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# Vegetation structure and tree diversity in habitats exploited by elephants in Benin (West Africa)

**Amahowé I.O.[1], Djossa A.B.[2,3], Adomou A.C.[4], Kabré A.T[5]. & Sinsin B.[3]**
[1]Université Polytechnique de Bobo-Dioulasso, 01 B.P. 1091 Bobo-Dioulasso 01 Faso ;
[2] Ecole Nationale Supérieure des Sciences et Techniques Agronomiques de Kétou &
[3]Laboratoire d'Ecologie Appliquée de la Faculté des Sciences Agronomiques,
[4]Département de Biologie Végétale, Faculté des Sciences et Techniques Université d'Abomey-Calavi, BP 526 Cotonou, Bénin.
[5]Université de Ouagadougou, 03 B.P. 7021 Ouagadougou, Burkina Faso

Corresponding author email: adomou@gmail.com, or adomouaristide@yahoo.fr
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## ABSTRACT

*Objectives*: This study aims to 1) assess the woody vegetation structure and plant diversity in the area used by elephants for several years and 2) the effect of selected environmental variables (palatable woody density, distance to water ponds and to paths, vegetation and the soil types) on the pattern of the damages created by elephants in habitats they utilized.

*Methodology and Results*: We used 100 plots of 30 m radius laid out in area used by elephants to assessed diameter and height class distribution within each vegetation type, and characterized phytodiversity using species richness, Shannon-Weaver index, and Smith and Wilson's evenness. We searched for environmental variables to better explain the pattern of damaged tree. We reported an overall stability state of the vegetation. Disturbances affected recruitment in higher height class. The diversity values are low indicating the insignificant effect of elephant on the phytodiversity. Attraction of elephant to woody vegetation may depend mainly on the availability of woody plant they feed on.

*Conclusions and application of findings*: These results highlight the interactions between elephants and vegetation and the main factors that drive their damaging behaviour towards tree species. They should guide park managers in making suitable habitat in terms of space and food for wildlife using preferred plant species to enrich and assist recruitment in gaps and degraded areas in natural habitats.

