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**RESEARCH PAPER**

# Woody vegetation groups and diversity along the altitudinal gradient in mountain forest: case study of Kahuzi-Biega National Park and its surroundings, RD Congo

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**Key words:** Forest type, Woody distribution, Diversity, Altitude, Mountain forest .

## Abstract

This study aims to determine the type of mountain forests in the Albertine Rift, to understand the distribution of woody species DBH ≥ 10 cm and their diversity. The investigations were conducted within 30 plots of 1 hectare located in Kahuzi Biega National Park and surrounding areas in DR Congo into mountain forest only. In total 16 797 individuals belonging to 212 specific taxa, 161 genera and 66 families were asses. Four forests types were identified along an altitudinal gradient using a hierarchical clustering (HCS) coupled to a correspondence analysis (AFC). These types are sub-mountain (1250-1500 m), lower mountain horizon (1500-1800 m), medium mountain horizon (1800-2400 m) and upper mountain horizon (2400-2600 m). Each forest type is characterized by a specific number of indicators species. The Sarcochore is the dissemination mode which dominates in the lower altitudes (1250-1800 m) and the Ballochore within higher altitudes (1800-2600 m). Based on the analyzes of variance (ANOVA), regression and correlation, the results showed that in general woody diversity decreases as altitude increases but exceptionally, only the specific abundance was positively correlated with the elevation. The additional study of the structural variability in forest types distinguished remains important to improve the understanding of functioning of these mountain ecosystems and ensure their better sustainability.

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## Introduction

Forests assure multiple functions. One of the most currently discussed is their contribution in climate change mitigation (Lescuyer and Locatelli, 1999; Locatelli *et al.*, 2008; GIEC, 2014). This function refers to the ability of forest ecosystems to be or not carbon sinks. The amount of aboveground biomass accumulated in forest ecosystem depends on the forest type. Therefore, the understanding forest composition and diversity is important before assessing its contribution to climate change mitigating (Henry *et al.*, 2010; Djomo *et al.,* 2010; Moonen *et al.,* 2014). This remains the case for mountain forests in the Congolese Albertine Rift.

Due to a high diversity, the difficult and always fragmentary systematic knowledge and to the different morphologies that take plants according to different altitudes, mountain forests attract researcher's attention for the past few decades to understand their role in the dynamic ecosystem functioning linked with changes in florist composition, diversity and structure (Plumptre *et al.*, 2007; Guillaumet, 2009; Delnatte, 2010). we note that these forests are rich in plant communities (Mutke *et al.,* 2011) and the Albertine Rift is known to be one of the hotspot areas of global biodiversity (Myers *et al.,* 2000; Linder, 2001).

Because of its recent creation (1970), Kahuzi-Biega National Park (KBNP) was not part of those protected areas intensely explored between 1920 and 1960 (Mangambu, 2013) despite its strategic phytogeographical position. The majority of scientific investigations carried out directly on this site are largely post-colonial. Among the most relevant, are the inventories of some taxonomic groups, such as wood-destroying fungi (Balezi, 2013), diversity in Bamboo community (Amani *et al.,* 2008), biogeography and systematic of ferns (Mangambu, 2013) and some forest dynamics studies (Balezi *et al.*, 2010; Masumbuko, 2011). Therefore, no article or thesis are dedicated directly to KBNP except in historical inventories of large exploration in the DRC, including the two highest mountains of KBNP (Kahuzi and Biega) in some marshes and areas along the Park (Kabare and Kalehe territories) (Pierlot, 1966; Fischer, 1993, 1996).

In mountain areas, distribution, abundance and plant species diversity vary with environmental factors, including altitude (Senterre, 2005; Körner, 2007; Jump *et al.*, 2009) and other ecological factors complementary to altitude (Mangambu, 2013). However, the perfect understanding of this relationship remains questionable in the scientific community (Sanchez-Gonzalez et Lopez-Mata, 2005). The altitudinal limits of vegetation can vary according to the particularities of each region (Cuello, 2002; Karger *et al.,* 2011), so that understanding plant species composition, abundance and diversity in connection with altitudinal gradient, for some regions, remain rudimentary and elusive (Forsyth, 1998).

