Biodiversity and Conservation **13:** 1555–1570, 2004.

Dendrometric characteristics as indicators of pressure of *Afzelia africana* Sm. dynamic changes in trees found in different climatic zones of Benin

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Received 5 November 2002; accepted in revised form 2 June 2003

Key words: *Afzelia africana*, Benin, Regeneration, Threats, Tree size

Abstract. *Afzelia africana* is a forest species used by local inhabitants for various purposes, especially as forage to feed cattle, as medicinal plant and its wood is used to make furniture or for cooking. Its utilisation in its current form constitutes a threat to this species. However, the lack of data on this species is a hindrance towards drawing up an efficient program for its sustainable management. In order to fill in some gaps in the knowledge of *A. africana* tree populations, dendrometric characteristics of this species were studied within different climatic zones where it occurs in Benin. Data collected on each of them included height and diameter, and with regard to the levels of pressure, five categories were defined namely: null, weak, moderate, severe and very severe. As far as diameter is concerned every size was taken into consideration in all the climatic zones. However, average diameter and height of the *A. africana* individuals varied significantly according to climatic zones. Anthropogenic pressure increased while moving from the humid zone towards the drier zone. Moreover, there was a noticeable significant change in the level and quality of pressure between trees found in the different climatic zones in the sense that the lower the height of the trees, the more severe the level of pressure exerted. Such a relationship was not significant when one considers tree diameter in accordance with the climatic zones in the country.

Introduction

Located in the low rainfall dry corridor named 'Dahomey Gap', Benin does not have as much forest zone as its neighbouring countries of the coastal zone of West Africa such as Côte d'Ivoire, Ghana and Nigeria. Its natural forest covers 2 538 000 ha (FAO 2001), which represents 23% of the total surface area of the country. This low forest surface of the country is due to increased demographic pressure with the subsequent high exploitation of *Afzelia africana*, a savannah tree species, by the local population for various purposes, specifically for feeding cattle (Sinsin 1993; Onana 1998), for traditional medicine (Kerharo and Adam 1974; Adjanohoun et al. 1989; Ahouangonou and Bris 1997) and for timber (Ahouangonou and Bris 1997; Bayer and Waters-Bayer 1999). Uncontrolled use of the species leads to degradation and reduction of its habitat and its population in the country. It is therefore urgent to gather data on endangered species, such as *A. africana*, with a view to assess its conservation status and also to develop effective conservation strategies.

Size class distributions have been used to understand the tree population dynamics (Cunningham 2001). They are considered to be a very useful predictive tool (Geldenhuys 1992). This tool could be used to evaluate the impact of man's activities on trees' population (Cunningham 2001). However, several other factors could affect the shape and the size of categories of distribution of a species (Van Wyk et al. 1996; Sokpon and Biaou 2002).

The major aim of this study is to determine the level of pressure on *A. africana* populations as a result of harvesting and utilisation of its leaves and small branches for fodder purposes. Dendrometric parameters were therefore collected, processed and analysed. This paper highlights the salient results of the study.

Study sites and studied species

Study sites

The study was conducted in the three bioclimatic zones of the Republic of Benin (112 622 km^2), located between 6°20′ and 12°25′ N and 1° and 3°40′ E in West Africa. These zones are: the sub-humid Guineo-Congolean affinity zone (from 6°25 to 7°30′ N), the Sudano-Guinean zone (from 7°30′ to 9°30′ N) and the Sudanian zone (from 9°30′ to 12°′ N) (White 1983). The stations surveyed in each of these climatic zones are indicated in Figure 1.

The rainfall regime is bimodal in the Guineo-Congolean zone (from April to June and from September to November) with a mean annual rainfall of 1200 mm. Beyond 8° N and towards the north, rainfall distribution becomes unimodal (May–October) with a mean annual rainfall above 900 mm.

The Guineo-Congolean zone has ferrallitic soils, deep and hardly fertile (700 000 ha), alluvial soils and heavy clay soils (360 000 ha) localised in the valleys of the Mono, Niger, Couffo and Oueme rivers, and in the Lama depression. These soils are rich in clay, humus and inorganic elements. The quality of the country's vegetation has suffered severe impoverishment as a result of various intense economic and human activities, specifically in the southern region, where human population density is high. In the southern zone, vegetation is composed of fallows and small forest patches of less than 5 ha. The original vegetation at its early stages was made up of semi-deciduous dense forests and Guinean savannah (Adjanohoun et al. 1989).