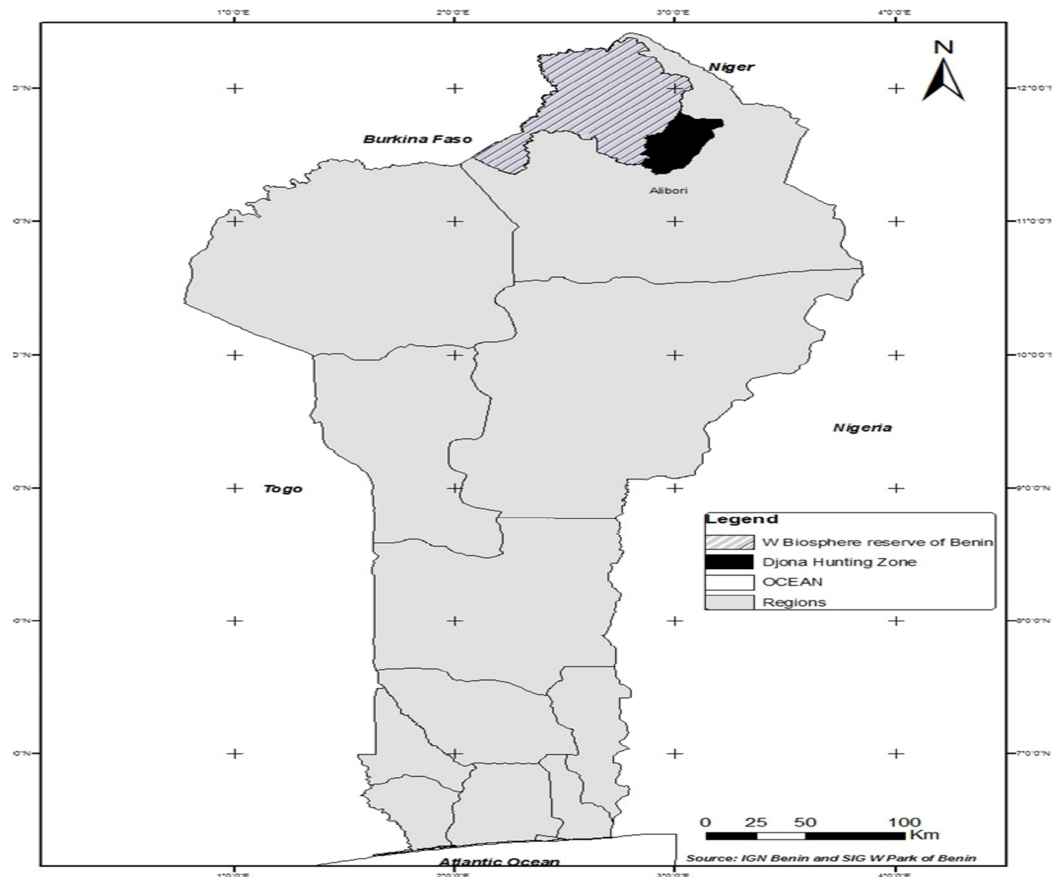
## INTRODUCTION

Disturbance by herbivores occurs in most of the natural ecosystems and plays a vital role in determining species richness and the structure of plant and animal communities (Moloney and Levin, 1996; Olofsson *et al.*, 2001; Grellmann 2002). Profound disturbances can reduce plant diversity, alter vegetation structure and eliminate animal species (Petraitis *et al.*, 1989; Pickett and White, 1985). Most opinions emphasize on the contribution of elephants to adult tree destruction and to natural habitat changes. The interactions between elephant and vegetation have often been studied in a broad context (Cumming, 1997; Osborn, 2002). Most of these studies were carried out in Eastern and Southern Africa and showed that the physiognomy and species composition of African savannah was highly determined by elephant (Barnes *et al.*, 1994; Osborn, 2002;

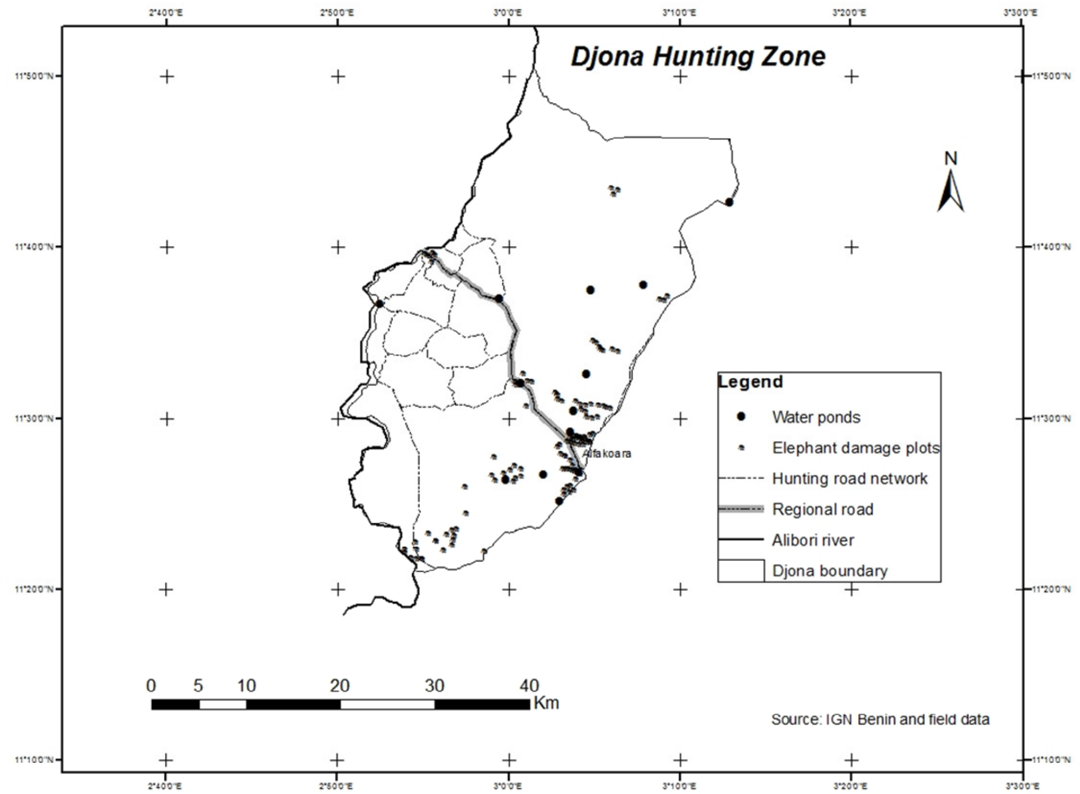
Loarie *et al.*, 2009). In West Africa, the size of suitable habitats for elephant is dramatically declining due to human activities (habitat fragmentation). Nevertheless, there is noticeable engagement of West African wildlife managers to assess these threats and to take action towards conserving elephant species for future generations (CMS, 2011). Elephant studies in West Africa were occasional and almost only focused on population dynamics. The last global census in the sub-region has shown that more than 50% of West African elephant was attached to the complex W-Arly-Pendjari (WAP) parks (Blanc *et al.*, 2004). Within the WAP protected areas, the Djona Hunting Zone related to the W Biosphere Reserve (Bénin side) is recognized to concentrate a large population of elephants in the WAP. Despite this abundance of elephants in the Djona Hunting Zone, there is little scientific information on the influence of these animals on the vegetation structure and floristic diversity. This study aims to 1) assess the woody vegetation structure and plant diversity in this area used by elephant for several years and 2) assess the effect of selected environmental variables (palatable woody density, distance to water ponds and to paths, vegetation and the soil types) on the pattern of the damages created by elephants in habitats they utilized.