Because this relationship is not yet well known in this region, the aim of this study is to distinguish the different forest types in the mountain forests in Kahuzi Biega National Park and its surroundings and to show that these types differ most strongly when their altitudes are far removed. We will seek to answer the question about the influence of altitude on species distribution (or grouping of vegetation), their functional traits and diversity in mountain forest.

## Materials and methods

### *Study area*

This study was conducted in the Congolese Albertine Rift region, eastern part of the Democratic Republic of Congo, specifically in the KBNP and community forests around the Park, near Bunyakiri locality (Fig. 1). KBNP is between 1 ° 36 'and 2 ° 37' South latitude and 27 ° 33 'and 28 ° 46' East longitude. There are two centers of endemism in the area: Guinea-Congo and afro-mountain. The study was done only in mountain formations. They are located between 1250 and 2600m altitude. Beyond was the Afro-alpine vegetation. Indeed, zone exploration shown that the forests in the transition zone between 1500 m and

1900 m altitude in KBNP are disturbed due to human activities of mining and carbonization (Amsini *et al.*, 2008; Brown et Kasisi, 2008), reason why the study was extended to community forests around but always in the same Rift region, targeting slightly disturbed ecosystems.

In this zone the average temperature is 20.5 °C. The rainfall is abundant, in the range of 1750-2000 mm / year (Yamagiwa *et al.*, 2005). The rain abundance varies with altitudinal elevation so that there is a high abundance in altitudes between 2400-2600 m and fog beyond 2900 m (Fischer, 1993). The overall average radiation 421.8 calories/cm$^3$ / month (Yamagiwa *et al.*, 2005). The average relative humidity is 86% (Mangambu, 2013). Soil in KBNP and in community forests is mostly sandy clay or clay with an acidic pH.

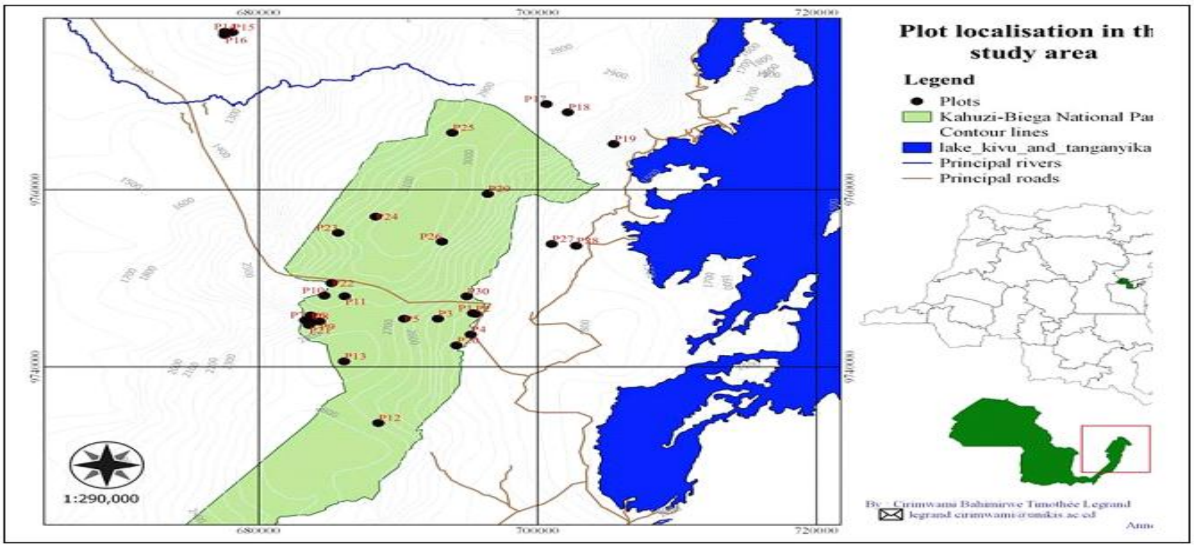

**Fig. 1.** Study area showing the distributions of different plots.

In this region, The vegetation stage occurs with altitude (Fischer, 1996; Mangambu, 2013) :
Lowland rain forest: between 650-1200m
Transition Rain forest, sub-montane: between 1250-1700 m
Mountain Rain forest: between 1700-2400 m
Bamboos community: between 2400-2600 m
Afro Sub-alpin stage between 2600-3326 m
Our study focuses only on mountain part, between 1250 to 2600 m altitudes.