In the Sudanian and the Sudano-Guinean zones, there are infertile mineral soils (1 500 000 ha) and ferruginous soils (8 600 000 ha). The Sudano-Guinean transition zone is characterised by mosaics of woodlands, dry dense forests, strewn with tree and shrub savannahs and gallery forests. The vegetation of the Sudanian zone consists of savannas and gallery forests with small trees and shrubs slightly

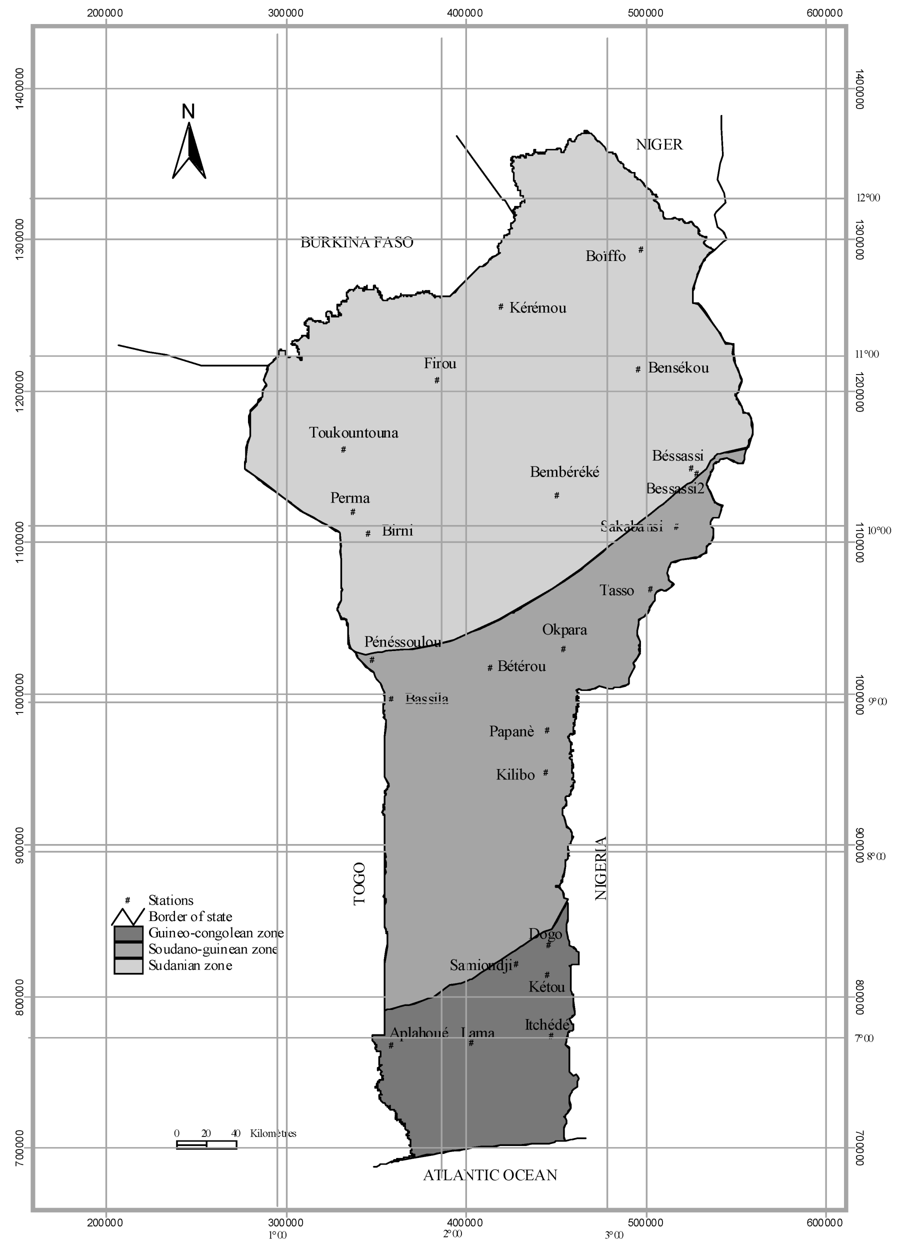

Figure 1. Stations surveyed.

covering the ground. The main activities of local communities are extensive agriculture, animal husbandry, and reckless exploitation of woodlands and gallery forests.

Studied species

A. africana is a timber species with high potentials for fodder and medicine. In the agro-pastoral zone of the country, the leaves are considered as important forage for cattle during the dry season. The branches are pruned by the Fulanis to feed their animals. The powdered bark of *A. africana* mixed with salt was reported to have improved cattle intake. *A. africana* is used for curing several diseases such as oedemas, intercostal neuralgias, convulsions, staturo-ponderal backwardness, and so forth. The powdered bark is used as a febrifuge and gastro-intestinal stimulant. When this powder is mixed with *Morinda lucida*, it is used as an antiseptic for wounds. The decoction of the roots of *A. africana* is used to cure blennorrhoea, stomach ache and hernias.

The timber of this species is one of the best sold in the open markets all over the country. Because of various usages, *A. africana* is currently under severe human pressure.

