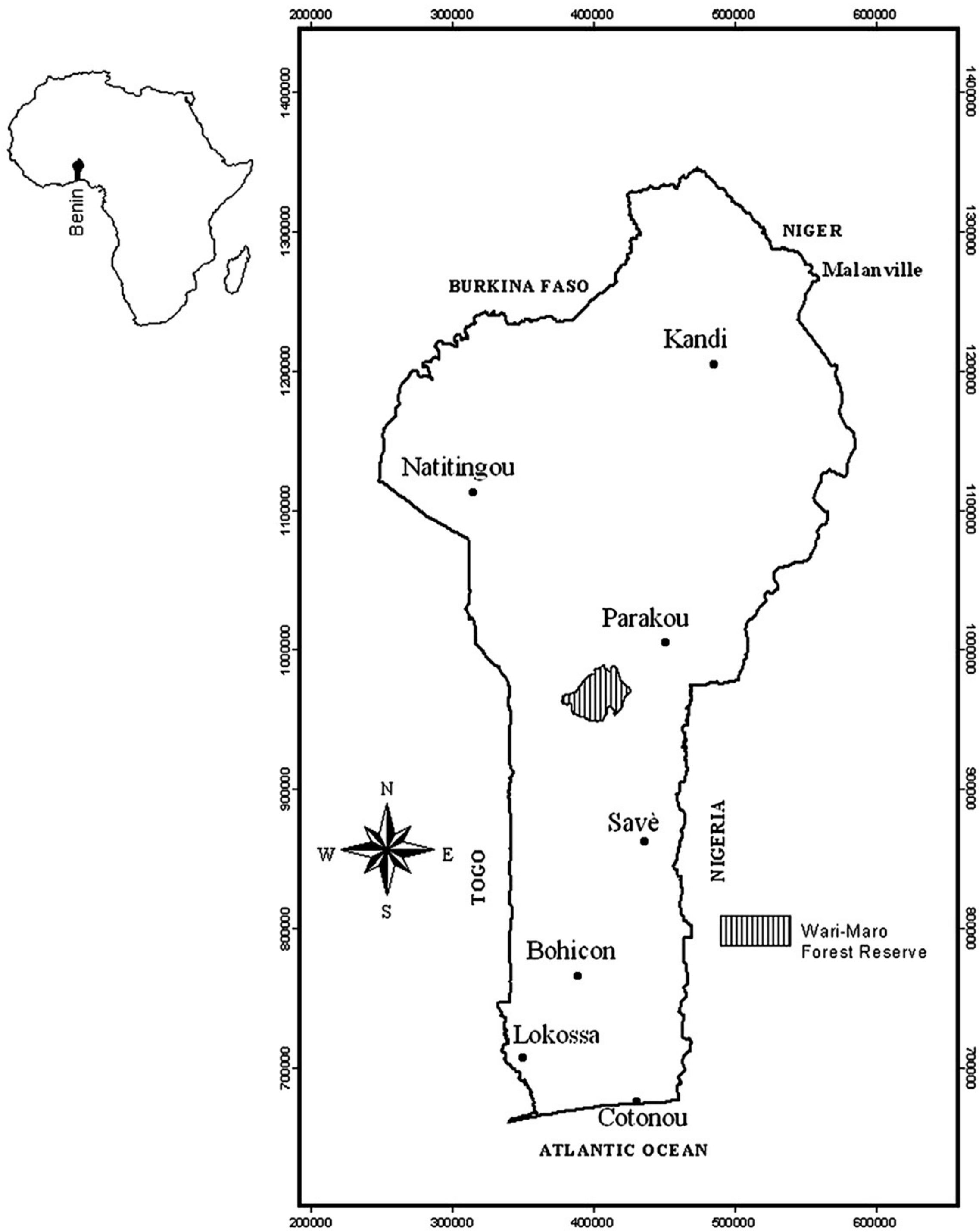

Fig. 1. Location of Wari–Maro Forest Reserve.

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savannah. The remaining part of the reserve is composed of shrub and grass savannas. The reserve is located in the Guineo–Sudanian transition zone defined by Aubreville (1970) as "natural stands of Guinean wood savannah" and by White (1983) as "Sudanian woodland mainly composed of *Isoberlinia* spp.".

