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Diversity, structure and effect of rare species and relative abundance of the over-represented species on arborescent layers' diversity

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Abstract

The present study aims to analyze diversity, structure and effect of rare species rate and relative abundance of the over-represented species on arborescent layers' diversity in Rubi Tele Domaine de Chasse (RTDC) mature forests. The RTDC (6227.74 km²) straddles the Tshopo and Bas-Uélé provinces in the North-Eastern part of the Democratic Republic of Congo (DRC). Inventories were realized and data were collected in 30 nested plots of 1 ha each where all trees with DBH ≥ 10 cm were taken into account. The floristic composition was evaluated thanks to taxonomic richness, Fisher's Alpha index, Pielou equitability index and to the determination of rare species' rate. Vegetation structure was determined using tree density, basal area and above ground biomass. The effect of rare species' rate and relative abundance of the over-represented species on arborescent layers diversity was appreciated. The results of this study revealed a variability of diversity and structure parameters in this layer category and not in the other. These results revealed, moreover, an existence of effect of the rare species rate and the relative abundance of the over-represented species on diversity and structure of arborescent layers.

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Introduction

Tropical forest ecosystems are one of the major reservoirs of biodiversity (Leigh *et al.*, 2004). They shelter more than fifty per cent of terrestrial species (FAO, 2015). But unfortunately, they are the most threatened where profound changes have occurred in recent decades (Yenni *et al.*, 2015). The vegetal formations of the Democratic Republic of Congo (DRC) are not spared from this drama of deforestation and considerable reduction or even extinction of wood resources diversity.

According to the FAO, the deforestation of tropical forests, which annually represented about 7 million hectares in the 1970s attains currently (1990-2015) approximately 10.4 million hectares each year (FAO, 2015). Among various factors responsible for this evolution, the considerable increase in populations has carried away the needs for wood and agricultural land and has led to the clearing of considerable areas of natural forests. Consequently, the structure of the stands leads to the reduction of the number, the basal area and the above-ground biomass of ligneous plants.

Through its effects on forest ecosystems, deforestation has been the basis for a new spatial redistribution of forests where individuals are unequally distributed among species (Pitman *et al.*, 1999). This inequitable distribution is illustrated, on the one hand, by the over-representation of a species, the case of monodominance (Gross *et al.*, 2000, Torti *et al.*, 2001; Makana, 2004; Barbier *et al.*, 2016, Kearsley *et al.*, 2017) and secondly by innumerable relatively rare species (Hubbell and Foster, 1986; Ngo and Dirk, 2013).

The understanding of this phenomenon of species dominance and rarity has prompted by several authors to attempt to formulate elements of response. Some thought this was due to specialization of layers (Terbogh *et al.*, 1996), disturbance (Ter Steege and Hammon, 2001), niche diversification (Connell, 1978), compensatory mortality (Connell *et al.*, 1984) and pathogen pressure (Gillett, 1962). Others, on the other hand, have assumed that environmental heterogeneity (Phillips *et al.*, 2003, Pitman *et al.*, 2001) and limited dispersal of diaspores (Condit *et al.*, 2002) of some species have a part in this phenomenon.

Several studies have focused on the phytosociology of tropical forests (Louis, 1947) to Yangambi, (Pierlot, 1966) on different altitudes, Mandango (1982) in the islands of Zaire River. Others, later, were also interested in the trade-offs put in place by the species of these forests (Gillet *et al.*, 1991; Senterre, 2005; Nshimba, 2008; Amani, 2011; Amani *et al.*, 2013). Kouob (2009) further found that in Cameroon the stand structure illustrated an over-representation of some ecologically dominant species or families, accumulating the largest number of individuals and most of the basal area.

The RTDC is one of the DRC's phytogeographic entities less known phytosociologically, floristically and structurally.

The only works carried out there are those of Lisingo (2016) and Katembo *et al.* (2018). Unfortunately, they have not analyzed the turnover of species. With this in mind, this study aims to analyze diversity, structure and effect of rare species rate and relative abundance of the over-represented species on arborescent layers' diversity in the RTDC's mature forests because conservation and management of forest ecosystems depend on.

