Original Research Article

Mid and submontane altitude forests communities on the West hillside of mount Bambouto (Cameroon): Floristic originality and comparisons

ASTRACT

Background and aims - Situated on the oceanic part of the Cameroon mountainous chain, the Western flank of Bambouto Mountains include the Atlantic biafran forests rich in endemic species but not well known. The objective of this work is to compare specific diversity, floristic composition and structure of two forests on this hillside.

Methods - The inventories have been carried out in 18 plots of 20 m~~*~~x 250 m plot established to cover all corners and centers of each forest in order to collect as many species as possible; also depending on the size of the forest block, vegetation physiognomy and altitude. Therefore, on a total area of nine hectares, all individuals with diameter at breast height ≥10 cm (dbh =1~~.~~.30 m above ground) were counted. ~~phytodiversity~~ Phytodiversity has been assessed based on the usual diversity indices; these are the Shannon, Equitability and Simpson indices. ~~the~~ The chi-square and Anova test were used to compare the data obtained.

Keys results - With 168 species recorded in 4 ~~four~~ hectares, the submontane forest noticeably appears richer than that of low and mid altitude (161 species in 5 hectares). Among these species, 46 are common to the two forests. The mean stands density with diameter at breast height (dbh) ≥ 10 cm recorded per hectare is 855 ± 32,7 at low and mid altitude forest and 1182 ± 38,4 at submontane forest. The diversity index, specific richness and the endemism rate values are comparable to those registered in other Central African sites. This result shows a great species diversity in the area as well as a good stability of these forests. Mean basal areas (respectively 60 m^2/ha and 52 m^2/ha in Fossimondi and in Bangang) are similar to those regularly observed in tropical rainforests. A total of 14 endemic species in Cameroon and 7 vulnerable were recorded in this study area.

Conclusions- The most meaningful differences in these two forests reside in their floristic composition and in the importance of some species in term of individual's number and basal area. Since the area is not yet profoundly explored, this work highlights its floristic importance for basis of a good management strategy.

Keywords:

Comment [J1]: ??

Formatted: Indent: First line: 0"

1. INTRODUCTION

Tropical forests are the richest in flora and fauna, but also the most endangered[**12**]. The annual loss of tropical forest cover was estimated at 13 million hectares between 2000 - 2010 [**15**]. In the year~~s~~ 2001, that of all Africa was estimated at 5.3 million hectares, that is 0.78% of the total forest area [**14**]. The Central African regions (Cameroon, Gabon) and Madagascar are among the most varied areas of woody species [**33**] but also the most threatened.

Cameroon forest ecosystems cover about 21 million hectares [**5**]. They are diversified, with more than 8,000 species of plants including more than 300 species of exploitable wood [**25**]. Part of these forests is located in the Cameroon mountainous chain, which is one of the biogeographic zones with a high degree of endemism. With extreme deforestation at over 415,000 hectares per year [**12**], no primary forests will remain in the coming years. Indeed, the population explosion, slash-and-burn agriculture

and the commercial exploitation of forests for the external market are among the main causes of deforestation in Cameroon.This deforestation leads to the loss of biodiversity, soil leaching and the increase in the greenhouse effect due to the overproduction of carbon dioxide [3**4**].The study of the relationships between environmental characteristics and plant community structure can not only reveal the mechanisms that control community structure but also predict the response of plant communities to changes in their environment; hence the importance of a good understanding of these transformations for effective environmental management [**29**]. The high-altitude areas, notably those of West Cameroon, are not exempt from the impact of these various anthropogenic factors, which is exacerbated by the high density of human populations and a generally very rugged terrain. The west hillside of the Bambouto Mountains is not only a refuge for a large number of endemic species but also for species endangered species. It is also a critical site for understanding the distribution of species along the Cameroon mountainous chain[**22**].

Research has shown that the composition and diversity of plant communities change with altitude, multiple disturbances, and other abiotic factors [**4,43,49**]. Very few botanical studies have been conducted on the western side of the Bambouto Mountains. Very few botanical studies have been carried out on the western slope of the Bambouto Mountains. It includes work on plant diversity in Lewoh-Lebangvillage [**17**], the publication of a conservation checklist based on collections along Fossimondi and Betchati villages [**22**] and the study of medicinal plants used in traditional medicine in Aguambou-Bamumbu village [**16**]. These works are still fragmentary and do not provide a complete view of the flora on this slope. Since plant species and community conservation strategies are based on specific richness and endemism rates [**24,26,32**], detailed information on vegetation on the western slope of the Bambouto Mountains is an important tool for establishing a forest ecosystem management plan in this area. Thus, to better understand and manage the submontane plant communities of Fossimondi and Bangang, it is therefore necessary to have a good knowledge of the ecology of these forest ecosystems, which constitute an important genetic reservoir for plant species. Some of these plants represent an important potential for medical and commercial applications. They are also essential habitats for wildlife.

The aims of this work are to carry out a comparative study of the floristic composition, diversity, vegetation structure and phytogeographic analysis of the Fossimondi submontane forest and the Bangang mid altitude forest species.

2. ~~2.~~METHODOLOGY

2.1. STUDYSITE

Located about 150 km from the Atlantic ~~ocean~~Ocean, the western slope of the Bambouto Mountains where the study was conducted is found in the oceanic part of the Cameroon Ridge [**35**]. The plant communities in this area (Fig. 1) are Biafran Atlantic forests [**9**]. Administratively, the studied zone is found in the southwest region of Cameroon~~; especially,~~ in Lebialem Highlands. Bangang Forest is located at an altitude between 200 m - 600 m. The mean geographical coordinates are 5 ° 36'10.5 " North latitude and 9 ° 54'24.5 " East longitude while the Fossimondiforest is between 1000 m - 1900 m altitude with geographical coordinates averaging 5 ° 37'54.5 " North latitude and 9 ° 57'57.6 " East longitude.

Comment [J2]: Only from plants? or also patra mammals and birds? Here it is important to highlight the importance of the study

Comment [J3]: The text is repeating information in the previous sentence

Comment [J4]: Handling and conservation only? Is there any plan to define areas for preservation, considering the endemic species? If so, it is worth referencing.

Comment [J5]: Add reference

Formatted: Numbered + Level: 1 + Numbering Style: 1, 2, 3, ... + Start at: 1 + Alignment: Left + Aligned at: 0.49" + Indent at: 0.74"

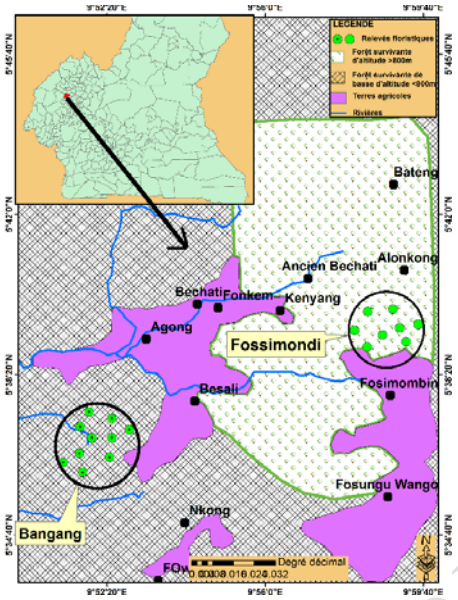

Figure 1: Location of Bangang and Fossimondi villages in the Southwest Cameroon region showing studied plots in the forests.