Woodlands support common species such as *Isoberlinia* spp., *Anogeissus leiocarpa*, *Butyrospermum paradoxum* and *Parkia biglobosa* (Orthmann, 2005). The most characteristic grass in the undergrowth is *Andropogon tectorum*. The more open tree-savannas are found in the northern part of Benin and characterized by the following taxa: *Isoberlinia* spp., *A. leiocarpa*, *Combretum micranthum*, *K. senegalensis* and *Boscia salicifolia*.

In tree-savannas, fire temperature ranged from 215 °C to values larger than 600 °C in December (Orthmann, 2005). Woodlands burnt generally later than tree-savannas. Woody biomass ranged from about 90 t/ha for the woodlands to about 40 t/ha for the tree-savannas (Orthmann, 2005). Moreover, tree-savannah sites were influenced by higher insolation and extremer conditions for air temperature, humidity and vapour pressure deficit than woodlands. Microclimatic conditions were found to be strongly correlated with tree cover. During the rainy season, the microclimate of the two vegetation types differed to a greater extent than during the dry season (Orthmann, 2005). Soil parameters, however, showed only slight gradual differences. Generally, tree-savannas were located in valleys and woodlands on upper slopes.

The study zone was characterized by a Sudano–Guinean climate with two seasons: a dry season from November to March and a rainy season from April to October. August was the month with highest rainfall (267.5 mm). Annual rainfall from 1964–1997 fluctuated between 1000 mm and 1100 mm with a mean of 1052 mm (Orthmann, 2005) and did not differ between the two studied vegetation types.

2.2. Inventory design and data collection

An inventory was carried out in the woodland and tree-savannah dominated by *Isoberlinia* (Fig. 2) based on a simple random sampling scheme. The sample unit was a rectangular plot of 30 × 50 m with four quadrats of 5 × 5 m inside the sample unit for the measurement of seedlings, saplings and poles.

The minimum sample size, n_t of the plots that were considered for the inventory, to guarantee a standard error of d equal 5% for the mean basal area was computed using the formula below:

$$n_t = t^2_{1-\alpha/2} cv^2 / d^2. \quad (1)$$

In Eq. (1), $t_{1-\alpha/2}$ ($\alpha = 5\%$) is the critical value of the t-distribution that converges to the normal distribution for larger sample ($n_t > 30$) and equal to 1.96; cv is the coefficient of variation of the overall basal area of *Isoberlinia* natural stands and was equal to 21.2% for *Isoberlinia* stands in the Oueme Superior Forest Reserve located also in the central part of Benin (Sagbo, 2000). This value was rounded off to 25% in order to increase the number n_t of unit plots (see Formula (1) and to guarantee a high precision for structural parameter estimation. The number n_t of the considered plots computed from Eq. (1) was then 96, with 50 in tree-savannah and 46 in woodland. The overall area inventoried was 14.4 ha, spread out in the Wari–Maro Forest. In the same vegetation type, the rectangular plots were placed at least 200 m apart.

Within a rectangular plot, all trees of diameter at breast height (dbh) more than 10 cm were sampled and their total height using a relascope, diameter at 1.3 m above the ground using a calliper and bark thickness at the same level by making a cut with a machete were measured. The name of each species and the number of trees per species were also recorded. For a tree forked into w main stems under 1.3 m, its diameter d was

Fig. 2. A view of a *Isoberlinia* mixed stand in tree-savannah.

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considered as the quadratic sum of the diameters ds_i (i=1,…, w) of the main stems:

$$d = \sqrt{\sum_{i=1}^{w} ds_i^2}.$$

In each of the four quadrats of a rectangular plot, *Isoberlinia* regeneration (seedlings, saplings and poles) was assessed and the height of saplings and poles was measured.

In order to describe the shape of the species, 88 trees were selected in various diameter classes and their diameter was measured at every 0.5 m from 10 cm above the ground, until 2.1 m and then every 2 m until 7 cm of stem diameter, using a relascope.

In both tree-savannah and woodland, the spatial distribution of *Isoberlinia* seedlings was described and analysed based on five *Isoberlinia* trees in each of the two following stages: young mature (10 cm ≤ dbh ≤ 30 cm), and mature trees (30 cm < dbh ≤ 60 cm). For each tree, the number of seedlings was noted in each of four concentric rings of 1 m wide around the tree.