Material and methods

Study area

Created through the 51th legislative Ordonnance/ Agri. since the 12th December 1930, the RTDC (Fig. 1) is located on south of the Buta city, spanning from 2°32'22.9" N to 2°43'50.04" N and 24°38'25.17" E to 25° 04' 35.98" E. The RTDC straddles the Tshopo and Bas-Uélé provinces in the north-eastern part of DR Congo where it covers an area of 6227.74 km² (ICCN, 2012).

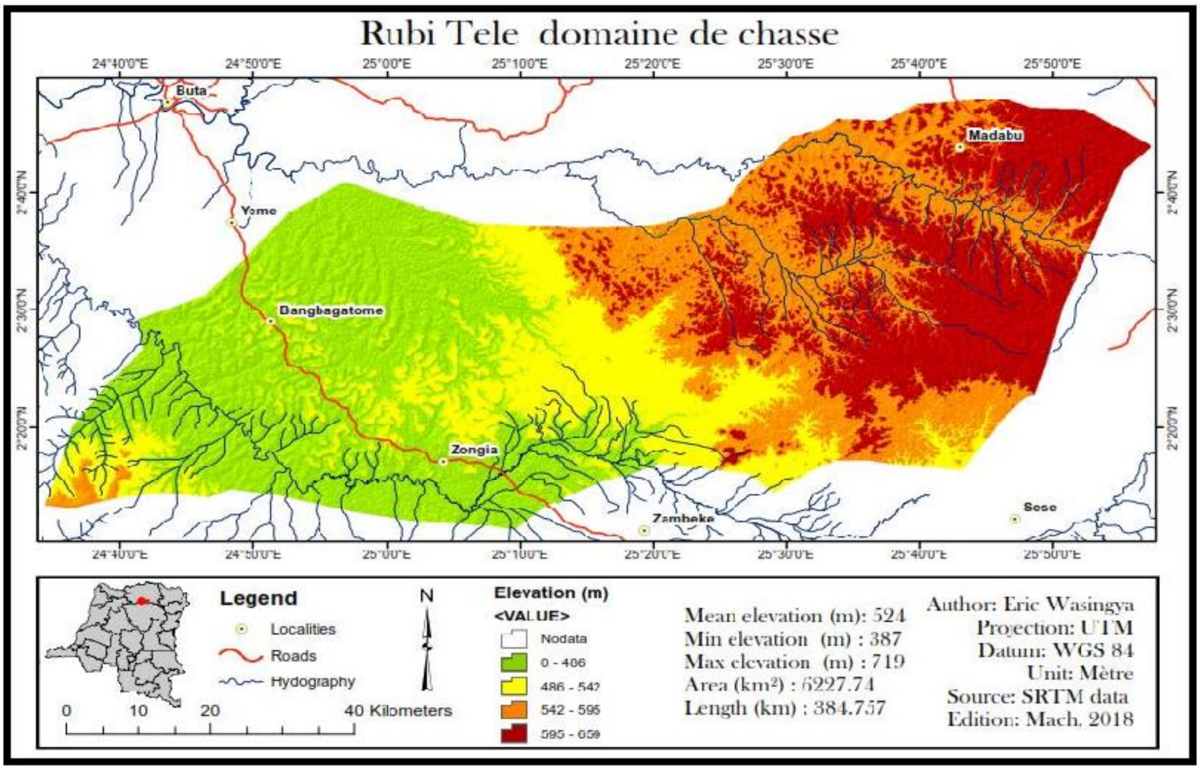

Fig. 1. Map illustrating the Rubi Tele Domaine de Chasse.

The RTDC benefit is under an Am type climate (Koppen, 1936). The monthly mean temperature fluctuates around 25°C and the yearly mean rainfall range from 1500 and 1800 mm.

Data collection

The sampling sites were chosen after the field prospection. Data were collected in 30 homogeneous plots of 1 ha each placed in mature forests established on periodically flooded soil (PI: 10 ha); on the dry deep soil (TFPr: 10 ha) and on dry gravelly soil (TFGr: 10 ha). Each survey was conducted according to the Integrated Synusial Phytosociology approach (Gillet *et al.*, 1991; Senterre, 2005; Nshimba, 2008; Amani, 2011; Amani *et al.*, 2013) where all trees with DBH ≥ 10 cm were taken into account and categorized into upper (A) and lower (Ad) arborescent layers. These ligneous plants have, in addition, been identified and measured (DBH).