Comment [J6]: Include a map with Cameroon on the African continent and the study region in the Cameroon country. The map shown does not allow the reader to have a precise geographical location.

Lebialem highlands has an equatorial climate characterized by two seasons; a long rainy season (from March to November) and a short dry season (from December to February). Temperatures range from 15.2°C to 18.2°C and 25°C to 27.7°C respectively in Fossimondi and Bangang with annual averages of 16.8°C and 26.34°C/year. Average rainfall is 2112 mm /year in Fossimondi and 2530 mm/year for Bangang (http://fr.climate-data.org/location/780244/, accessed on 01-02-2016).

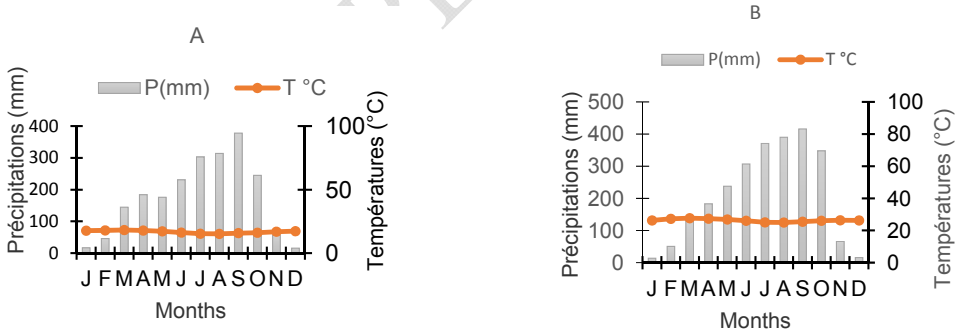

Figure 2: Ombrothermal diagram of Fossimondi (A) and Bangang (B) villages (source: http://fr.climate-data.org/location/780244/, accessed 01-02-2016)

2.2.Sampling and collection method

Sampling plotswere chosen based on work that has been carried out in tropical forests, particularly in Cameroon [**49**] and Burundi [**20**]. These phytodiversity plots are 250 m x 20 m (0.5 ha). The census was done on all woody trees with a diameter greater or equal to 10 cm (at 1.30 m). Depending on the size of the forest block, vegetation physiognomy and altitude, 10 and 8 plots were established respectively in the Bangang mid-altitude forest and the Fossimondi submontane forest (fig. 1). Some species were identified directly in the field using common identification criteria such as trunk and morphology, leaf type and arrangement, rhytidome nature and bark etc. Samples of unidentified species were collected; then brought back to the Cameroon Herbarium for identification by comparison

Comment [J7]: Was any field ID guide used? among the team of researchers were there any botanists with experience in identifying region species? Clarify, the reader needs to have elements to rely on the results presented.

with the herbarium samples or using the documents dealing with flora in the tropical zone. The nomenclature of the species encountered was confirmed using the online African Plant Database (Conservatoire du Jardin Botanique de Genève http://www.villege.ch/musinfo/bd/cjb/africa/recherche.php?langue=en). The taxonomic nomenclature adopted is the phylogenetic botanical classification of angiosperms [**6**].

Phytogeographic analysis were evaluated using White's method [**53-54**] and others publications on Cameroon flora [**10,19,22,44**]. The following categories have been assigned to species: Widespread species (Ld) such as pan-tropical and paleotropical species, Guineo-Congolese species (Gc), Upper and Lower Guinean species (Gs), Lower Guinean species (Gi), Cameroonian species (Cam) and Southwest Cameroon species (So-Cam)

2.3. Data analysis

In order to estimate absolute specific richness through the species-individual relationship, regardless of sample size [**18**], the Margalef index (Rm) was used.

Rm = S-1/LogN where N is the number of individuals in the area and S the number of species in the area.

The degree of stability of the flora of the two forests was estimated base on the specific quotient (Q) [**43**] noted Q = S/Ge with Ge representing the number of genera

Basal area (G), relative dominance (D %) and relative frequency (F %) of species were also calculated to get an idea of the degree of filling and forest structure. These formulas are noted

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

G in m^2/ha, S the area in hectare and di the diameter of the tree i

Relative dominance = (basal area of a species/total basal area) x100

Relative frequency = (Frequency of species i/sum of all frequencies) x100

Different diversity indices such as Shannon's diversity index(H), Simpson index and evenness indexwere used to determine the diversity.

- Shannon's diversity index formula is $H = -\sum_{i=1}^{s} \frac{Ni}{N} \log_2 \frac{Ni}{N}$

Ni: Number of individuals of a given species i, i ranging from 1 to s (total number of species). N: Total number of individuals.log: decimal logarithm.

- species evenness index (Equitability) were evaluated based on the formula: Eq = H/$\log_2$N0 with N0: total number of species

-Simpson's diversity index (D') directly representative of the heterogeneity obtained by subtracting the Simpson index calculated at its maximum value 1[**39,40**].

$$D = \sum_{i=1}^{s} \frac{Ni(Ni-1)}{N(N-1)}$$ D'=1-D with

Ni: number of individuals of the given species i; i ranging from 1 to s (total number of species)

N: total number of individuals

These three diversity indices were chosen to provide a more complete view of the structure of the different plant communities. They were calculated using PAST 2.09 software. Shannon's diversity index considers the rarest species; Simpson's diversity index is rather sensitive to the most abundant species. On the other hand, the Equitability Index, ranging from 0 to 1, indicates the degree of diversity achieved in relation to the maximum possible and better expresses intra-community variation. When regularity is low (tends towards 0), it indicates a dominance phenomenon; however, when it is high (tends towards 1), there is a regular distribution of individuals among species, resulting in a lack of dominance [**36**]. The significance between the results was determined by the chi2 and ANOVA test (Bonferroni post-hoc test) using XLSTAT 2014.5.03 software.

Ethical aspects

Comment [J8]: Where was this identification conducted? in the laboratory citing the Laboratory and the Institution

Comment [J9]: It is not necessary to quote the formulas in the article. These indices are well known in the literature. Follow the same instruction for the following cases

Comment [J10]: Explain better to the reader why use all these indexes? Together with Margalef, they are influenced by the sample effort that is not always possible to control. To compare the richness between areas, I suggest a rarefaction analysis.

Comment [J11]: Although this is a field study, some samples were collected. Another aspect is access to the area. If it is public, the government agency responsible should be aware. If it is a private area, the owners should be aware. These ethical issues need to be clarified.