2.3. Data analysis

2.3.1. Structural parameters

For each plot, the following parameters were calculated:

The tree-density of the stands (N): i.e. the average number of trees per sample plot, expressed as stems per hectare:

$$N = \frac{n}{s}, \tag{2}$$

n being the overall number of trees in the plot and s the unit area of the plot (s=0.15 ha).

The basal area of the stand (G): i.e. the sum of the cross-sectional areas at 1.3 m above ground level of all trees on a plot, expressed as m^2/ha:

$$G = \frac{\pi}{4s}\sum_{i=1}^{n} 0.0001 d_i^2 \tag{3}$$

d_i being the diameter (in cm) of the ith tree of the plot; s the unit area of the plot (s=0.15 ha).

The mean diameter of the tree (D): i.e. the diameter of the tree with mean basal area expressed as cm:

$$D = \sqrt{\frac{1}{n}\sum_{i=1}^{n} d_i^2}, \tag{4}$$

with n being the number of trees found on the plot and d_i, the diameter of the ith tree (in cm).

The Lorey's mean height (H): i.e. the average height of all trees found in the plot, weighted by their basal area, expressed as meters (Philip, 2002):

$$H = \frac{\sum_{i=1}^{n} g_i h_i}{\sum_{i=1}^{n} g_i} \text{ with } g_i = \frac{\pi}{4} d_i^2, \tag{5}$$

g_i and h_i being the basal area (in m^2/ha) and the total height (in m) of the tree i. This mean height is more stable than an unweighted mean height because it is less affected by mortality and harvesting of the smaller trees and constitutes an important index for woody species management.

The four dendrometric parameters defined above were computed for the whole plot and for *Isoberlinia* trees separately. The following four parameters were only computed for *Isoberlinia* trees:

The mean density of regenerations (N_r): i.e. the average number of *Isoberlinia* regenerations (seedlings, saplings) per hectare, expressed as plants/ha:

$$N_r = \frac{1}{4}\sum_{i=1}^{4} dr_i \text{ with } dr_i = \frac{n_i}{sq}, \tag{6}$$

dr_i being the density of seedlings and saplings in quadrat i; the number of *Isoberlinia* regeneration is n_i and sq, the unit area of the quadrat (sq=0.0025 ha).

The mean height of *Isoberlinia* saplings and poles (h_r):

$$h_r = \frac{1}{n_r}\sum_{i=1}^{n_r} h_i, \tag{7}$$

where h_i is the height of sapling or pole i and n_r is the total number of these plants in the 4 quadrats of the targeted plot, expressed as cm.

The bark factor (k): i.e. computed for *Isoberlinia* trees in order to assess the importance of the valuable wood in the overall volume of a tree (Husch et al., 1982):

$$k = \frac{\sum_{i=1}^{n'} d_{ui}}{\sum_{i=1}^{n'} dp_i} \text{ with } d_{ui} = dp_i - 2e_i, \tag{8}$$

e_i being the bark thickness measured on the tree and dp_i the diameter over bark of the tree i and n', the number of *Isoberlinia* individuals found on the plot.

The basal area contribution (Cs, in per cent) is defined as the part of *Isoberlinia* trees in the overall basal area of all trees in the plot:

$$Cs = 100\frac{Gp}{G}. \tag{9}$$

Gp is the basal area of the *Isoberlinia* trees and G is the basal area for the whole plot.

Three ecological parameters were considered as follows:

The species richness (S, in species) is the estimated number of tree-species in tree-savannah and in woodland. For a given vegetation type, the estimated species richness is computed using the formula below (Haas et al., 2006):

$$S = r\left[1 - \frac{(1-q)b_i}{\sum_{i=1}^{n} ib_i}\right]^{-1}. \tag{10}$$

where r, the overall number of tree-species recorded in the n inventoried plots of the vegetation type; b_i is the number of

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species found on the ith plot. The parameter q is computed as follows:

$$q = \frac{n}{N_a} \text{ with } N_a = \frac{A}{s},$$

where s is the area of the plot and A, the area of the targeted natural stand that was estimated at 50,057 ha and 56,088 ha for woodland and tree-savannah, respectively; n is the number of inventoried plots.