Methods

Six stations were selected in the Guineo-Congolean zone, nine stations in the Sudano-Guinean zone and 12 stations in the Sudanian zone. Observations and measurements were carried out in these stations, both in protected areas (national parks and reserve forests) and state ranch and village zones (free zones). In each station, one or two rectangular sample plots of $1000\,m^2$ were established and considered as a centre of the plot, the first individual of *A. africana* randomly selected. A total of 669 individuals of *A. africana* were measured: 160 individuals in the Guineo-Congolean zone, 198 individuals in the Sudano-Guinean zone and 311 individuals in the Sudanian zone. The parameters recorded in each plot were as follows:

- The diameter and height of all individuals, with dbh (diameter at breast height) above 10 cm;
- The proportion of branches cut or mutilated and the total number of branches for each individual of *A. africana*, were considered and analysed in accordance with the following five levels of pressure:

  P0 = null: individuals without damage (without branch neither cut nor mutilated trunk),
  P1 = weak: individuals with 0–25% of their crown pruned,
  P2 = average: individuals with 25–50% of their crown pruned,
  P3 = severe: individuals with 50–75% of their crown pruned,
  P4 = very severe: individuals with 75–100% of their crown pruned.

- The causes of mutilations on trees were identified.

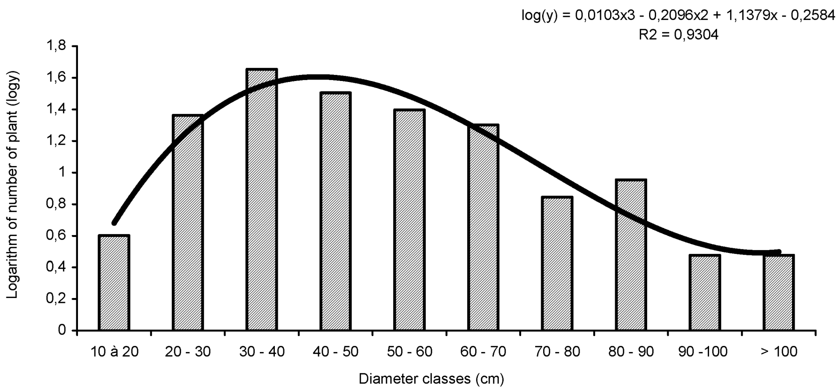

Figure 2. Diameter size-class distribution for *A. africana* in the Guineo-Congolean zone.

Data analysis consisted of analysing variations in the diameters and heights of individuals according to climatic zones. The Newman and Keuls test of comparison was used to compare tree diameter and height among the different climatic zones. In addition, factorial analysis was carried out to identify the localities with similar levels of pressure. While taking into consideration data adjustment models such as the test of normality, of homogeneity and the independence of regression residues, the transformation of variables was utilised to measure the height and diameter distributions of individual trees. For each transformation process, three tests were therefore undertaken, namely: the test of normality, the test of independence of residual variance and the decline residual independence test of Breush-Pagan.

In addition, the impact of climatic and anthropic pressure on tree height within each climatic zone was evaluated by studying the trees' height-class distribution. The distribution was undertaken according to height size categories among individuals without pressure (P0) and those with moderate pressure (P1 and P2), to the ones with severe pressures (P3 and P4) as well.

Results

Tree diameter (dbh) variations according to climatic zones

Diameter class-size distribution

Diameter class-size distribution for *A. africana* was not significantly different according to climatic zones (Figures 2–4). A bell-shaped distribution type was observed for each climatic zone. The two extreme class-size individuals are absent in the three zones. The slight differences in the distribution noticed are the logarithmic function in the Guineo-Congolean zone ($\log(y) = 0.0103x^3 - 0.2096x^2 + 1.1379x - 0.2584$) while it is a polynomial function in the Sudano-Guinean zones ($y = -0.0456x^5 + 1.2012x^4 - 10.912x^3 + 38.203x^2 - 36.821x + 17.267$) where individuals with a diameter between 20 and 60 cm are most predominantly

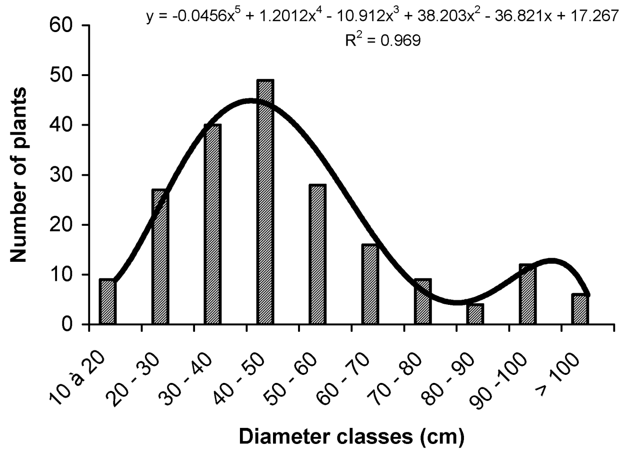

Figure 3. Diameter size-class distribution for *A. africana* in the Sudano-Guinean zone.