## MATERIAL AND METHODS

**Study area:** The Djona Hunting Zone (DHZ) (115200 ha) is located in the north of Bénin in the department of Alibori (Dauzan, 1991; Burini, 2004). It belongs to the W Biosphere Reserve of Benin between the latitudes 11°20'-11°60'N and longitudes 2°50'-3°20'E (ECOPAS, 2005).).




(a)




(b)

**Figure 1**: Location of the Djona Hunting Zone in Bénin (a)(West Africa) and the vegetation sampling plots within the DHZ (b)

The mean annual rainfall (from 1980 to 2009) in this region is 968.4 ± 148.2 mm. The rainfall regime is unimodal with one rainy from May to October and the second a dry season from November to April. The elephant distribution shows a seasonal pattern that goes with the damage on the woody vegetation within the study area. The annual mean temperature for the same period was 33.5°C for maxima and 21.75°C for the minima. The geomorphology of the DHZ is crystalline plateau (Tehou and Sinsin, 2000

The soils of the study site are ferruginous and leached on crystalline rocks. The Alibori River is the only one important watercourse in this area receiving water from its tributaries. In addition, there are few water ponds scattered within the protected area that all together provide drinking water to the wildlife; as major source of drinking water in the area, it attracts the livestock coming from the villages around DHZ. Thus, competition occurs on foraging resources between wild animals and livestock (Francisco, 2009). There is potential risk of disease contamination due to the use of the same pasture by ungulates from both sides. The main vegetation corresponds to the Sudano-sahelian transition savannahs with shrub savannahs as the dominant vegetation type (White, 1983; Adjanohoun *et al.*, 1989; Adomou, 2006). The most representative woody plant species include: *Acacia sieberiana* (Leguminosae-Caesalpinioideae), *Combretum spp* (Combretaceae), *Piliostigma thonningii* (Leguminosae-Caesalpinioideae), *Terminalia avicennioides* (Combretaceae), *Vitellaria paradoxa* (Sapotaceae), *Detarium microcarpum* (Leguminosae-

Caesalpinioideae), *Burkea africana* (Leguminosae-Caesalpinioideae), and *Balanites aegyptiaca* (Zygophyllaceae); *Crossopteryx febrifuga* (Rubiaceae), *Strychnos spinosa* (Loganiaceae) and *Gardenia erubescens* (Rubiaceae)

**Data collection**

**Pilot survey:** We first interviewed wildlife guards, foresters and local committees working for the conservation and the management of the DHZ to get the exact location of the habitats where elephants occur at different periods of the year. We then conducted a quick field control on the indicated habitats and proceeded on the selection of the research sites. The signs of habitat use by elephants were remaining foods, damaged trees (broken, debarked, uprooted), dung, tracks, etc.