The Shannon diversity Index (I_{sh}) is computed using the following formula:

$$I_{sh} = -\sum_{i=1}^{b} \frac{n_i}{n} \log_2 \frac{n_i}{n}, \quad (11)$$

where n_i is the number of trees of species i, n is the overall number of trees inventoried in the plot and b is the number of species recorded on the considered plot.

The Pielou evenness index (Eq) measures the diversity degree of a stand compared with the possible maximum and computed for each plot as follow:

$$Eq = \frac{I_{sh}}{I_{\max}} \text{ with } I_{\max} = \log_2 b. \quad (12)$$

In Eq. (12), I_{sh} represented the value of Shannon diversity index; $I_{\max}$ was the maximum value of the diversity index and b, the number of tree-species recorded in the considered plot.

Apart from the species richness for which only the mean value is computed for each of the two vegetation types, the mean and coefficient of variation of the other parameters were computed for tree-savannah and for woodland. These two vegetation types were compared using the Student t-test on each of the parameters except for Shannon diversity index and Pielou evenness index. The probability of the Ryan–Joiner test of normality (Ryan and Joiner, 1976) of less than 0.01 for the two parameters indicated that these two last parameters were not normally distributed. To compare the two vegetation types the non-parametric Mann–Whitney U test was therefore applied. In order to characterize the spatial distribution of the trees in each of the two vegetation types the Blackman Index I_B was computed:

$$I_B = \frac{\sigma_N^2}{\mu_N}, \quad (13)$$

where σ_N^2 is the variance and μ_N is the mean of the overall tree-density of the stands.

2.3.2. Establishment of the stem diameter structure of the stands

To produce a diameter histogram for the whole stand and for *Isoberlinia* individuals all trees were grouped into stem diameter classes of 5 cm width. The truncated normal distribution was used to approximate the actual histogram of stem diameters of all *Isoberlinia* of individual plots. For the whole stand, a truncated negative exponential distribution, characteristic to uneven-aged stands, was used. As only trees with a diameter of more than 10 cm were included, the two truncated distributions were limited to values above 10 cm. A log-linear analysis was performed to check the accuracy of these approximations. For the small-size classes encountered in this study such a test is more robust than the traditional Chi-square test.

2.3.3. Height–diameter relationship and stem taper function for Isoberlinia

The height–diameter relationship was established for *Isoberlinia* trees by adjusting the model that gave the best fit:

$$Lnh = a + bd + cd^2,$$

where h is the total height of the tree (in meters) and d is the diameter (in centimeter).

Moreover, the form of an *Isoberlinia* tree has been described by adjusting a stem taper function for diameters measured at different levels on 88 trees. The stem taper function expresses the variation of the size of trees from the base to the top. The Riniker model has been used (Tarp-Johansen et al., 1997):

$$d_i^2 = 4p(h - l_i)^r. \quad (14)$$

where d_i is the diameter of the tree (in cm) at l_i meters above the ground; h is the total height of the tree (in meters); p is a constant that varies between 0.5 and 5 cm/m (Bary-Lenger et al., 1988) and is related to the decrease of the tree diameter (in cm) per meter and r is the constant related to the exponential decrease of the tree diameter ($r \geq 0$). To adjust the model in Eq. (14), the logarithmic transformation was applied:

$$ln\left(d_i^2\right) = ln(4p) + rln(h - l_i), \quad (15)$$

for which r and ln(4p) are estimated by using the least square method.

2.3.4. Spatial distribution patterns of Isoberlinia seedlings and saplings

To describe the spatial distribution of seedlings and saplings, the mean and coefficient of variation of seedlings and saplings in the four rings around mother trees were computed applying an ANOVA with 3 factors (vegetation type, diameter class and ring).

3. Results

3.1. Dendrometric parameters

The mean values and the coefficient of variation of the parameters for woodland and tree-savannah are presented in Table 1. Only three parameters presented significant differences between tree-savannah and woodland: the overall density (225.2 stems/ha in tree-savannah and 202.8 stems/ha in woodland), the overall mean height (13.1 and 14.6 m, respectively) and the mean height of *Isoberlinia* trees (14.1 and 16.8 m, respectively).