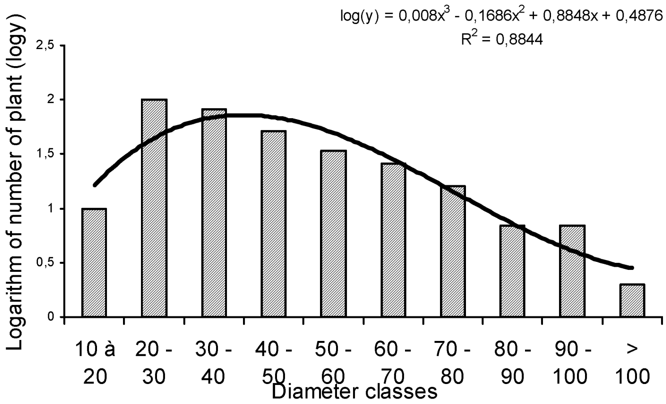

Figure 4. Diameter size-class distribution for *A. africana* in the Sudanian zone.

represented in the stands. The small diameters are less represented at the sites. However, the diameter distribution showed a second peak with low amplitude in the upper diameter categories (Figure 3).

In the Sudanian zone (Figure 4), the diameter size-class distribution matches a logarithmic function ($\log(y) = 0.008x^3 - 0.1686x^2 + 0.8848x + 0.4876$). This pattern reveals constant reduction in the number of *A. africana* individuals from the lower diameter categories to the upper diameter categories.

The mean diameter

The mean diameter for *A. africana* trees varies significantly from 42 cm in the Sudanian zone to 48 cm in the Sudano-Guinean zone ($p < 0.05$). The test of Newman–Keuls classifies the different climatic zones into two homogeneous

Table 1. Bioclimatic zones classifications based on diameter of *A. africana* trees.

Climatic zone	Mean diameter[a] (cm)	Number of individuals measured
Sudano-Guinean zone	48 A	198
Guineo-Congolean zone	47 A	160
Sudanian zone	42 B	311

[a]There is no significant difference between mean diameters followed by the same letter.

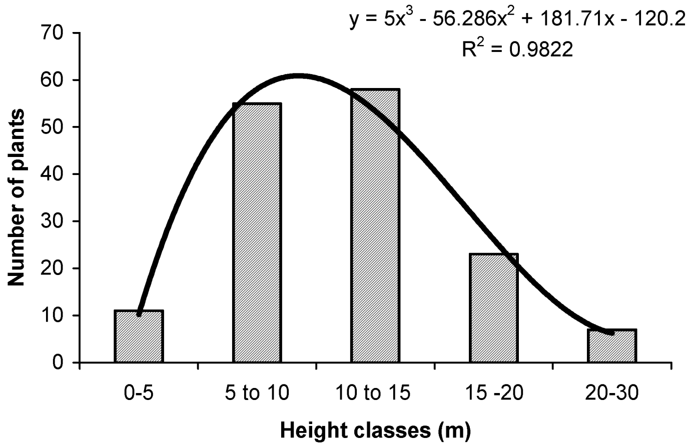

Figure 5. Height size-class distribution for *A. africana* in the Guineo-Congolean zone.

groups when considering the mean diameter (Table 1). The Guineo-Congolean and Sudano-Guinean groups are separated from the Sudanian one.

Tree height variations according to climatic zones

The height class distribution

The height class distribution for *A. africana* varied in accordance with specified climatic zones (Figures 5–7). It was roughly a bell-shaped curve in the Guineo- Congolean zone and fitted to an increasing polynomial function ($y = 5x^3 - 56.286x^2 + 181.71x - 120.2$). The median height class size varies from 12.5 to 17.5 m. In the Sudano-Guinean zone, the distribution was truncated in the low height categories and fitted a logarithmic function ($\log(y) = -0.4289x^2 + 1.2616x + 1.1167$; $R^2 = 1$). The height size-class distribution in the Sudanian zone was different from the other zones and fitted a reverse function ($1/y = 0.0351x^2 - 0.1455x + 0.1514$; $R^2 = 0.8304$).

But in the three zones, individual trees with up to 30 m height were observed.

The mean height

This study shows that in Benin, the mean height of *A. africana* varies from 9 m in the Sudanian zone to 13 m in the Guineo-Congolean zone. With regard to the

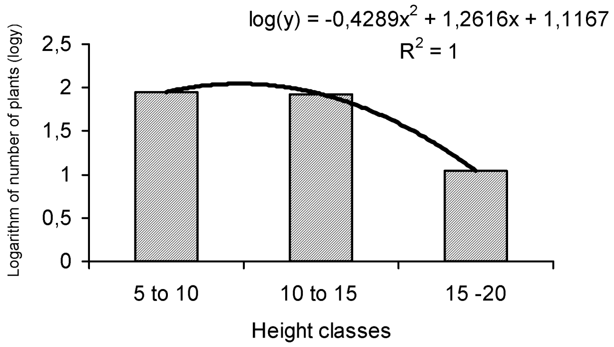

Figure 6. Height size-class distribution for *A. africana* in the Sudano-Guinean zone.

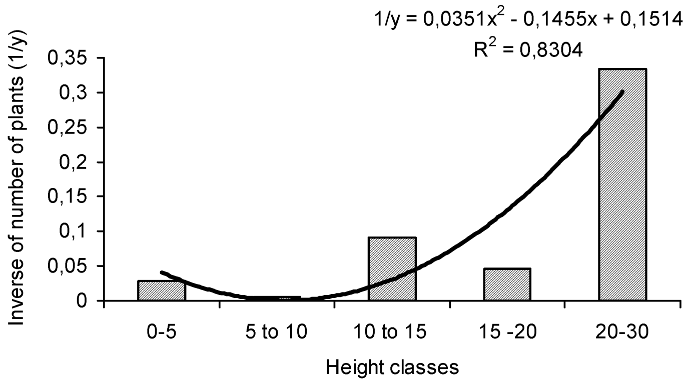

Figure 7. Height size-class distribution for *A. africana* in the Sudanian zone.