Formatted: Indent: First line: 0"

3. RESULTS

3.1. Species richness, abundance and dominance

In the Fossimondisubmontane forest, 4,837 individuals have been recorded belonging to 168 species, 131 genera and 61 families. The number of species per plot varies between 33 and 51 (41.25 ±7.74). The absolute specific richness according to the Margalef Index (Rm) is 15.20. In contrast, in the Bangang mid-altitude forest, the 4,285 individuals recorded include 161 species, 127 genera and 48 families, with a Margalef (Rm) value equal to 14.17. The number of species varies between 35 and 62 per plot (with mean of 44.3 ± 7.24). The average number of individuals is 855 ± 32.7 and 1182 ± 38.4 per hectare in Bangang and Fossimondi forest, respectively (Table 1).

Table 1: Total area studied, number of individuals and specific richness in the Fossimondisubmontane forest and the Bangang medium altitude forest. (*R: plot, Ni. ha-1: number of individuals per hectare, S: area per hectare, S. ha-1: average specific richness per hectare and RM: Margalef absolute richness, FDI: Fossimondi ; BG : Bangang*)

Sites	R	S.ha^{-1}	Ni.ha^{-1}	$\bar{x}$ S. ha^{-1}	RM
Submontaneforest (FDI)	8	4	1,182±38,4	83 ± 15,48	15,20
Mid altitude forest (BG)	10	5	855±32,7	89 ± 14,48	14,17

~~In contrast, in the Bangang mid-altitude forest, the 4285 individuals recorded include 161 species, 127 genera and 48 families, with a Margalef (Rm) value equal to 14.17. The number of species varies between 35 and 62 per plot (with mean of 44.3 ± 7.24). The average number of individuals is 855 ± 32.7 and 1182 ± 38.4 per hectare in Bangang and Fossimondi forest respectively.~~ Of a total of 329 woody species inventoried, 47 are common to both forests, 121 are found exclusively in the Fossimondi submontane forest and 114 occur only in the Bangang mid altitude forest.

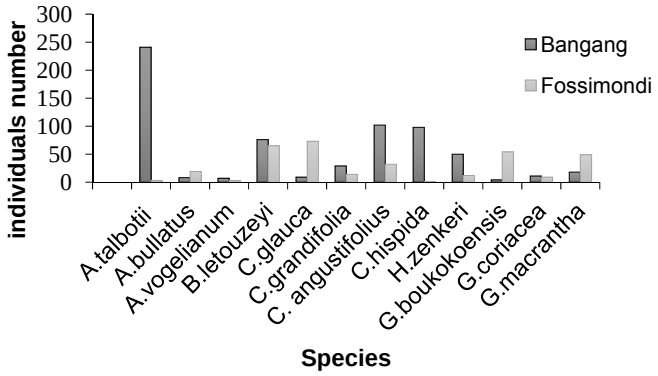

Figure 3: Comparison of the numbers of the most abundant species common to both forests(*A. taboltii: Anglylocalyxtalbotii*, *A. bullatus: Allophylusbullatus, A. vogelianum: Antidesmavogelianum, B. letouzei : Beischmiedialetouzeyi, C.glauca : Caloncoba glauca, C. grandifolia : Carapagrandifolia, C. angustifolius : Chytranthusangustifolius, C. hispida : Cola hispida, H. zenkeri : Hypodaphniszenkeri, G. boukokoensis : Gambeyaboukokoensis, G. coriacea : Grewiacoriacea, G. macrantha : Grosseramacrantha*)

However, these species observed in both forests have different absolute abundances; Figure 3 shows the numbers of the 12 most abundant common species in the two forests. Species showing high absolute abundances in Bangang compared to Fossimondi are represented by: *Anglylocalyx talbotii* (241 individuals, Photo1), *Beischmiedialetouzeyi* (76 individuals), *Chytranthusangustifolius* (102 individuals), *Cola hispida* (98 individuals) and *Hypodaphniszenkeri* (50 individuals). In Fossimondi, on

Comment [J12]: Texts written in English use "." to separate decimal places and "," as miliar separator. Review in all cases.

Comment [J13]: Whittaker curves can best express abundance

Comment [J14]: Add author of the species, according to the rules of scientific nomenclature in Botany. In all cases

Comment [J15]: Linked words, see this throughout the text in all cases

the other hand, the species with high absolute abundances compared to Bangang are: *Allophylus bullatus*(19 individuals), *Caloncoba glauca* (73 individuals, Photo2), *Gambeyabou kokoensis* (54 individuals) and *Grosseramacrantha* (49 individuals). The ratio of number of species/number of genera or specific quotient (Q) is 1.19 and 1.18 for the Fossimondi and Bangang forests, respectively.

Figure 4: Young pods of *Angylocalyxtalbotii* in Bangang forest (photo1Ndam W.T.) *Caloncoba glauca* flower in the Fossimondi forest (photo2Tiokeng B.)

Comment [J16]: Pictures of one or two species recorded do not help the reader to understand more about the study, on the contrary, the question arises, why not the other species? I suggest the removal of Figure 4 from the text and its inclusion as supplementary material to the article, where authors can add a list of identified species and photos of all or most abundant ...

Among the exclusive species of the submontane forest, there are several abundant species: Heckeldora ledermannii (478 individuals), Santiria trimera (456 individuals) Tabernaemontana sp. (274

Formatted: Font: Not Italic

individuals), Leptaulus daphnoïdes (232 individuals). In the middle altitude forest, Napoleonaea egertonii (297 individuals), Cola chlamydantha (230 individuals), Alexis cauliflora (144 individuals) and Diogoa zenkeri (263 individuals) are highly representative among the species that are exclusive to it.

3.2. Specific diversity

Examination of the diversity indices (Table 2) reveals that they vary little, not only within the same stand but also between the two forest communities. Shannon diversity index ranges from 2.63 to 3.43 (3 ± 0.25 on average) in the Fossimondi forest. It is between 2.78 and 3.73 (3.17 ± 0.22 on average) in Bangang Forest. Pielou's Equitablity varies between 0.74 and 0.95 (0.80 ± 0.03 on average); between 0.76 and 0.89 (0.83 ± 0.03 on average) respectively in Fossimondi and Bangang. The Simpson index is between 0.86 and 0.95 (or 0.91 ± 0.02 on average); between 0.89 and 0.96 (or 0.92 ± 0.02 on average) in Fossimondi and Bangang respectively. The comparison of the values of each index between the two forest communities using ANOVA test shows that there is no significant difference between the averages of these different indices obtained in the two forests (Table 2).