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Table 1
Structural parameters of *Isoberlinia* stands in woodland and tree-savannah: means, coefficient of variation (*cv*) and *p*-values of the *t*-tests

Parameter	Tree-savannah		Woodland		*p*-value
	Mean	*cv* (%)	Mean	*cv* (%)	
Whole Stands					
Tree-density (N, stems/ha)	225.2	32.3	202.8	43.4	0.050
Mean diameter (D, cm)	23.2	20.5	24.4	21.8	0.118
Basal area (G, m^2/ha)	9.4	38.8	9.4	45.5	0.954
Mean height (H, m)	13.1	19.6	14.6	25.5	0.040
Isoberlinia trees					
Tree-density (N_{Iso}, stems/ha)	89.9	73.3	78.7	99.5	0.293
Mean diameter (D_{Iso}, cm)	27.9	31.1	30.4	33.3	0.100
Basal area (G_{Iso}, m^2/ha)	5.5	62.7	5.4	63.9	0.811
Mean height (H_{Iso}, m)	14.1	18.8	16.8	21.6	0.020
Bark factor (k)	0.90	8.1	0.92	5.1	0.090
Basal area contribution (Cs, %)	53.9	41.9	51.8	47.3	0.572
Density of seedling and sapling (N_r, plants/ha)	1200	89.9	1040	156.1	0.740
Sapling and pole mean height (h_r, cm)	11.7	84.4	44.7	141.8	0.197
Ecological parameters					
Species richness (S, species)	17.0	–	14.3	–	–
Shannon Index (I_{sh})	2.9	15.0	2.8	22.3	0.741
Pielou evenness (Eq)	0.71	10.1	0.73	19.7	0.182

In the same vegetation type (tree-savannah or woodland), the values of the mean diameter and mean height of *Isoberlinia* trees are higher than the ones related to the whole stand. The *p*-values of the pairwise *t*-test were less than 0.05. The Blackman Index, I_B, computed for these stands was equal to 23.5 and 38.2 for tree-savannah and woodland, respectively, indicating a spatial aggregative distribution of trees in the stands. Table 1 showed also that the species richness was higher in tree-savannah than in woodland. Shannon Diversity index and Pielou's evenness index had almost the same values in the two vegetation types.

3.2. Structure of Isoberlinia stands

The structure of the *Isoberlinia* mixed stands in Wari–Maro Forest Reserve was described through the stem-diameter and tree-height distributions. The diameter distribution of the trees was established for each vegetation type (Fig. 3).

Fig. 3 shows an inverse J-shaped stem diameter structure for the whole stand in tree-savannah as in woodland but the probability of adequacy of the truncated negative exponential distribution (log-linear analysis) in tree-savannah ($p = 0.014$) indicates that the stem diameter structure does not follow this characteristic distribution of mixed stands. *Isoberlinia* trees showed a bell-shaped stem diameter structure for the two stands, with the 20–25 cm DBH class best represented (18.6%) in tree-savannah, whereas in woodland trees of DBH between 15 and 20 cm were the more common. The truncated normal distribution adjusted for the diameter structure in the two stands provided a significant fit (the probability of the log-linear analysis is more than 0.8 for the two stands).

The tree-height distributions established for the *Isoberlinia* species (Fig. 4) showed a bell-shaped structure in the two stands (the probability obtained from the log linear analysis was 0.13 for tree-savannah and 0.46 for woodland). The 13–15 m height class was the best presented in both the tree-savannah (29.5%) and in the woodland (23.5%). However, the trees with height more than 15 m are more common in the woodland (61.8%) than in the tree-savannah (38.8%).