Data analysis

The floristic diversity of the A and the Ad arborescent layers was assessed by means of richness (families, genus, species), Fisher's Alpha index and Pielou equitability index. The rate of rare species has also been evaluated.

The following structural parameters were performed to characterize the woody stand:

Tree density: is the number of trees per unit area (individuals/ha);

Tree basal area (G): corresponds to the cross-sectional area of these trees at diameter at breast height (DBH). It is expressed as follows: $G\ (m^2\ /\ ha) = \pi D^2\ /\ 4$ where D is the DBH.

Estimated aboveground biomass (AGB): refers to the total mass of living organisms on a unit area. It is expressed in Million grams per hectare (Mg / ha): $AGB = \rho \times \exp(-1{,}499 + 2{,}148 \ln(D) + 0{,}207 (\ln(D))^2 - 0{,}0281 (\ln(D))^3)$ (Chave *et al.*, 2005) where ρ is the woody density.

The relationship between the rate of rare species with alpha diversity and that of the relative abundance of the dominant species with the Pielou equitability of upper A and lower Ad arborescent layers were calculated. Stats were done thanks to Excel 2016 and R 3.1.3 softwares. Analysis of Variance (ANOVA) with Tukey's tests were used to assess the differences between the values of richness (families, genus, species), floristic diversity, rare species rates, density, basal area and aboveground biomass between the A and Ad arborescent layers of the targeted mature forests. The student's t test was used to assess the effect of the species rate and the relative abundance of the over-represented species on the diversity of A and Ad layers.

Results and discussion

Diversity and species rarity

A total of 184 species divided into 155 genus and 44 families was recorded in the nested plots.

The comparison of richness (at the family, genus and species levels), diversity (Fisher alpha and Pielou equitability index) and the rate of rare species between A and Ad arborescent layers of different forest types (PI, TFPr and TFGr) showed a difference in some cases and not in others (Table 1).

Table 1. Diversity and proportion of rare species.

Groups	Family	Genus	Species	Fisher α	Pielou	% rare species
PI_A	12.2±2.90^{a}	16.8±4,61^{a}	17.9±5.92^{a}	5.48±2.42^{a}	0.47±0.21^{a}	51.35±13.73
TFPr_A	7.6±3.24^{b}	10.9±4.12^{b}	11.2±4.34^{b}	2.97±1.45^{b}	0.31±0.07^{b}	57.29±13.43
TFGr_A	9.7±3.06^{a,b}	14.4±4.01^{a,b}	15.1±4.56^{a,b}	4.54±1.75^{a,b}	0.51±0.04^{a,b}	57.28±9.02
p	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	> 0.05
PI_Ad	16.9±3.21	24.3±7.02	28.9±8.14	8.06±3.33	0.6±0.09	43.22±9.79
TFPr_Ad	15.0±2.49	22.2±4.61	28.5±6.33	8.75±2.31	0.61±0.09	47.56±11.72
TFGr_Ad	17.9±3.25	28.7±6.60	15.1±4,56	4.54±1.75	0.51±0.04	43.25±13.09
p	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05	> 0.05

Within column means per taxon followed by the same letter were not significantly different from each other at *P* = 0.05 following Tukey's comparisons.

The species diversity differed from one compartment to another and from one forest type the another (Table 1). This difference was influenced by the comparison of means of the A layer's diversity index between forest types. The A and Ad layers of the mature forests were dominated by the family Fabaceae, followed by the Rubiaceae and Sapotaceae (A), Ebenaceae and Clusiaceae (Ad).

Table 2. Dispersion of density, basal area and aboveground biomass (AGB) values of nested plots.

	Density		Basal area		AGB	
Forests	A	Ad	A	Ad	A	Ad
PI	158.2 ± 49.55	311.9 ± 73.42^{a}	25.5 ± 4.64	6.74 ± 3.10^{a}	401,22±70,36^{a}	67,78±37,61
TFPr	137.5 ± 21.42	224.3 ± 39.38^{b}	28.4 ± 2.61	4.08 ± 1.04^{b}	494,17±55,12^{b}	34,83±11,11
TFGr	134.7 ± 28.25	279.7 ± 48.84^{a,b}	27.82 ± 3.17	5.21 ± 1.37^{a,b}	472,33±61,97^{b,c}	43,21±13,22
P	> 0.05	< 0.05	> 0.05	< 0.05	< 0,05	> 0,05

Within column means per flayer followed by the same letter were not significantly different from each other at *P* = 0.05 following Tukey's comparisons.