Comment [J17]: Rarefaction curves can better demonstrate the wealth relationship between the two environments

Comment [J18]: The anova test would be indicated to compare the abundance obtained for each sample. It is not indicated to compare indices that may already biased due to sample effort or randomization of sample units

Table 2: Variation of diversity indices in the Fossimondi (FD) and Bangang (BG) forest *plots H: Shannon index;Eq : Equitability of Pielou ; D' : Simpson diversity, Al : altitude, $\bar{x}$: mean*

Comment [J19]: Citing the altitude of the sample units would be more informative a correlation test with the variables of richness and abundance

Mid-altitude forest				
Plots	H	Eq	D'	Al (m)
BG1	3,63	0,88	0,96	431
BG2	3,15	0,84	0,93	613
BG3	3,1	0,82	0,91	544
BG4	3	0,79	0,91	298
BG5	3,09	0,89	0,96	304
BG6	3,17	0,86	0,95	216
BG7	3,37	0,82	0,96	577
BG8	3,28	0,84	0,94	388
BG9	3,14	0,83	0,93	322
BG10	2,78	0,76	0,89	291
$\bar{x}$Indices	3,17 ± 0,22**a**	0,83 ± 0,03**a**	0,92 ± 0,02**a**	

Submontaneforest				
Plots	H	Eq	D'	Al (m)
FD1	2,89	0,78	0,9	1585
FD2	2,83	0,79	0,9	1451
FD3	2,63	0,74	0,86	1392
FD4	3,19	0,82	0,94	1431
FD5	3,43	0,87	0,95	1246
FD6	2,86	0,81	0,92	1405
FD7	2,99	0,83	0,92	1354
FD8	3,17	0,80	0,93	1440
$\bar{x}$indices	3 ± 0,25**a**	0,80 ± 0,03**a**	0,91 ± 0,02**a**	

The values of each mean per column followed by the same letter are not significantly different (p = 0.05).

3.4. Frequency, dominance and basal area

Table 3 summarizes some parameters (relative dominance (Do), relative frequency (Fr) and basal area (ST) that highlight the horizontal structure of each forest formation studied. It includes the ten most dominant species in the two forests. In the Fossimondi forest the most dominant species (13.10%), the most frequent (2.43%) and showing the highest basal area (31.54 m^2/ha) is Santiriatrimeria; other species with a high dominance are: Cola acuminata (6.35%), Leptaulusdaphnoïdes (4.40%), Cola digitata (4.39%), Tabernamontana sp. (3.41%), Drypetesmolunduana (3.02), Placodiscusangustifolius (2.22%), Zenkerellacitrata (1.53%), Rinorealongipetalum (1.48%) and Ritchieamacrantha (1.45%). In contrast, in the Bangang forest, Piptadeniastrumafricana is the most dominant species (9.85%) while Napoleonaeaegertonii has the largest basal area and is also the most frequent (2.26%) and most dominant (5.46%). The other most dominant species are: Pycnanthusangolensis (5.25%), Hymenostegiaafzelii (4.35%), Lophiraalata (4.08%), Irvingiagabonensis (3.94%), Diogoazenkeri (3.03%), Cordia platythyrsa (3.00%), Pentadesmagrandifolia (2.92%) and Beilscmiedialetouzei (1.61%). These dominant species differ completely from one forest to another. The average overall basal area is 60.9 ± 15.38 m^2/ha for Fossimondi Forest and 52.63 ± 16.19 m^2/ha for Bangang Forest respectively.

Table 3: Some of the most important species in terms of relative dominance *(Do), basal area (ST) and relative frequency (Fr) in the Fossimondi (FDI) and Bangang (BG) forests*

	D (%)		Fr (%)		ST(m^2/ha)	
Species	FDI	BG	FDI	BG	FDI	BG
Piptadeniastrum africana	0,00	9,85	0,00	0,90	0,00	1,70
Napoleonaea egertonii	0,00	5,46	0,00	2,26	0,00	5,84
Pycnanthus angolensis	0,00	5,25	0,00	2,03	0,00	5,45
Hymenostegia afzelii	0,00	4,35	0,00	0,90	0,00	0,97
Lophira alata	0,00	4,08	0,00	0,45	0,00	3,60
Irvingiagabonensis	0,00	3,94	0,00	1,13	0,00	4,08
Diogoazinkeri	0,00	3,03	0,00	0,90	0,00	2,04
Cordiaplatythyrsa	0,00	3,00	0,00	0,22	0,00	3,06
Pentadesmagrandifolia	0,00	2,92	0,00	0,90	0,00	3,06
Beilschmiedialetouzeii	0,00	1,61	0,00	1,58	0,00	1,84
Santiriatrimeria	13,10	0,00	2,43	0,00	31,54	0,00
Cola acuminata	6,35	0,00	0,91	0,00	15,23	0,00
Leptaulusdaphnoides	4,40	0,00	0,60	0,00	10,57	0,00
Cola digitata	4,39	0,00	0,34	0,00	10,55	0,00
Tabernamontanasp.	3,41	0,00	2,13	0,00	8,18	0,00
Drypetesmolunduana	3,02	0,00	1,52	0,00	7,26	0,00
Placodiscusangustifolius	2,22	0,00	0,91	0,00	5,34	0,00

Comment [J20]: Times new roman ?

Comment [J21]: Author... see al cases

Comment [J22]: Scientific Names in Italic

Comment [J23]: Use "." as decimal separator

Zenkerellacitrina	1,53	0,00	0,69	0,00	3,68	0,00
Rinoreaoblongifolia	1,48	0,00	1,21	0,00	3,57	0,00
Ritchieamacrantha	1,45	0,00	0,91	0,00	3,49	0,00

3.5. Family Dominance

In terms of relative family dominance, Figure 5 shows the predominance of Fabaceae (12.19%), *Malvaceae* (6.61%) and *Myristicaceae* (6.53%) in the Bangang Mid Altitude Forest. In the submontane forest of Fossimondi, there is a significant overlap of Burseraceae (31.43%), *Sterculiaceae* (29.74%) and *Euphorbiaceae* (18.84%). According to the specific richness of the families, the Bangang forest is dominated by *Euphorbiaceae* (15 species), *Fabaceae* (*Leguminoseae*) forest with 15 species including six *Caesalpiniaceae*, five *Papillionaceae* and four *Mimosaceae* and *Malvaceae* (14 species) while in the Fossimondi forest we notice *Rubiaceae* (19 species) and *Euphorbiaceae* (13 species).

(a) (b)

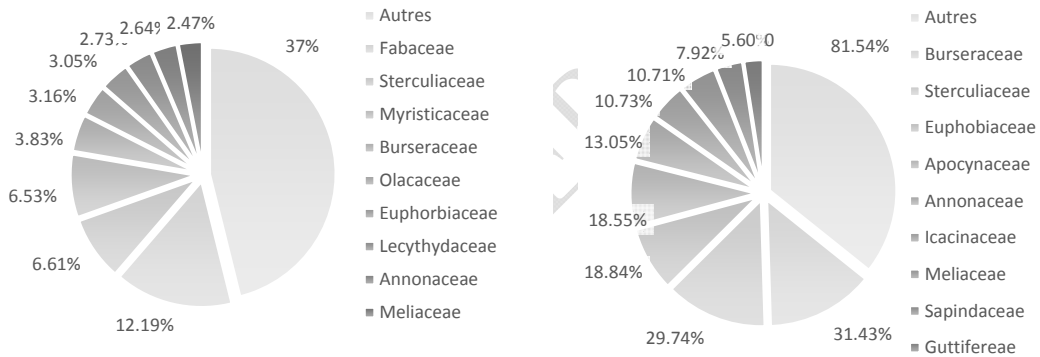

Figure 5: Relative dominance (Do) of the 10 most represented families in Bangang (a) and Fossimondi (b)

Comment [J24]: Replace with a table, listing the families one below the other. The percentages placed side by side for each environment will facilitate comparison by the reader

3.6. Diameter classes

Large shrubs [10-20] are strongly represented (Fig. 6) both in Bangang Forest (802 individuals/ha) and Fossimondi Forest (978 individuals/ha). The small trees (20 to 50 cm in diameter) show the mean absolute abundance of 97 individuals / ha and 127 individuals / ha for Bangang and Fossimondi forests respectively. Individuals with diameters greater than 50 cm are very poorly represented and decrease sharply as the diameter increases. They now show only 5 and 7 individuals / ha respectively in the Bangang and Fossimondi forests. This abundance decreases even more rapidly when tending towards large trees. The Chi-square test applied to compare the number of individuals between the diameter classes of the two zones show that there is no significant difference in the number of individuals in these classes compared (X^2=19.67, α = 0.05).