Table 2. Mean heights comparison for *A. africana* between the climatic zones.

Climatic zone	Mean heights[a] (m)	Number of individuals measured
Guineo-Congolean zone	13 A	160
Sudano-Guinean zone	10 B	198
Sudanian zone	9 C	311

[a]The letters A, B and C indicate significant differences between the three zones with respect to height ($p < 0.05$).

stations, the lowest mean height is observed in Penessoulou (4 m) located in the Sudanian zone while the highest is observed in the reserve forest of Lama (17 m) located in the Guineo-Congolean zone.

Analysis of variations of the mean heights of *A. africana* trees (Table 2) showed a significant difference from one climatic zone to another ($p < 0.05$). The mean height decreases progressively from the humid (Guineo-Congolean) to the driest

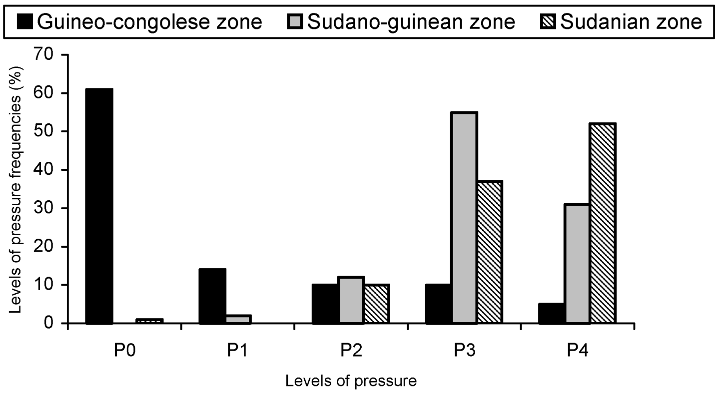

Figure 8. Frequencies of level of pressure in the different climatic zones. The figures P0–P4 indicate the different levels of pressure (P0 = null, P1 = weak, P2 = average, P3 = severe, P4 = very severe).

zones (Sudanian). In fact, the tallest individual trees were found in the Guineo-Congolean zone (e.g. in the Lama Forest Reserve (17 m) and in Pobè (16 m)). While in Penessoulou, Sudano-Guinean zone and in Segbana, Sudanian zone, individual trees observed measured 4.20 and 5.25 m, respectively.

Levels of pressure on A. africana in the climatic zones

The levels of pressure varied according to climatic zones (Figure 8). Pressure was low in the Guineo-Congolean zone and gradually increased when moving towards the Sudanian zone. The highest frequencies of the pressure levels P3 (severe pressure) and P4 (very severe) were recorded in the Sudano-Guinean and Sudanian zones. On the contrary, in the Guineo-Congolean zone, the highest frequencies were recorded for the levels of pressure null (P0) and low (P1). The Sudano-Guinean zone presented an intermediate situation. Indeed, in the Guineo-Congolean zone, more than 60% of the trees measured were neither pruned nor debarked. Almost all the trees of *A. africana* recorded in the Sudanian and Sudano-Guinean zones were mutilated. The Sudano-Guinean zone has the highest frequencies of severe pressure on trees (55% against 52% in the Sudanian zone).

Influence of pressure on tree heights

Figures 9 and 10 compare the tree heights with and without pressures in the Guineo-Congolean zone. The impact of the pressure is both on the number of individuals and on the height, where the height size class 20–30 m disappears with very severe pressures. For the Sudano-Guinean zone the 10–15 m height size class no longer exists under very severe pressure conditions (Figures 11 and 12). In the

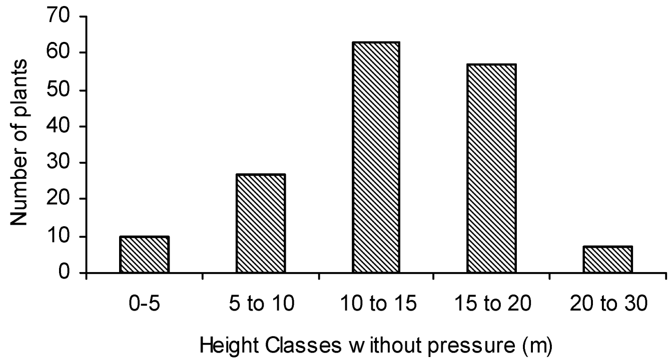

Figure 9. Height size-class distribution for *A. africana* in the Guineo-Congolian zone without pressure (P0).