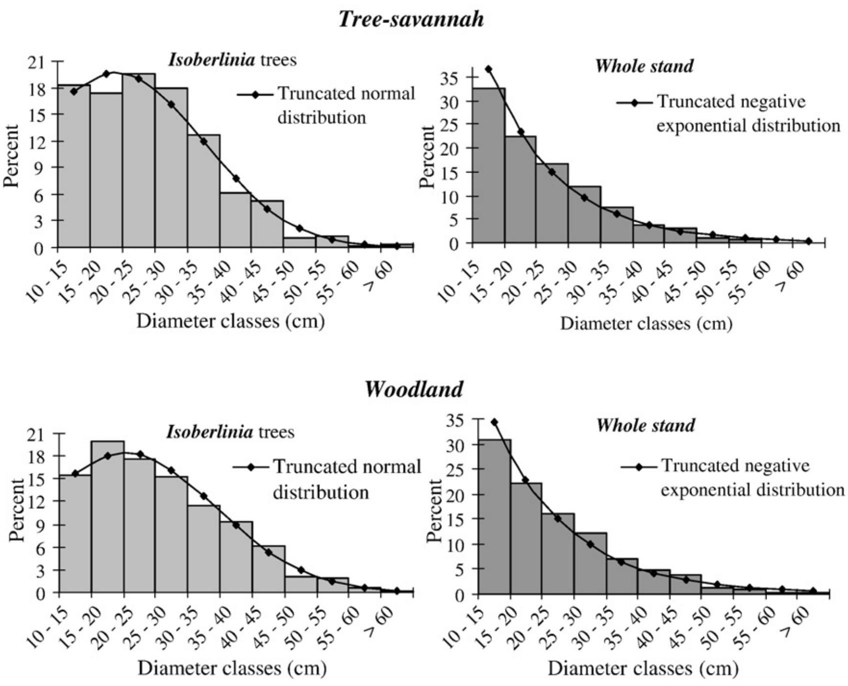

Fig. 3. Stem diameter structure of *Isoberlinia* mixed stands.

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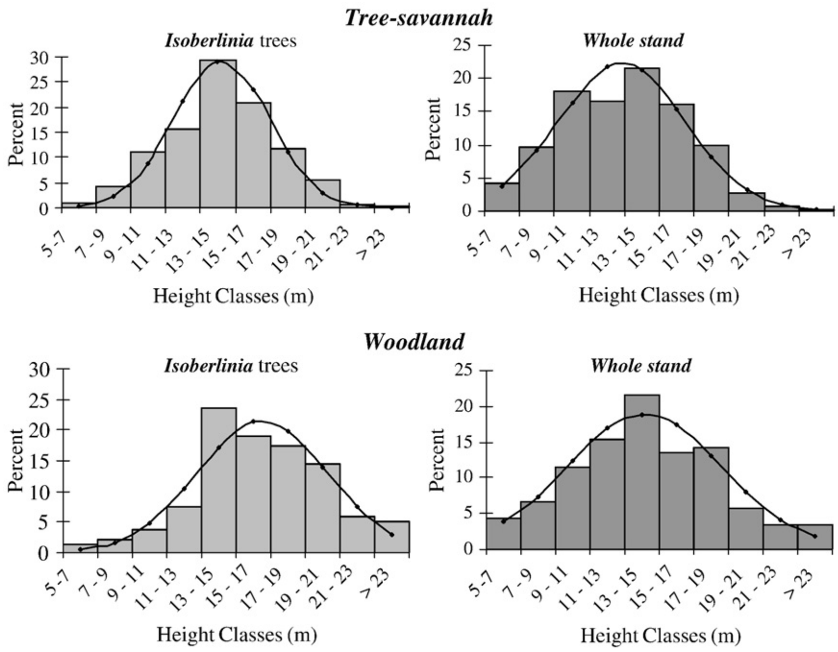

Fig. 4. Tree-height structure of *Isoberlinia* stands in tree-savannah and woodland.

For the whole stand, the tree-height distribution was similar in tree-savannah and woodland. The height class most represented was constituted of trees with 13 to 15 m in height that represented 21.6% of the trees in the two vegetations types. The adjusted truncated normal distribution was statistically acceptable in both cases ($p = 0.95$ and $p = 0.94$).

3.3. Shape of Isoberlinia trees

The shape of *Isoberlinia* trees was described through the height–diameter relationship and stem taper function of the species. The height–diameter relationship allows an estimate of the height of *Isoberlinia* trees from their dbh (Fig. 5).

This relationship has an exponential form and the diameter explains 48.9% of the overall variability of the height.