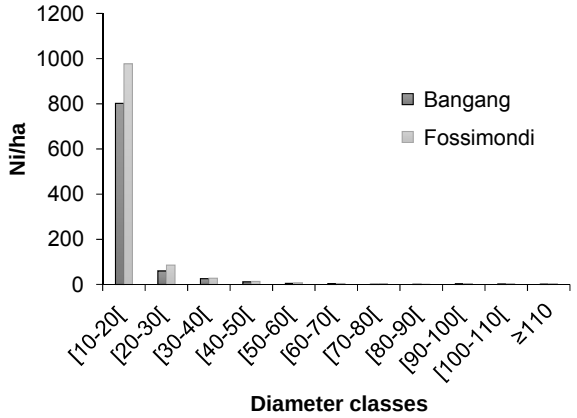

Figure 6: Distribution of individuals per hectare by diameter classes in Bangang and Fossimondi mid-altitude and submontane forests (Ni: number of individuals per hectare)

3.7. Phytogeographic distribution of taxa

In the Fossimondi forest, the phytogeographical status could be attributed to 131 species out of the 168 inventoried. In the Bangang forest, the phytogeographic status was determined for 139 out of 160 species recorded. The basic element in both forests is formed by species with a lower Guinean-dominant phytogeographic area (Figure 7). The proportions of this element are higher in Bangang Forest (56%) than in Fossimondi Forest (34.24%). Next come the Guinea-Congolese domain species with proportions of 31% and 20%, respectively, in the Bangang and Fossimondi forests. The other phytogeographical elements consisting of widely distributed species from southwest Cameroon, the Upper Guinea and Cameroon are much more abundant in Fossimondi and thus reflect the floristic particularity of this submontane forest formation. A total of 17 endemic species in Cameroon have been recorded. In general, both forests are of the same phytogeographic origin. The chi-square test used to compare the proportions of phytogeographic elements recorded in the two forests does not show significant differences in these proportions between the two phytogeographic distributions (X^2=11.07, α = 0.05).

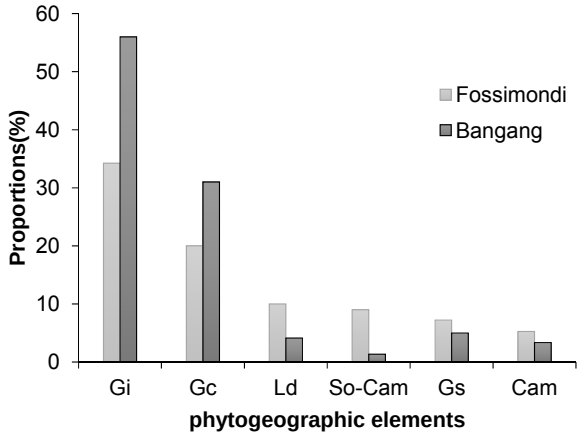

Figure 7: Comparative phytogeographic spectra of species in the Fossimondi and Bangang forests *(Ld: Broadly distributed species, Gc: Guineo-Congolese, Gs: Upper Guinean, Gi: Lower Guinean, Cam: Cameroon and So-Cam: Southwest Cameroon).*

Formatted: Font: Not Italic

4.DISCUSSION

4.1. Composition, richness and diversity of flora

The mean absolute abundance values (855.3±32 individuals/ha and 1182.5 ±38 individuals/ha respectively in Bangang and Fossimondi forest) are close to those observed by Tiokeng[**51**] in Mekoup forest (894 ± 22 individuals/hectare) located at 2740 m on the Bambouto mountains. However, they are higher than those observed in other dense forests in tropical Africa. This is the case of the Ngovayang forest in southern Cameroon [**19**] which shows an average of 532±75 individuals/hectare, the Monte Mitra forest in Equatorial Guinea with 548 ± 108 individuals/hectare [**7**], the Monts Cristal in Gabon which shows 562 ± 17 individuals/hectare [**47**], forest species from Takamanda in southwest Cameroon with 446 ± 40 individuals/ha [**46**], and Nouabale-Ndoki in Congo with 300 individuals/hectare [**48**]. The specific richness registered in the Lebialem Highlands (Bangang, Fossimondi) is closer to that observed by other researchers [**38,46**]. However, they are significantly lower than those observed by Balinga[**8**]. The low values of the specific quotient values recorded in the two forests reflect their maturity [**21**].

Comment [J25]: What can explain these differences? describe if this is due to climate, relief, anthropic actions ...

The Shannon diversity index values obtained in this study indicate that these ecosystems are rich in species according to Kent & Coker [**23**]. These results confirm those of Pielou's Equitability which are ranged in Odum optimal interval [**36**]. These results indicate a more or less regular distribution of individuals within species, but also the stability of these forests. Simpson index data are comparable to those observed not only in Niger's Fauna forest galleries, which range from 0.86 to 0.96 [**1**] and in Ruvubu National Park by MASHARABU et al [**30**] in Burundi (0.94 -0.96). They are also comparable to those observed in the sacred forest of Mbing Mekoup by Tiokeng[**51**] in the Western Highlands of Cameroon (0.63 to 0.89). They are close to the value one and thus reflect a high diversity in both sites [**39**].