The dominance of of the family Fabaceae suggests that these forests belong to the great evergreen ombrophilous forest type that covers the Congolese basin. Our results are supported by those by Kouka (2000) in Odzala National Park (Congo), Yongo and De Foucault (2001) in Ngotto Forest (Central African Republic), Mosango (1991), Nshimba (2005, 2008), Amani (2011) and Amani *et al.* (2013) in the Tshopo region (DRC), Sonké (1998) and Kouob (2009) in Dja (Cameroon) and Kimpouni *et al.* (2013) in the Upper Sangha (Republic of Congo). Similar results were obtained in the forests of Brazil (Benvenuti-Ferreira and Coelho, 2009), the Amazon (Nebel *et al.*, 2001) and those of Eastern Ghats (Jayakumar *et al.*, 2009).

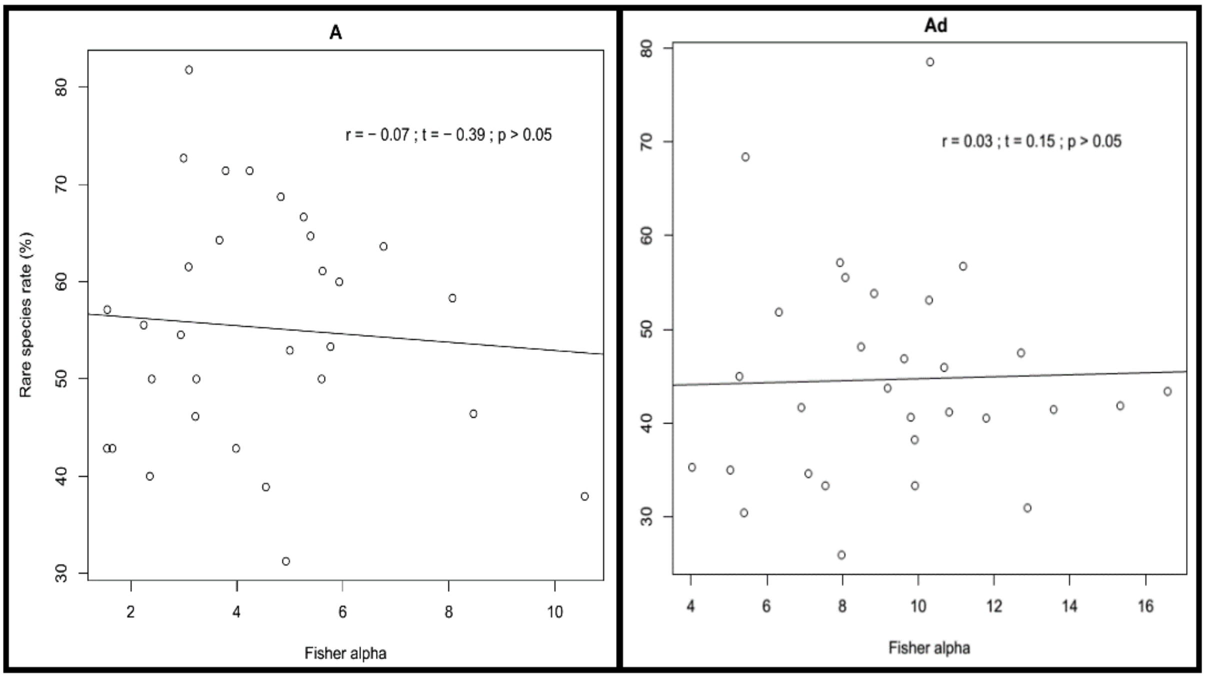

Fig. 2. Relation between the rate of rare species and the Fisher's alpha index of the arborescent layers.

This numerical importance of the family Fabaceae was partly attributed to the dissemination mode of most species members of this family which are zoochores and disseminated by the herbivores that consume them (Ouédraogo, 2009; Abdourhamane *et al.*, 2013). The similarity of the floristic diversity in the Ad arborescent layer inventory is explained by the favorable light and moisture conditions that allow most species to thrive. This finding is corroborated by that experienced by Kouob (2009) in Cameroon and by Nshimba (2008), Lisingo (2009), Amani (2011) and Amani *et al.* (2013) in DRC.