**Floristic inventory:** Three habitat (vegetation) types were targeted: shrub and tree savannahs, woodlands, and riparian forests. 100 circular plots of 30 m radius were laid out in each habitat type for floristic inventory of damaged trees. Circular plot has the advantage to overcome the boundary effect and thus is less vulnerable to errors (Lackmann, 2011). The size of the plot (30 m radius or 2828.57 $m^2$) was adopted taking into account the minimum area covered by a herd of elephants eating in a given habitat. We recorded variables such as vegetation type (*cf.* classification of Yangambi), soil texture (visual appreciation), land and clay content, vegetation burning index that consider visible burning impact on tree barks, signs of elephant activities (dung, tracks, broken or fallen trees etc.). Within each circular plot, all trees with diameter at breast height (DBH) ≥ 10 cm were tagged and measured: individuals were counted, DBH was taken using a diameter-tape and tree height was estimated using clinometers (SUUNTO). The floristic list was made for each plot and the plant nomenclature followed the Analytical Flora of Benin (Akoègninou *et al.*, 2006). In order to assess the effect of selected environmental variables on the elephant damage patterns we counted the number of damaged trees within each 30 m-radius circular plot. Damaged trees included those that were broken, fallen, uprooted, debarked etc. We used the expertise of experienced elephant hunters to distinguish tree damaged by elephants from damages due to abiotic factor such as wind or storm. We also measured distances from habitats exploited by elephants with signs of damages to water ponds as well as distances to paths using ribbon.

**Data analysis**

The tree-density of the stands (N), i.e. the average number of trees per plot was computed in trees/ha as:

$$N = \frac{n}{s} \qquad (1)$$

n is the overall number of trees in the plot, and s the area (s = 0.283 ha).

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

$$G = \frac{\pi}{40000s} \sum_{i=1}^{n} di^2$$

di is the DBH (in cm) of the i-th tree of the plot; s = 0.283 ha.

The mean diameter of the trees (D, in cm), i.e. the diameter of the tree with the mean basal area in the stand:

$$D = \sqrt{\frac{1}{n} \sum_{1}^{n} di^2}$$

where n is the number of trees recorded in the plot, and di the diameter of the i-th tree in cm.

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

$$H = \frac{\sum_{1}^{n} gihi}{\sum_{1}^{n} gi} \qquad \text{with } g_i = \frac{\pi}{4} di^2$$

gi and hi are the basal area (in $m^2$/ha) and the total height (in m) of tree i.

The following ecological parameters were assessed using the Evenness program (http://www.nateko.lu.se/personal/benjamin.smith/software):

- The species richness (S) is the number of species recorded in the whole stand.
- The Shannon's Diversity Index (H', in bits) is computed using the following formula:

$$H' = - \sum_{i=1}^{S} pi Log_2 pi$$

where

S = total number of species in the community (species richness) ;

Pi = abundance of the ith species expressed as a proportion of total number of trees inventoried in a given vegetation type (habitat). Values of the index usually lie between 1.5 and 3.5, although in exceptional cases, the value can exceed 4.5 (very high diversity).

* The Simpson's dominance index (D') was calculated

using the formula:

$$D' = \sum_{i=1}^{s} pi^2$$

Where pi is the relative abundance based on number of individuals per species. D ranges from 0 to 1 in case of complete dominance.

* The Evenness index of Smith and Wilson (Evar) was used as a measure of equitability (Smith & Wilson, 1996; Biaou, 2009). It is independent from species richness and has equal sensitivity to rare and abundant species. Evar ranges from 0 to 1, with 1 indicating equal abundance of all species and values close to 0 indicating dominance of one or few species.

**Vegetation Structure of habitats exploited by elephant's populations in the Hunting zone of Djona:** The study of the vertical and horizontal structures of the vegetation exploited by elephant population is crucial for the understanding of ecosystem functioning. This study can help to make clear the effect of elephant's disturbances on the vegetation structure.