The particular richness of *Euphorbiaceae* noted in both forests as well as *Rubiaceae* in Fossimondi forest has been observed by other researchers, particularly in Campo-Ma'an forest in southern Cameroon [**50**]. The high values of species richness, species diversities and abundances observed in the studied sites as well as the floristic specificities can be attributed to a variability in ecological niches that accompany changes in relief and altitudinal gradient. In addition, soil texture and moisture content (proximity to rivers, hilltops) are variable and can be a factor in species variations. More generally, small-scale climate variability related to relief and altitude determines factors such as sun exposure and temperature that may explain the spatial and temporal distribution of taxa. Indeed, the mountainous terrain leads to variations in temperature and precipitation as well as certain climatic conditions in submontane areas (presence of clouds and fog) that can contribute significantly to the high diversity and structure of these ecosystems. In addition, the location of the study site in a region influenced by the Atlantic monsoon gives it moisture from the Atlantic Ocean and high amounts of precipitation (≥ 2000 mm an-1) [**45**]. It has also been shown that, during arid periods, persistent stratiform clouds along the Atlantic coast of Central Africa have been a source of small precipitation and moisture in the lower hills and mountains, under a generally dry climate [**27**], thus helping to maintain forest cover during the past geological times in the coastal regions of the Gulf of Guinea. According to Pascal [**37**], higher species richness may also result from the degree of resilience of the ecosystem or its adaptability to global climate variations. For example, it can be assumed that the floristic characteristic of the vegetation on the western flank of the Bambouto Mountains is related to the fact that it has been little disturbed by climatic variations at different temporal scales observed at several sites in Central Africa [**27,52**].

The Fabaceae family is among the most dominant in the Bangang forest, the importance of this family is one of the characteristics of the Guineo-Congolese forests [**54**; such dominance has been observed in other dense humid forests in tropical Africa [**19,50**]. However, this family is totally absent in the Fossimondi forest where the Burseraceae are the most important. Burseraceae would be among the families considered as indicators of mature Atlantic forests [**42**]. The numerical importance of these families would reflect the resistance capacity of the seedlings of these families and better regeneration despite environmental constraints.

4.2. Structural elements

An examination of the highly dominant species in the two forests shows that they are different from one forest to another. The variability of climatic factors such as precipitation, temperature, cloud cover and even variation in human influence could explain these differences. These species with significant dominance are not necessarily the most frequent. Indeed, in dense tropical humid forests, the high species richness makes a large number of species uncommon or rare; therefore, most of the forest's structure and biomass is composed of a relatively small number of species [11,**37**].

The average overall basal area of stands (60 m2/ha and 52 m2/ha respectively in Fossimondi and Bangang forests) shows higher values than those found in Ngovayang forests [**19**] with 34.6 m2/ha, Monte Mitra in Equatorial Guinea [**7**] with 31.2 m2/ha, Crystal Mountains in Gabon (Sunderland et al. 2004) with 39.5m2/ha. Nevertheless, they remain within the range ofbasal area commonly recorded in dense tropical rainforests. Indeed, Mosango & Lejoly [**31**] showed in dense tropical forests that basal areas generally vary between 25 and 50 m2/ha.

The distribution of diameter classes is that of a function close to a decreasing exponential as often found in dense tropical rainforests (Pascal 2003; [**1**]). This distribution is characterized by the high density of small diameter and young individuals in the stand unlike large individuals who have few surviving members when they approach the seed class. Some factors, such as relief, soil and altitude, could influence the diameter growth of individuals. Indeed, some authors such as Aiba & Kitayama [**2**]have shown a decrease in the average tree size with increasing altitude. Similarly, in hilly areas with steep slopes, the soils are less stable and could not support very large trees. No large-scale logging has yet been carried out in the study area; sampling remains limited to medicinal plants and firewood, so the distribution observed is probably natural.

Comment [J26]: Discuss the anthropic action, Can the anopic action influence the number of plants per hectare and the mean diameter of the plants by the eventual cut of plants with larger diameter?

4.3. Phytogeographic types

The floristic background is dominated by species from the lower Guinean domain (56% and 34.24% respectively in Bangang and Fossimondi). These values are comparable to those obtained in Ngovayang by Gonmadje et al [**19**] (32%), Korup by Kenfack et al [**33**] (44%) and Monte Alen by Senterre[**41**] (45%). However, they are significantly higher than those noted in the Dja reserve by Senterre (23%), Campo-Ma'an by Tchouto et al. [**50**] (29%) and the central forests of Gabon by Doucet (2003) where 22% of species in the lower Guinean domain are observed. The predominance of this phytogeographic element in the sites is consistent with the belonging of the flora studied in this phytogeographic sector as defined by Aubreville[**3**]and White[**53**]. We can also think of the maturity of these forests because they seem to be very little degraded. This Lower Guinea area is influenced by the Atlantic monsoon and the cooling effect of the Benguela current, which results in high atmospheric humidity even in the dry season [**45,54**].

5.CONCLUSION

Comment [J27]: Times new roman ?

Despite the relatively high altitude of the two forests studied, the analysis of the flora of these communities shows the main features of dense humid forests. The diversity and specific richness of the Fossimondi and Bangang forests are comparable to those recorded in tropical African forests; they are very rich forests. The most significant differences in these two forests are in their floristic composition and in the importance of certain taxa in terms of number of individuals and basal area. If *Sterculiaceae* are among the most dominant families in both forests, Burseraceae and *Euphorbiaceae*have a greater importance in Fossimondi forest while this predominance is attributed to *Myristicaceae* and Fabaceae in Bangang. Environmental factors lead to a selection of the most suitable species for each site. Unlike the Fossimondi forest where *Santiriatrimeria* and *Cola acuminata* are the most dominant, the Bangang forest is dominated by *Piptadeniatrumafricana* and *Napoleonaeaegertonii*. The global status of species according to the IUCN Red List revealed 10 vulnerable and 5 endangered species. *Rhaptopetalumgeophylax*, *Medusandrampomiana*, *Argocoffeopsisfosimondi*, *Medusandrampomiana*, *Oncobalophocarpa*, *Deinbolliaoreophila*, *Napoleonaeaegertonii* are among the endemic plants identified in the site. Although work on wildlife is also rare in this area, some research by non-governmental organizations such as ERuDeF (Environment and Rural Development Foundation) on birds on the western flank of the Bamboutos (Lebialem Highlands) has identified several endemic birds (*Tauracobannermani*, *Bradypterusbangwaensis*, *Platysteiralaticincta*, *Ploceusbannermani*) and some mammals (*Loxodantaafricana, Gorilla gorilladeihli*, *Troglodytes vellerosus*, *Cercopithecus nictitans*, *Cercopithecuserythrotis*, *Cephalophusogilbyi*) within the site. However, it would be interesting for further studies to focus not only on the diversity of the fauna even less explored but also on the flora of epiphytes, orchids, vines and herbaceous plants. Similarly, soil analysis of these ecosystems would provide a better understanding of their relationship to the living environment.

Comment [J28]: Include author name descriptor This is a discussion

Comment [J29]: Should areas be preserved? or can they be managed and exploited? Given the richness and abundance found, can environments contribute to the conservation of endemic and endangered species? These answers should be in the conclusion.

Ethics approval and consent to participate
Not applicable.
Consent for publication
Not applicable.
Availability of data and material
No additional data are required; all information is clearly stated in the main manuscript.
Competing of Interests
There is no competing interest.

REFERENCES

[**1**]Agbodjogbe GJ*.Analyse de la Structure des Galeries Forestières de la Réserve Totale de Faune de Tamou (RTFT) en République du Niger*. Mémoire de Master international, BEVT, Muséum National d'Histoire Naturelle, Paris IRD, Sud expert plantes, Université de Dschang, Université Abdou Moumouni .59 p ;**2011**.