In the whole, our results partly verify the hypothesis according to which the layer's specific diversity would differ from one mature forest type to another. However, it should be noted that the diversity of the RTDC forests is lower compared to that of the Amazonian and South-Eastern Asia rain forests. The higher species in these forests is an evidence of their age (Willis and McElwain, 2002). Following Condit *et al.* (2002), African tropical forests result from a recent speciation process.

Forest structure

The inventory and dendrometry (Table 2) carried out on 12463 trees of the A and Ad arborescent layers of the nested plots revealed a variation of the density and basal area values in the Ad arborescent layer ($p < 0.05$) but not in the A arborescent layer ($p > 0.05$). On the other hand, a difference was observed as to the values of the estimated aboveground biomass in the A arborescent layer ($p < 0.05$) but not for in the Ad arborescent layer ($p > 0.05$).

In tropical forests, the tree density ranges from 300 to 700 at DBH ≥ 10 cm/ha (Richards, 1996). Our results (PI = 470 individuals/ha, TFPr = 362 individuals/ha and TFGr = 414 individuals/ha) remain in this range and are similar to those obtained earlier in the Guineo-Congoleese domain (Sonké, 1998; Makana *et al.*, 2004; Nshimba, 2008; Peh, 2009; Kouob, 2009; Lisingo, 2015).

The mean basal area of plots established on periodically flooded soil (PI) was 32.28 m^2/ha while it amounted 32.48 m^2/ha on the dry deep sol (TFPr) and 33.02 m^2/ha on the dry gravelly soil (TFGr).

The observed difference in the mean values of the basal area in the Ad layer did not influence the global basal area of the targeted forest types. This effect can be explained by the negligible contribution of that layer to the global basal area.

In the North-eastern part of the DRC, the values of the basal area of trees with DBH ≥ 10 cm are in the range of 18 to 50 m^2/ha in tropical forests (Dawkin, 1963). These values are close to those reported for the Uele and Epulu forests in DRC (Gerard, 1960; Hart, 1985; Makana *et al.*, 2004) and for the Cristal Mountain of Odzala and Dja forests in Cameroon (Sonké, 1998; Kouob, 2009). Hence, our results suggest that the sampled forests in the RTDC have attained the climax and they are free of anthropogenic disturbances.

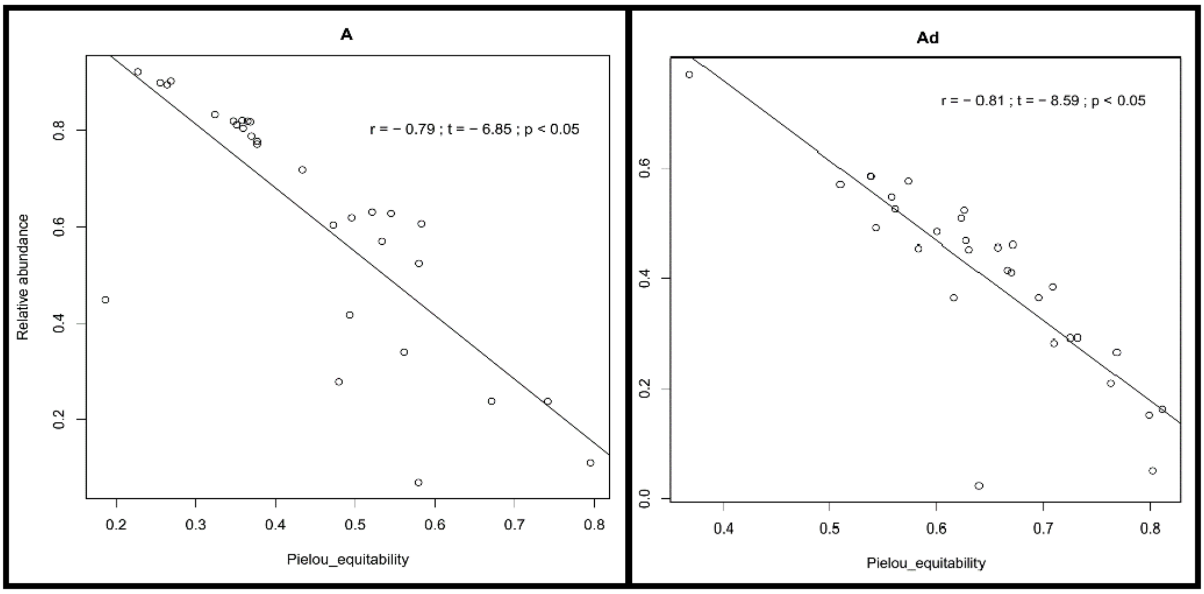

Fig. 3. Relationship between relative abundances of the over-represented species and Pielou equitability index of arborescent layers.