To establish the stem diameter structure of vegetation types (woodlands, shrub and tree savannahs, and riparian forest) exploited by elephants, all the recorded trees were grouped into diameter classes of 10 cm in order to obtain enough diameter classes (theoretically at least 10). This allows the adjustment of Weibull theoretical distribution to the observed shape (Rondeux, 1999). The tree densities were assessed for diameter classes. For the height structure, classes with 2 m amplitude were considered. The observed different diameter structures were adjusted to the 3-parameter-Weibull distribution because of its flexibility (Johnson and Kotz, 1970; Burk and Newberry, 1984), whose density function, f is expressed for a tree-diameter x as follows:

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} \exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$$

where x = tree diameter;

a = 10 cm for the diameter structure and 2 m for the height structure;

b = scale parameter linked to the central value of diameters and heights;

c = shape parameter of the structure.

For each identified group, diameters of trees were used to estimate the parameters b and c based on the maximum likelihood method (Johnson and Kotz, 1970). The log-linear analysis was performed in SAS (SAS Inc., 1999) in each case to test the adequacy of the observed structure to the Weibull distribution. The considered model described by is as follows:

$$\text{Log Frequency} = F + F_{\_Class} + F_{\_Adjustment} + \varepsilon$$

F = mean frequency of the classes;

$F_{\_Class}$ = non-randomly gap linked to the differences in frequency between classes;

$F_{\_Adjustment}$ = non-randomly gap linked to differences between observed and theoretical frequencies;

$\varepsilon$ is the error of the model. The hypothesis of adequacy between both distributions is accepted if the probability value of the test is higher than 0.05.

When c < 1 the distribution shows an inverse J-shaped that characterises natural multispecific stands; c = 1 for decreasing exponential distribution characteristic of disturbed stand on the brink of extinction.

When 1 < c < 3.6, the distribution is qualified as asymmetric positive often founded indicating monospecific stands dominated by young individuals of small diameter. When c = 3.6, the distribution is symmetric showing a bell-shape of normal distribution characterising monospecific stands or natural stands that experienced selective logging; and if c > 3.6, the distribution is negative asymmetric and the stand is characterised by a monospecific stand dominated by old individuals (Husch *et al.*, 2003).

By applying the Weibull equation to trees of DBH ≥ 10 cm, it should be pinpointed out those mature shrubs such as *Piliostigma thonningii*, *Annona senegalensis*, *Crossopteryx febrifuga* are overlooked and thus are not taken into account in the interpretation of the results.

**Effect of selected environmental variables on the pattern of damages**: The generalized linear model with Poisson distribution function was used to explain the damage tree pattern (Crawley, 2007). Because of the overdispersion found (Residual deviance/degree of freedom >> 1), we chose the negative binomial distribution that allowed us to fit the best model. From the full model including a set of environmental variables ("palatable woody density", distances from water pounds and paths, vegetation and soil types) with two ways interactions, and using Aiccmodavg package for stepwise deletion, we ended up with the best model including each factor effect without any interaction.

## RESULTS

**Vegetation structure and habitat quality:** The dendrometric and ecological characteristics of the vegetation types used by elephants are presented in table 1. The mean basal area was higher in the riparian forest than in the open habitats (woodlands and savannahs). Values of tree density, mean diameter, Lorey's height are similar among the three vegetation types ($p > 0.05$).