[**2**]Aiba S-I, Kitayama K. Structure, composition and species diversity in an altitude –subtrate matrix of rain forest trees communities on Mount Kinabalu, Bornéo. *Plant Ecologie* **.1999 ;140** : 139-157.

[**3**]Aubreville A. Position chorologique du Gabon. *In*: Flore du Gabon 3: 3–11. Paris, Muséum National d'Histoire Naturelle ;**1962**.

[**4**]Achoundong G. Les forêts sommitales au Cameroun. *Bois et Forêts des Tropiques*.**1996** ; 247 : 37-53. French

[**5**]Amine M, Bessong J.B. Conserving biological diversity in managed tropical forest. *In:* Blockhus J.M., Dillenbeck M, Sayer J.A. The IUCN Forest conservation programme. Gland, Switzerland: IUCN; Yokohama, Japan: ITTO, 1-15; **1992**.

[**6**]Angiosperm Phylogeny Group (APG III). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *In* Botanical Journal of the Linnean Society. **2009**; 161(2)105-121http://dx.doi.org/10.1111/j.1095-8339.2009.00996.x

[**7**]Balinga MPB, Issembe Y.A, Sunderland T.C.H, Nzabi T, Obiang D, Nyangadouma R. Quantitative vegetation assessment of the Monte Mitra forest using 1-hectare biodiversity plots (BDP's). *In*: Sunderland TCH(ed) A biodiversity assessment of the Monte Mitra forest, Monte Alen National Park, Equatorial Guinea. http://carpe.umd.edu/resources/Documents/. 94 p; **2005**.

[**8**]Balinga MPB. A vegetation assessment of the Waka national park, Gabon. CARPE Report. 34 p. http://carpe.umd.edu/resources/Documents/; **2006**.

[**9**]Bergl, RA., Oates, JF., Fotso, R. (2007) Distribution and protected area coverage of endemic taxa in West Africa's Biafran Forests and Highlands. *BiologicalConservation,* 134: 195-208. http://dx.doi.org/10.1016/j.biocon.2006.08.013

[**10**] Cheek M, Pollard JB, Darbyshire L, Onana J-M, Wild C. The plants of Kupe, Mwanenguba and the Bakossi Mountains, Cameroun. A conservation Checlist. Royal Botanic Gardens, Kew Richmond, Surrey, TW9 3AB, UK. 508 p; **2004**.

[**11**]Collinet F. Essai de regroupement des principales espèces structurantes d'une forêt dense humide d'après l'analyse de leur répartition spatiale (forêt de Paracou - Guyane). Thèse, Université Claude Bernard-Lyon 1. 313 p ;**1997**. French

[**12**]Dajoz R. Précis d'écologie, Paris, Dunod-Sciences sup, 615 p ; **2003**. French

[**13**]Ekoko F. The political Economy of the 1994 Cameroon Forestry Law. CIFOR Centre for *International Forestry Research* (CIFOR). 41p; **1997**.

[**14**]FAO. Evaluation des résourcesforestièresmondiales 2000. Rapport principal, Etude FAO, Forêts, Rome 140 p; **2001**.French

[1**5**]FAO. Evaluation des ressources forestières. Document de travail. FAO, 25p ; **2010**.

[**16**]Focho DA, Ndam WT, Fonge BA. Medicinal plants of Aguambu –Bamumbu in the Lebialem highlands, Southwest province of Cameroon. *African Journalof Pharmacy and Pharmacology*.**2009**; 3(1): 001-013.

[**17**]Fonge BA, Tchetcha DJ, Nkembi L. Diversity, Distribution, and Abundance of Plants in Lewoh-Lebang in the Lebialem Highlands of Southwestern Cameroon.*International Journal of Biodiversity*. **2013**; Volume 2013(2013), Article ID 642579, 13 p. Hindawi Publishing Corporation http://dx.doi.org/10.1155/2013/642579

[**18**]Grall J, Coïc N. Synthèse des méthodes d'évaluation de la qualité du benthos en milieu côtier. Réseau benthique (REBENT), Institut universitaire Européen de la Mer, Université de Bretagne occidentale, Laboratoire des sciences de l'environnement marin. 91 p;**2005**. Available: www.rebent.org French

[**19**]Gonmadje C.F, Doumenge C, Mckey D, Tchouto G.P.M, Sunderland T.C.H, Balinga M.P.B, Sonké B. Tree diversity and conservation value of Ngovayang's lowland forests, Cameroon.*Biodiversity and* conservation. **2011** ;20 (12) : 2627-2648. http://dx.doi.org/10.1007/s10531-011-0095-z

[**20**]Hakizimana P, Bangirinama F, Habonimana B, Bogaert J. Analyse comparative de la flore de la forêt dense de Kigwena et de la forêt claire de Rumonge au Burundi. *Bulletin Scientifique de l'Institut National pour l'Environnement et la Conservation de la Nature.***2011**;9 : 53-61. French

[**21**]Hakizimana P, Bangirinama F, Havyarimana F, Habonimana B, Bogaert J. Analyse de l'effet de la structure spatiale des arbres sur la régénération naturelle de la forêt claire de Rumonge au Burundi. *Bulletin Scientifique de l'Institut National pour l'Environnement et la Conservation de la Nature*.**2011** ;9 : 46-52 French

[**22**]Harvey Y, Tchiengué B, Cheek M. The Plants of LebialemHighlands,Cameroon : A Conservation Checklist.Royal Botanic Gardens: Kew; 170p; **2010**.

[**23**] Kent M, Coker P. Vegetation description and analysis - a practical approach. John Wiley & Son. 354p. + annexes;**2003**.

[**24**]Kier G., Barthlott W. Measuring and mapping endemism and species richness: a new Methodological approach and its application on the flora of Africa. *Biodiversity and Conservation* .**2001**;10:1513–1529 http://dx.doi.org/10.1023/A:1011812528849

[**25**]Letouzey R.Notice de la carte phytogéographique du Cameroun au 1/500 000. Domaine de la forêt dense humide toujours verte. Toulouse, France : Institut de laCarte Internationale de la Végétation ; Yaoundé : Institutde la Recherche Agronomique (Herbier National), 62-142 ; **1975**.French

[**26**]Lovett JC, Rudd S, Taplin J, Frimodt-Moller C. Patterns of plant diversity in Africa south of the Sahara and their implications for conservation management. *Biodiversity and Conservation.***2000**;9:37–46 http://dx.doi.org/10.1023/A:1008956529695

[**27**]Maley J. Fragmentation de la forêt dense humide africaine et extension des biotopes montagnards du quaternaire récent : nouvelles données polliniques et chronologiques. Implications paléoclimatiques et biogéographiques. *PaléoécologieAfricaine*; **1987**.18:307–334 French

[**28**]Maley J, Brenac P. (1998) Vegetation dynamics, paleoenvironments and climatic changes in the forests of western Cameroon during the last 28,000 years B.P. *Review of Palaeobotany and Palynology*.**1998**; 99 (2):157-187 http://dx.doi.org/10.1016/S0034-6667(97)00047-X

[**29**]Marion B. Impact du pâturage sur la structure de la végétation : interactions biotiques, traits et conséquences fonctionnelles. Thèse de Doctorat / Université de Rennes 1, sous le sceau de l'Université Européenne de Bretagne. Mention : Biologie. Ecole Doctorale Vie- Agro-Santé. Unité de recherche 6553 EcobioEcosystèmes, Biodiversité, Evolution. UFR Sciences de la Vie et de l'Environnement. 236 p;**2010**French.