The mean aboveground tree biomass of forests established on periodically flooded soil was 465 Mg / ha while it averaged 529.01 Mg/ha for those established on dry deep soil and 515.09 Mg/ha for those growing on dry gravelly soil. Nevertheless, these values of the above-ground biomass occupied by individuals in A layer vary from one forest to another but not for those in the Ad layer. This trend is justified by the fact that each species has a specific density which is especially higher for most individuals in the A layer. However, it should be noted that the difference observed by comparing the A layer mean values did not affect the aboveground biomass of individuals from the two considered layers.

Rarity and over-representation of species

The rate of rare species in the A arborescent layer (Fig. 2) correlates negatively with the floristic diversity of the A arborescent layer ($r = - 0.07$; $t = - 0.39$; $p > 0.05$), whereas it was positively correlated with the floristic diversity in the Ad arborescent layer ($r = 0.03$; $t = 0.15$; $p > 0.05$). In addition, this rate did not differently affect the diversity of arborescent layers.

Fig. 3 shows that the relative abundances of the over-represented species of the A ($r = - 0.79$; $t = - 6.85$; $p < 0.05$) and Ad ($r = - 0.81$; $t = - 8.59$; $p < 0.05$) arborescent layers negatively correlate and affect differently the distribution of individuals between species.

The significantly different positive correlation for the Ad ($r = 0.44$, $t = 2.60$, $p < 0.05$) and not for the A ($r = 0.11$, $t = 0.61$, $p > 0.05$) arborescent layers may be explained by a fluctuation in the species richness in the Ad arborescent layer and similarity of this diversity in the A arborescent layer.

It can also be explained by the influence of the relative abundances of the over-represented species on the values of the Pielou equitability index of A ($r = -0.79, t = -6.85, p < 0.05$) and Ad ($r = 0.81, t = -8.59, p < 0.05$) arborescent layers but not by the rate of rare species in A ($r = -0.07, t = -0.39$ $p > 0.05$) and Ad ($r = 0.03, t = 0.15, p > 0.05$) Fisher's α index' values. This finding is corroborated by the results obtained by Condit *et al.* (2002), Duivenvoorden *et al.* (2002), and Hardy and Sonké (2004) who assumed that the aggregation of the ecologically dominant species would be caused by a limited dispersal of diaspores. Similar tree behavior has been observed in *Gilbertiodendron dewevrei* monodominant forests, where the high relative abundances of the dominant species induce a lower functional richness (Kearsley *et al.*, 2017) and a narrow functional niche (Villéger *et al.*, 2008). With a high potential for competition, the dominant species increases the rate of rare species. However, it would be worth to note that the rarity of species is subjective and dependent on the environment and the type of inventory (Kouob, 2009). As to its dependency to the environment, the presence of rare species is explained by their heliophilic temperament that stop the diaspores to regenerate under shade or by moving its diaspore from one place to another. As to the inventory type, one species may be rare in this arborescent layer and common in another (Kouob, 2009). This observation is similar to our results, whereby some species were, on the one hand, common in one forest type and rare on another hand (e.g. *Angylocalyx pynaertii, Monodora angolense, Dialium excelsum*) and, on the other hand, frequent in a stratum and rare in another (e.g. *Diogoa zenkeri, Cola griseiflora, Klainedoxa gabonensis, Irvingia gabonensis, Pancovia harmsiana, Julbernardia seretii*).

Conclusion

From this study, we found that the parameters of taxonomic diversity and structure analyzed at A and Ad arborescent layers varied in part from one layer of mature forests to another. The low species richness in targeted mature forest's arborescent layers has finally found response because the individuals in these layers were not evenly distributed among the species. This low richness is justified by an over-representation of the dominant species.

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