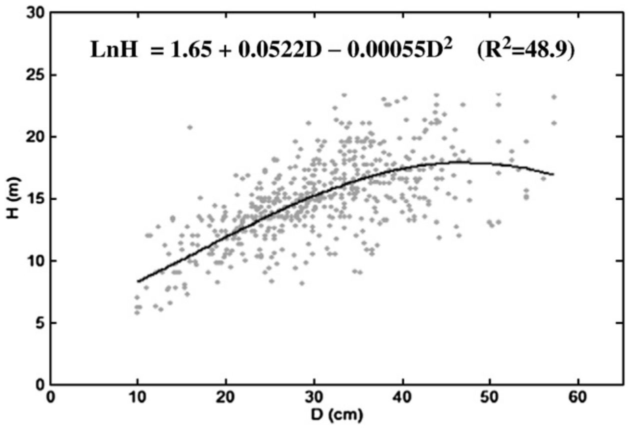

Fig. 5. Height–diameter curve for *Isoberlinia* spp.

As far as the stem taper function was concerned, an adjusted Riniker model (Tarp-Johansen et al., 1997) led to the following function:

$$d_i^2 = 7.44(h - l_i)^{1.97} \quad (R^2 = 85\%)\,. \tag{16}$$

This relationship shows that the diameter of the species decreases on average by 1.9 cm/m. This stem taper function can be used to estimate the volume of any portion of the stem of *Isoberlinia* trees, between two levels h_1 and h_2 using the formula:

$$V(h_1, h_2) = \frac{\pi}{4}\int_{h_1}^{h_2} d^2 dl = \frac{\pi}{4}\int_{h_1}^{h_2} 7.44(h - l)^{1.97} dl \quad (h_1 < h_2). \tag{17}$$

In Eq. (17), $V(h_1, h_2)$ is the volume of the portion of the stem between levels h_1 and h_2.

Table 2
Mean (m in plants/m^2) and coefficient of variation (cv) of the density of *Isoberlinia* seedlings and saplings in various rings around young and matured trees

Natural Stand	Tree	Ring1		Ring2		Ring 3		Ring4	
		m	*cv* (%)	*m*	*cv*(%)	*m*	*cv*(%)	*m*	*cv*(%)
Tree-savannah	Young	1.4_a	148.1	0.7_{ab}	99.7	0.1_b	169.6	0.1_b	107.0
Tree-savannah	Adult	0.2_a	233.5	0.6_{ab}	264.4	0.1_b	100.0	0.1_b	90.3
Woodland	Young	0.5_a	177.1	0.2_{ab}	263.0	0.0_b	263.3	0.0_b	107.6
Woodland	Adult	1.2_a	216.3	0.6_{ab}	232.1	0.2_b	256.7	0.2_b	230.7

For each vegetation type, values with the same letter are not significantly different (Student–Newman–Keuls test).

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3.4. Spatial distribution patterns of Isoberlinia seedlings and saplings

The spatial distribution of *Isoberlinia* seedlings and saplings was described through their mean density in various rings around mother-trees (Table 2). Irrespective of the vegetation type or the diameter class of trees, the mean density of seedlings and saplings decreased when moving away from the trees (from ring 1 to ring 4). For example, the mean density of seedlings and saplings varied from 1.4 plant/m^2 to 0.1 plant/ m^2, from ring 1 to ring 4 for *Isoberlinia* young trees in tree-savannah and 1.2 plant/m^2 to 0.2 plant/m^2 for matured trees in woodland. The analysis of variance gave a probability of 0.001 confirming the significance of the observed differences among rings. The results of Student–Newman–Keuls test showed 3 groups of rings: the ring 1 with the highest seedling and sapling density; the ring 2 with intermediate seedling and sapling density; the rings 3 and 4 with the lowest seedling and sapling density.

We noticed also that in each ring around mother trees, the mean density of seedlings was almost the same in the two vegetation types. The same trend was also observed as far as the two diameter classes of mother trees were concerned.

4. Discussion and conclusion

4.1. Structural features for Isoberlinia dominated stands

A structural analysis of dominated *Isoberlinia* vegetation types has been done in the Wari–Maro Forest Reserve through an inventory in 96 rectangular plots.