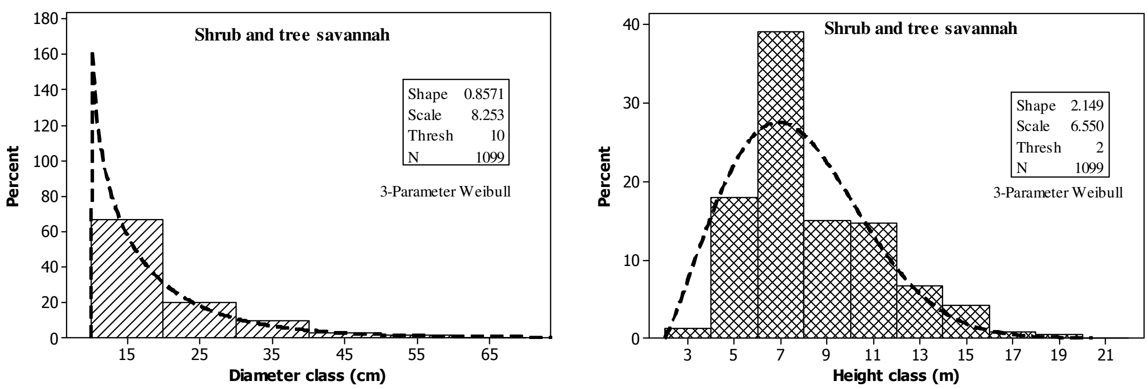
**Diameter and height class structures:** The observed diameter structure for the three vegetation types showed an inverse "J" shape, characteristic of multispecific plant communities (figure 2) with c-value of the Weibull distribution smaller than or close to 1, characteristic of multispecific or uneven-aged communities. The 10–20 cm dbh classes were the best represented whereas individuals with dbh > 40 cm dbh were scarce regardless the vegetation type. We found a good adjustment of the observed diameter distribution to the Weibull theoretical distribution ($p > 0.05$).

**Table 1:** Vegetation structure and the quality of habitats utilised by elephants in the Djona Hunting Zone

| Parameters | Woodlands | Shrub & tree savannahs | Riparian forest | p-value |
|---|---|---|---|---|
| **Structural** | **Mean ± σ** | **Mean ± σ** | **Mean ± σ** | |
| Tree density (n/ha) | 176.13 ± 17.6 | 167.97 ± 78.12 | 248 ± 93.38 | 0.09 |
| Mean diameter (cm) | 22.79 ± 5.2 | 21.95 ± 5.15 | 26.33 ± 5.74 | 0.17 |
| Lorey's height (m) | 10.58 ± 2.35 | 9.85 ± 2.34 | 11.95 ± 1.26 | 0.07 |
| Basal area (m²) | 7.76 ± 4.63 | 6.55 ± 3.86 | 13.22 ± 6.03 | 0.02* |
| **Habitat quality** | | | | |
| Species richness | 6 | 6.27 | 6 | |
| Shannon wiener index | 1.45 | 1.54 | 1.42 | |
| Simpson dominance index | 0.30 | 0.28 | 0.31 | |
| Smith and Wilson evenness | 0.69 | 0.74 | 0.57 | |

*p<0.05; **p<0.01

The height distribution patterns exhibited a bell-shaped distribution for all vegetation types. Individuals having a height ranging from 4 to 13 m (or [4-13]) were the most represented in the shrub and tree savannahs, [4-17] for the woodlands, and [6-16] for the riparian forest. The log-linear analysis (computed for each height structure) indicated a good adjustment of the observed distribution to Weibull distribution ($p > 0.05$).