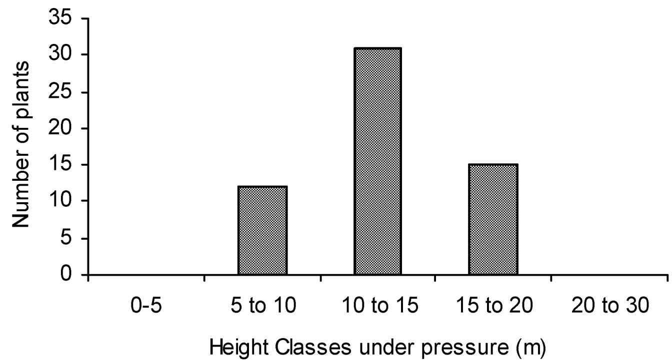

Figure 10. Height size-class distribution for *A. africana* in the Guineo-Congolian zone with pressure (P1–P4).

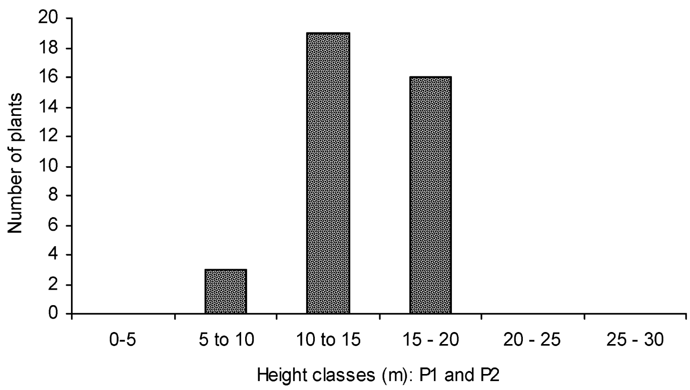

Figure 11. Height size-class distribution for *A. africana* under weak and average pressure in the Sudano-Guinean zone (P1 and P2).

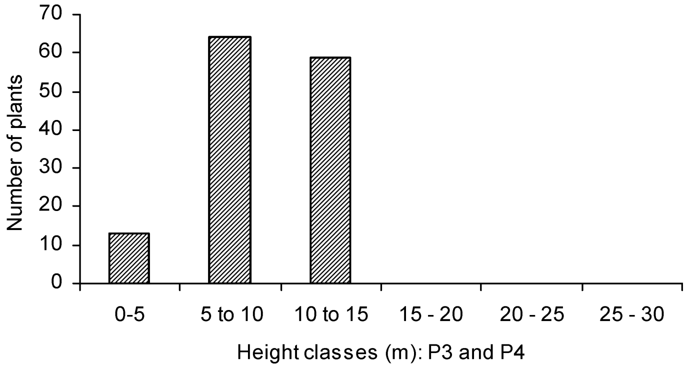

Figure 12. Height size-class distribution for *A. africana* under severe pressure in the Sudano-Guinean zone (P3 and P4).

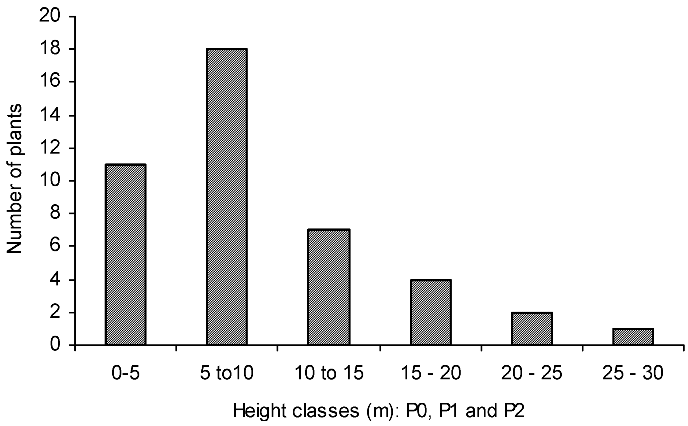

Figure 13. Height size-class distribution for *A. africana* under null and average pressure (P0, P1 and P2) in the Sudanian zone.

Sudanian zone, with minimum pressure (P0–P2), a good distribution of heights from 5 to 30 m is observed but there are no more individuals of height size class 20–25 m under severe pressure (Figures 13 and 14). The number of individuals per height size class is relatively low. Within the parameters ranging from severe to very severe pressures, the maximum heights observed are 15 m. But the number of individuals is higher than under low pressure conditions.

In conclusion, in virtually all the climatic zones, various pressures influence the growth of *A. africana*.

The factorial analysis (Figure 15) of the matrix crossing the 25 surveyed stations, coupled with the different levels of pressure (P0–P4), identified three homogeneous groups of stations according to their levels of pressure.

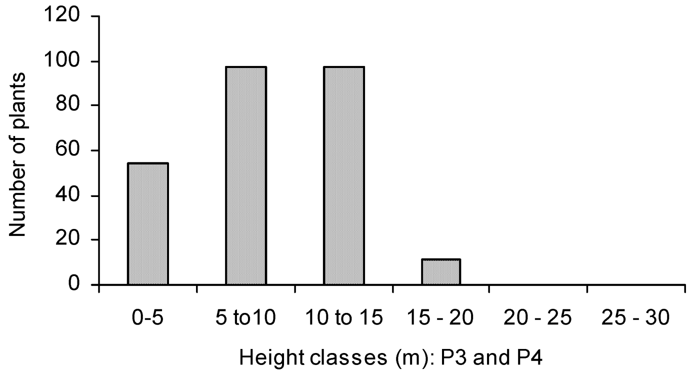

Figure 14. Height size-class distribution for *A. africana* under severe pressure (P3 and P4) in the Sudanian zone.