In terms of the dendrometric parameters, the study showed that the overall tree-density, the overall height and the mean height of *Isoberlinia* trees of the stands were the discriminant parameters of woodland and tree-savannah. The trees in woodland were on average taller than in tree-savannah. Moreover, *Isoberlinia* trees were on average taller than the other trees of the mixed stands, indicating the dominance of the species in the considered stands. The overall tree-density was higher in tree-savannah than in woodland. The dominance of *Isoberlinia* trees in the stands was also shown by its relatively high basal area contribution (54% and 52%, respectively in tree-savannah and woodland). These values were higher than the 36% obtained in the Ouémé Supérieur Forest Reserve (Sagbo, 2000), but our values for the overall stand density and the density of *Isoberlinia* were lower. However, due to the constant human pressure on trees in forests, the tree-density obtained by Sagbo (2000) must be updated. Moreover, the values of the Blackman Index (I_B) obtained in this study was quite high (23.5 and 38.2 in tree-savannah and woodland, respectively) confirming the gregarious nature of the *Isoberlinia* species. These values were higher than those recorded for other gregarious species such as the *Vittelaria paradoxa* ($I_B = 5$; Gnanglè, 2005). But it is useful to note that, according to Dajoz (1975), the gregarious distribution is explained not only by the nature of the species (especially the dispersal mode) but also by the heterogeneity of the substrate. Mama and Adeniyi (2005) recorded a mean diameter of 19.9 cm for *Isoberlinia* trees in the savannah stands of the centre of Benin. This value is lower than the one obtained here and could be due to the inventory design and the place where the inventory has been done. Table 1 showed that the bark factor was not affected by the vegetation type (tree-savannah or woodland). The overall bark factor was 0.91 indicating, according to Husch et al. (1982) that the part of the bark volume in the volume of *Isoberlinia* log was equal to $1-k^2$, i.e. 17.2%. The established stem taper function helps to deduce that the *Isoberlinia* tree diameter declines on average 1.9 cm per meter up the tree.

With regards to the ecological parameters, the species richness and the Shannon Diversity Index were lower compared to the respective values of 47 and 3.92 recorded by Mama and Adeniyi (2005). The equal value of the Pielou Evenness index recorded in woodland and tree-savannah despite the large difference observed in their species richness could be viewed as the similar distribution of the species in the two vegetation types. It is known that a low value of Pielou Evenness index implies the dominance of at least, one species in the stand (Dajoz, 1975). So, the high value obtained for Pielou evenness in the study showed that the dominance of *Isoberlinia* trees was not in terms of species frequency but in terms of stand density and mean height.

The stem diameter structure established for *Isoberlinia* stands seems to indicate that human pressure does not negatively affect the structure of the stands. But this structure did not take into account small trees (less than 10 cm of dbh). The density of seedlings and saplings was around 1000 per hectare in the stands, but with a high coefficient of variation. Their average height seems to be higher in woodland than in tree-savannah probably due to the more important competition for light in woodland where the density of trees was significantly the highest (compared with the one related to tree-savannah). The density of the *Isoberlinia* seedlings and saplings around the mature trees showed that regeneration was more abundant below the trees and confirmed the fact that the main dispersal mode of the species is dropping the seeds from pods under the mother tree and suckering that encourage the aggregated distribution (Bationo et al., 2005).

4.2. Defining management strategies for Isoberlinia stands

In Benin, no relevant conservation strategies have been defined for *Isoberlinia* species. Apparently, the structure and spatial distribution patterns of *Isoberlinia* in Wari–Maro Forest Reserve (Northern Benin) showed regular distribution patterns, in woodland and tree-savannah, indicating low pressure on the species *in situ*. The scarcity in the stands of an optimum density of sexually mature individuals (sexually mature diameter trees) would accordingly be a weakness for the regeneration of the populations. For *Isoberlinia* species, one important action should be to limit human disturbance by restricting access into forests sites. Larger scale and longer term control might have a stronger effect on the species conservation success but this involves substantial additional material and financial resources. Limiting forest fragmentation may efficiently benefit the species conservation, while maintaining an open structure to the forests will favour ground vegetation and disturbance. Our results suggest that

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effective conservation will require several simultaneous actions, aimed at decreasing matured trees logging and increasing recruitment through enhancing habitat suitability. Besides limiting human perturbations, an appropriate silvicultural strategy should improve the quality and surface of present patches, independent of their size and localization. Forest structure and composition can also be improved through assisted regeneration of the species.

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