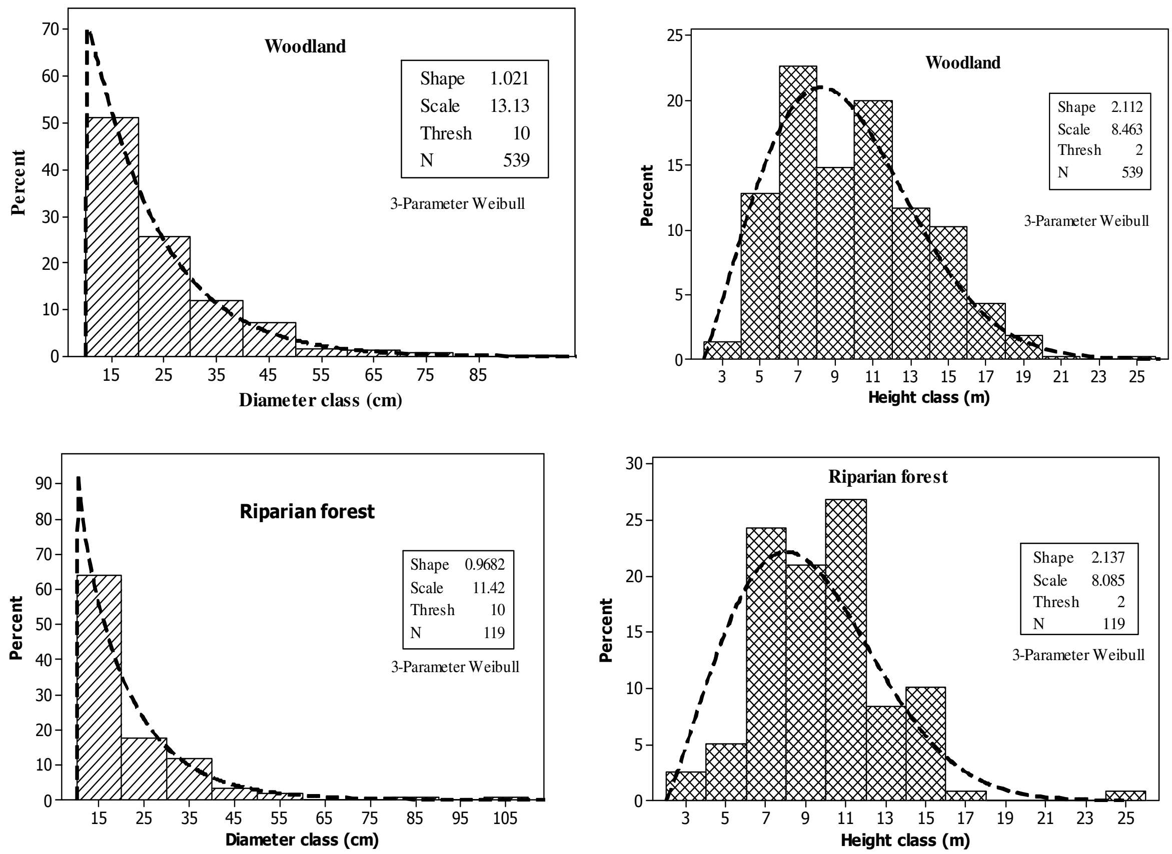



**Figure 2:** Diameter and height structure within the three vegetation types

**Factors influencing the damage patterns:** Table 2 synthesises the generalised linear model performed on the following set of environmental factors: "palatable woody density", the distance to water ponds, the distance to paths/roads, the vegetation types, and the soil types. The best model gave in output Null deviance: 192.21with 99 as degrees of freedom; Residual deviance: 99.17 with 89 as degrees of freedom; AIC: 629.36

**Table 2:** Generalised linear model explaining the pattern of damaged trees by environmental variables.

| Coefficient | Estimate | p_value |
|---|---|---|
| Intercept | 2.31E+00 | 2e-16 *** |
| Palatable woody density | 1.27E-03 | 0.01 ** |
| Distance to water | -1.32E-04 | 0.07 |
| Distance to path/road | -6.13E-05 | 0.00 *** |
| Riparian | -0.37 | 0.11 |
| Shrub | 0.04 | 0.77 |
| Woodland | 0.06 | 0.65 |
| Clay-Sandy soil | 0.24 | 0.29 |
| Lateritic soil | 0.67 | 7.70e-05 *** |
| Slimy-sand soil | 0.61 | 9.58e-05 *** |

*** $p < 0.001$

The environmental variables such as the "palatable woody density", the distance to roads and the soil types significantly influenced the model ($p<0.05$) showing that the intensity of damages caused by elephants (palatable woody density) was most influenced by accessibility to habitats (distance to paths/roads) and by the soil types.