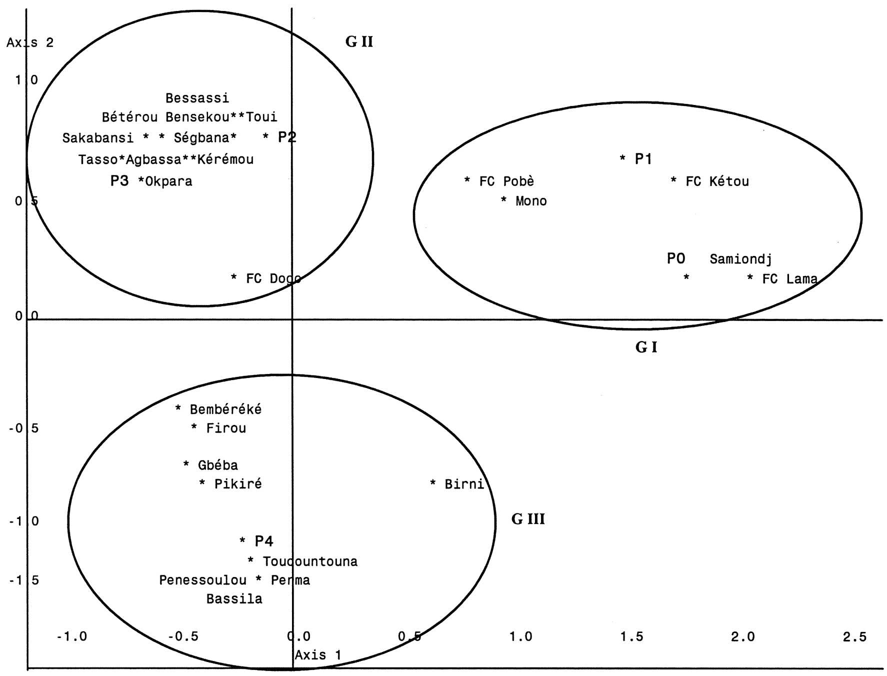

Figure 15. Factorial analysis for the level of pressure and the localities surveyed. The figures P0–P4 indicate the different levels of pressure (P0 = null, P1 = weak, P2 = average, P3 = severe, P4 = very severe).

Group I (GI), including the reserve forests of Lama, Ketou and Pobe, the ranch of Samiondji and forest patches at Lonkly and Azovè in Kouffo province, is mainly composed of the stations located in the Guineo-Congolean zone. It is well correlated with the lowest levels of pressure (P0 and P1) (Figure 8). It regroups stations where *A. africana* trees were undergoing relatively low pressure. Indeed, in these stations, 66% of the individuals recorded were intact and less than 10% of individuals were subjected to severe or very severe pressures.

Group II (GII) is composed of the following stations: Tasso, Sakabansi, Keremou, Okpara, Beterou, Segbana, Bensékou, Agbassa, Dogo, Toui and Bessassi. In these clustered stations important pressures occurred with regard to mutilations on the branches of *A. africana*. This group was correlated with the average (P2) and severe (P3) levels of pressure (Figure 8). Intact individuals in these stations were absent or rare.

Group III (GIII) comprises the stations Bassila, Penessoulou, Perma, Bembereke, Firou, Gbeba, Pikire, Birni and Toucountouna. In these stations individual trees were under very severe level of pressure (P4), and intact trees (P0) were rare.

The stations in groups II and III are generally characterized by a high mutilation pressure on *A. africana* and are located in the Sudanian or Sudano-Guinean zones. Group II encompasses not only several stations of the Sudano-Guinean zone such as Okpara, Toui, Beterou and Agbassa, but also stations from the Sudanian zone, including Keremou, Segbana, Sakabansi and Bensekou.

Discussion

The tree diameter and height size-class variations according to climatic zones

It was noticed in general that most of the diameter shape categories are represented within each climatic zone. This could be explained by the presence of protected areas within each surveyed zone. In protected areas, the pressure on *A. africana* is low. In all climatic zones, there was a high concentration of individuals in the diameter classes ranging from 20 to 50 cm. This low amplitude reveals the existing pressure on the individuals of the other diameter classes. These pressures are mainly due to the commercial logging of individuals with diameters above 50 cm, followed by the high foliage pruning and the de-barking of trees for traditional medicine purposes. These pressures were accentuated in the Sudanian zone, which is the main transhumance zone at country level, and where illegal and uncontrolled logging activities of high diameter trees were observed.