[**30**]Masharabu T, Noret N, Lejoly J, Bigendako MJ, Bogaert J. Etude comparative des paramètres floristiques du Parc National de la Ruvubu, Burundi.*International journal of tropical geology, geography and ecology*.**2010** ; 34: 29 - 44 French

[**31**]Mosango M, Lejoly J. La forêt dense à *Piptadeniastrumafricanum*et *Celtismildbraedii*des environs de Kisangani (Zaïre). 12eCongrès AETFAT. Mitteilungenaus dem InstitutfürallgemeineBotanik in Hamburg 23b: 853-870;**1990**. French

Formatted: Spanish (Colombia)

[**32**]Myers N, Mittermeier RA., Mittermeier CG, DA Fonseca, Gab Kent J. Biodiversity hot spots for conservation priorities. *Nature*. **2000**; 403:853–858http://dx.doi.org/10.1038/35002501

[**33**]Kenfack D, Duncan WT, Chuyong G, Condit R. Rarity and abundance in diverse African forest. *Biodiversity and Conservation.*2006;**16**: 2045-2075. DOI 10.1007/s10531-006-9065-2

[3**4**]Ndih J.K. Déforestation au Cameroun : causes, conséquences et solutions. *Alternative Sud.***2008** ; 15 : 155-174 French

[**35**]Nzogning A, Le Mont Cameroun : un volcan actif. Contribution à l'étude géographique physique appliquée. Thèse de doctorat 3ème cycle, Université de Yaoundé. 447 p ; **1997**.

[**36**]Odum E.P. Écologie. Doin, Paris, 257 p ;**1976**. French

[**37**]Pascal J-P. Notions sur les structures et dynamiques des forêts tropicales humides. Descriptions et dynamique des milieux forestiers. *Revue. Forestière. Française.* LV numéro spécial 2003, p.118-130 ;**2003**. http://hdl.handle.net/2042/5765 DOI : 10.4267/2042/5765 French

[**38**]Parmentier I, Harrigan RJ, Buermann W, Mitchard ETA, Saatch S, Malhi Y, Bongers F et al. Predicting alpha diversity of African rain forests: models based on climate and satellite-derived data do not perform better than a purely spatial model. *Journal of Biogeography*;**2013**. doi:10.1111/j.1365-2699.2010.02467.x

[**39**] Pearson TH, Rosenberg R. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanographiy Marine Biology Annual Review*.**1978**;229-311. French

[**40**]Pielou EC. An introduction to Mathematical Ecology. Wiley Interscience, John and Sons, New York. 286 p;**1969**.

[**41**]Senterre B. Recherches méthodologiques pour la typologie de la végétation et la phytogéographie des forêts denses d'Afrique tropicale. Thèse de doctorat, Université. Libre de Bruxelles, Belgique 345 p ;**2005**. French

[**42**]Senterre B, Lejoly J. treesdiversity in the Nsockrainforest (Rio Muni, Equatorial Guinea). Acta botanica Gallica.**2001**;148(3):227-235 DOI: 10.1080/12538078.2001.10515890

[**43**]Sonké B, LEJOLY J. 1998. Biodiversity study in Dja Fauna Reserve (Cameroon): using the transect method. *In*: C.R. Huxley, J.M. Lock & D.F. Cutler (eds.) Chorology, Taxonomy and Ecology of the Floras of Africa and Madagascar, Royal Botanic Gardens, Kew, 171-179p;**1998**.

[**44**]Sonké B. Forêts de la Réserve du Dja (Cameroun) : Etudes floristiques et structurales. *Scripta BotanicaBelgica*. **2005** ;32: 144. French

[**45**]Suchel J-B. La répartition des pluies et les régimes pluviométriques au Cameroun. Travaux et Documents de Geographie Tropicale, CEGET-CNRS, Bordeaux, France et Université Fédérale du Cameroun, Yaoundé, Cameroun 287 p ; **1972**.French

[**46**]Sunderland TCH, Comiskey JA, Besong S, Mboh H, Fonwebon J, Dione MA. Vegetation assessment of Takamanda Forest Reserve, Cameroon. *In*: Comiskey JA, Sunderland TCH, Sunderland-Groves JL (eds) Takamanda: the biodiversity of an African rainforest, SI/MAB series.**2003**;8:19-53Smithsonian *BiodiversConserv*institution, Washington.http://nationalzoo.si.edu/ConservationAndScience/MAB/conservation/about/publications.cfm

[**47**]Sunderland TCH, Walters G, Issembe Y. A preliminary vegetation assessment of the Mbé National Park, Monts de Cristal, Gabon. CARPE Report. http://carpe.umd.edu/resources/Documents/ 51p;**2004**.

[**48**]Sunderland TCH, Balinga MB (2005) E ´ valuation preliminaire de la vegetation du parc national de Nouabale ´-Ndoki et de sa zone tampon, Congo. CARPE Report. http://carpe.umd.edu/resources/Documents/.

[**49**]Tchiengue B. Etude écologique et floristique de la végétation d'un massif de la ligne du Cameroun : le Mont Koupe, Thèse de Doctorat 3e cycle, Université de Yaoundé I. 238 p ;**2004**. French

[**50**]Tchouto G.P, Yemefack M, de Boer WF, De Wilde JJFE, Cleef A.M. Biodiversity hotspots and conservation priorities in the Campo-Ma'an rainforests, Cameroon. *Biodiversity and Conservation.***2006** ;15 :1219-1252 http://dx.doi.org/10.1007/s10531-005-0768-6

[**51**]Tiokeng B. Diversité, structure, utilisations et mode local de conservation de quelques forêts sacrées dans les Hautes Terres de l'Ouest du Cameroun. Thèse de Master, Université de Dschang. 122 p;**2009**. French

[**52**] Vincens A, SchwartZ D, Elenga H, Reynaud-Farrera I, Alexandre A, Bertaux J et al. (1999) Forests response to climate changes in Atlantic Equatorial Africa during the last 4000 years BP and inheritance on the modern landscapes. *Journal of Biogeography*. **1999**; 26: 879–885. http://dx.doi.org/10.1046/j.1365-2699.1999.00333.x

[**53**]White F. The Guineo-Congolian Region and its relationships to other phytochoria. *Bull. Jard. Bot. Nat. Belg.***1979**;49 (1/2): 11-55. http://dx.doi.org/10.2307/3667815

[**54**] White F. The Vegetation of Africa. A descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa. Natural Resources Research, 20, UNESCO, Paris. 356 p;**1983**.