## DISCUSSION

**Effect of elephant activities on vegetation and phytodiversity:** The structure of the vegetation exploited by elephants in the Djona Hunting Zone (DHZ) showed a high number of small trees while the number of large trees is low. This natural distribution is found in stable ecosystem (Gaoué, 2000; Kossou, 2007; Ouédraogo *et al.*, 2008; Senzota *et al.*, 2009). Thus, the vegetation of DHZ presents visible stability although it has been utilized for many years by elephants (Thiombiano *et al.*, 2005). This can be regarded as an adaptation of natural ecosystems to animal disturbances. Pfeiffer (1989) found that elephant showed an amazing ecological adaptation. Adult and big trees are more prone to being damaged by elephants, and the natural trade-off was ruled by the recruitment of individuals from the natural regeneration. Despite the trampling and browsing of young trees, elephant did not affect the recruitment ability of trees and the demographic structure of woody communities. Several factors account for tree vulnerability to elephant disturbance: exposure to mutilation, thickness of the bark, weakness of the root system (shallow root) and substrate instability (O'coonor *et al.*, 2007). Bell (1985) worked in East Africa on elephant's damages on vegetation and confirmed these factors but stressed on the preference for specific plants such as *Adansonia* and *Acacia* that were identified like cause of habitat's vulnerability to elephants' disturbances. The author reported with the same study that when these species dominate one habitat, the impact of elephants can be so pronounced to induce a conversion to grassland when fire intervenes to accelerate and deepened the disturbances. Previous studies have found that elephants prefer lowland forest habitats (Kinnaird *et al.*, 2003; Hedges *et al.*, 2005; Azad, 2006; Pradhan & Wegge, 2007) where nutritious foliage is abundant showing a direct link of the disturbances of elephants with the need of food resources. This finding demonstrated why elephants affects more habitats where exist the plants they prefer. Belayneh and Demissew (2011) reported the preference of elephants for fruit trees and according to Kalemera (1989); plants shorter than 1m tend to be ignored. Other workers have found a preference of elephants for adult trees, which may entail switching from stem and leaf browsing to bark stripping as height increases beyond 4 m (Barnes, 1983; Smallie and O'Connor, 2000). This can explain the utilization of larger (DBH > 55 cm) and tall trees we reported with the present study.

We reported in this study that old and high trees (height > 21 m) were rare and were more frequent in the riparian forest than in savannahs and woodlands. Individuals between 7 and 11 m high were well represented in almost all the vegetation types that were exploited by elephants. This can be because the tree uprooting, the branch breaking and the browsing regime did not allow the recruitment of individuals towards higher classes. Therefore, elephant seems to contribute to the creation and the maintenance savannah ecosystems (Valeix *et al.*, 2011; de Beer *et al.*, 2006). In the DHZ, the reported elephant effects are likely to provide excellent services for grassland establishment because the dominant trees are not very large and tall to develop extended and thick shadow detrimental to grasses that necessitate light for their establishment. This situation that favour grasses is beneficial to ungulates and this regarded as an ecosystem service. The species diversity in habitats used by elephant in the Djona Hunting Zone (DHZ) is low compared with the value found by Natta (2003) in the Sudanian zone. Elephant disturbances probably contributed to this low woody plant diversity in the study area. Negative effects of herbivores on phytodiversity were reported by Mligo and Lyarum (2008) in a situation where both livestock and wild mammals fed on vegetation what is likely to occur in the study zone where there are permanent conflicts between cropping activities and herds breeding, all this coupled with the presence of water sources situated in the protected area leading to constant attraction of livestock to the same pastures and water points with wildlife. However, some studies presented elephants as excellent agents that contribute to increasing plant diversity (Western, 1989; Rao *et al.*, 1990; Botha et *al.*, 2002). Therefore, the impact of elephants on the vegetation and phytodiversity remains a controversial debate.

**Environmental variables and elephant damages patterns:** Our results revealed that the type of the vegetation could significantly influence damages caused by elephants through their feeding behaviour. Habitats that are rich in large and tall trees seem to be more exposed to elephant damages. Contrary to the results found by several authors (De Villiers and Kok, 1988; Owen-Smith, 1988; Ben-Shahar, 1993), distance to water was not the only factor that drives the elephant or disturbance on a given habitat. This study reports the distance to roads as negatively correlated with the intensity of the damages caused by elephants. This implies that elephant movements were not influenced by human presence since park managers for patrols, hunting and touristic activities use roads. These roads seemed to trigger the behaviour of elephants towards branch breaking, uprooting and debarking of trees alongside the roads. We also found that tree damages were remarkable on lateritic soils that are colonised by population of *Detarium microcarpum* which fruits are preferred by elephants. The clay soil is not preferred by elephants because of its instability that makes it difficult to walk. The heavy body of this large mammal seems to trigger his feeding behaviour and habitat selection. It is also common to come across elephant tracks following roads over relatively long distance in a park or to observe a group of elephants avoiding a rocky terrain (Pers. observation).

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