In general, trees are shorter in the Sudano-Guinean zone where most of the trees are within a narrow range of class height (5–20 m). In the Guineo-Congolean zone, greater tree heights such as 17–28 m in Lama reserve forest (6°55′ N), and 15–20 m at Pobè station (7° N) were recorded. This fast growth could be explained *inter alias*, on one hand, by the protected area status of these stations where *Afzelia* trees are protected from pruning; and on the other hand by the more favourable rainfall regime occurring in these areas situated in the Guineo-Congolean climatic zone where bush fire is rare in forest patches.

Several authors (Paradis and Houngnon 1997; Cunningham 2001; Sokpon and Biaou 2002) have used the diameter size-class distribution as a field method to assess the impact of harvest practices on the regeneration of the species. It is also a valid tool for assessing the pressure undergone by a tree species population. However, it is important to take into consideration the species temperament and the development stage of the population when analysing its diameter or height size-class distribution.

It was observed in this study that in the three climatic zones, the species has a bell-shaped curve for its diameter size-class distribution. The same distribution was observed by Paradis and Houngnon (1997) in Lama Reserve, Benin. This distribution was also found by Sokpon and Biaou (2002) in another forest reserve in Benin (Bassila reserve forest). According to Cunningham (2001), the bell-shaped curve indicates either light required or competition-intolerant species or low numbers of seeds due to an unusual reproductive strategy. But *A. africana* is known as a shade-intolerant species. According to Sokpon and Biaou (2002), its diameter size-class distribution indicates the absence of young trees with less than 20 cm diameter and also difficulty for its recruitment in a heavy clayed-soil forest such as the Lama Reserve. The absence of individuals with larger diameters mainly in the Sudanian zone could be explained by logging activities where the trees are facing very severe pressure, which can lead to the extinction of the population of the species. Indeed, the big trees are the best seed-bearers of the population, which ensures the production of seeds and thus supports the regeneration of the species. The scarcity in the stands of an optimum density of sexually mature individuals (sexually mature diameter trees) will accordingly be a weakness for the regeneration of the population.

Impact of pressure on the tree height and diameter within climatic zones

The comparison made for the tree heights in the same climatic zone, such as the Guineo-Congolean zone without pressure (Figure 9) and under pressure (Figure 10), shows that the height class size 20–30 m is no longer represented within the areas under pressure. The species height varies from 4.20 m (Penessoulou) in the Sudanian zone to 17.20 m (Lama Reserve) in the Guineo-Congolean zones. This trend is in accordance with the data collected (8–10 m) in savannah by Ahouangonou (1997) on the same species. Kerharo and Adam (1974) indicated that the species could grow up to 25–30 m under favourable conditions while it is short and stocky in Senegal (dry zone). This means that climatic conditions influence the species growth (the height of the species). Climatic conditions are not the single factor that influences the height of the species, as the study shows individual trees with up to 30 m height within the three climatic zones. This study also demonstrated the reduction in the same climatic zone of tree population heights in severe and very severe pressure conditions. Pressure (pruning, debarking, etc.) influences, amongst others, the growth of *A. africana*.

Repeated tree crown pruning observed between 8° N and 12° N, in a region after bush fires during the dry season, is the main cause of the pressures on *A. africana*. This pruning practice reduces the growth of the tree. Bayer and Water-Bayer (1999) note that pruning and coppicing strongly influence the quantity of leaves proportionate to the branches and in accordance with the growth of trees. The species is also used in traditional medicine and as timber species. Onana (1998) observed in the northern part of Cameroon that this practice of regular pruning and coppicing performed by herdsmen, the frequent bush fires and the regular browsing of the seedlings, already jeopardise many populations of *A. africana* in the Sudano-Sahelian zone. This is the reason why FAO has also selected this species for a conservation programme in Cameroon (Palmberg 1987). In Benin, no relevant conservation strategies have been put in place for this tree species that is under increasing severe pressures. Its conservation becomes more than ever urgent.

Conclusions

The size-class distribution and the average values of *A. africana* tree height and diameter allowed the assessment of the level of pressure affecting the populations of this species within the different climatic zones of Benin. The height and the diameter of the species varied significantly from one climatic zone to another. The lowest diameter was observed within the latitudes ranging from 8° N to 12° N. This area includes the localities where *A. africana* is facing very strong pressure. On the contrary, the big individuals of *A. africana* were recorded in the Guineo-Congolean zone (extending from 6°25′ N to 7°30′ N) with recorded lowest pressures. In certain ecosystems such as the reserve forest of Lama, which are well-protected areas, are found very good individuals of *A. africana* because of the absence of the various forms of human pressure.

In situ conservation measures of the species should be taken in areas where the species is facing low pressures. In addition, measures focussing on the enrichment of the impoverished forests with the species should be one of the major concerns of Benin forest managers. Silvicultural techniques successfully experimented on the species in other African countries could be adapted to Benin conditions, as was the case for *Tectona grandis* (teak).

Acknowledgements

This work was completed with the financial support of the United Nations Environment Programme (UNEP) provided by the Sub Saharan African Forest Genetic Resources Programme (SAFORGEN) of the International Plant Genetic Resources Institute (IPGRI). We would like to thank these institutions.

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