*Data collection*

Data on plant diversity were collected in 30 permanent plots (1ha each), as proposed by Gentry (1988). Each parcel was subdivided in four small plots (0.25ha) in order to facilitate inventories. For a balanced sampling on different altitude levels, ten plots were placed respectively between 1250-1700 m; 1700-2150 m and 2150-2600 m in the mountain forests by targeting the least disturbed forest. Inside the parcel, all woody with DBH ≥ 10 cm to 1.30 m were considered in the study. For each individual, the scientific or common name (Yumoto *et al.*, 1994), the DBH and height were recorded using respectively a DBH meter and a Laser Ace. The average altitude of the plot and its coordinates were also taken. The identification of species collected in forest was verified by comparison with reference specimens preserved in the herbarium of the Centre for Research in Natural Sciences Lwiro (LWI), INERA Mulungu (MLGU).

*Data analysis*

In this study, different forest types were identified using an ascending hierarchical classification (HCS) coupled with a correspondence analysis (CA) (Lepš and Šmilauer, 1999; Oksanen, 2014) based on a binary table, presence-absence (Roux and Roux, 1967;

Faith *et al.*, 1987; Lenoir, 2016). This approach avoided the Guttman effect observed with the abundance data (Meddour, 2011), minimizing the effect of rare species and give a map of CA with the inertia of ascending hierarchical classification. The aggregation model for the ascending hierarchical classification is that of Ward because it uses the concept of inertia. The approach IndVal was used to determinate characteristic species of each type of forest (De Cáceres, 2013). For each indicators species, both probabilities of fidelity and occurrence were calculed. The first corresponding to the exclusive membership to the forest type, while the second indicates the frequency of the species within the forest. In addition, the diaspore and morphological types of each species were indicated (Habiyaremye, 1995).

Diversity index (richness, abundance, Simpson 1-D (Eq1), Fisher alpha (Eq 2), Shannon Weaver (Eq 3) Evenness (Eq4)) were used to characterize the diversity for each plot (Lande, 1996; Magurran, 2004; Oksanen, 2014).

*Eq(1)* $S = \sum \boldsymbol{fi}^2$ *avec* $\boldsymbol{fi} = \frac{Ni\,(Ni-1)}{NT(NT-1)}$ $S$ varies between 0 and 1 for minimum and maximum diversity. $Ni$ is a number of individual for one specie and $NT$ a total number of individual for all species.

*Eq(2)* $S = a\ln(1+N/\alpha)$ with $\alpha$ = Fisher alpha index, $N$= total number of individual and $S$ total number of species.

*Eq(3)* $H' = \sum [(Ni/NT) * Log_2\,(Ni/NT)]$ with $H'$ = Shannon index.

*Eq(4)* $EQ = H'/\log 2(S)$ ; $EQ$ = Evenness and varies between 0 and 1.

To understand relationship between diversity and altitude, correlation and multiple regressions were used. Furthermore, the analysis of variance one way (ANOVA) was applied on a linear model between altitude and abundance and between altitude and species richness in order to show the influence of altitude on these index according forest types. All tests were done using the R 3.0.2 software and considered significant at the 5% level.

## Results

### *Change in floristic composition and species distribution along altitudinal gradient*

For this study, 16 797 individuals were recorded in 30 plots of 1 ha each. In total, 212 specific taxa belonging to 161 genera and 66 families were identified. About 99 % of the individuals recorded were identified up to species level.

The remaining 26 individuals were identified to the vernacular name but their genus and families remain unidentified. The floristic composition is influenced by altitude level. Four forest types are distinguished related to the altitudinal gradient (Fig. 2).

Indeed, second axis (var 4.69; p <0.001) separates sub-montane to upper mountain. The first one (var 2.13; p = 0.03) separates mountain forest into different groups. Thus, we have mountain type higher horizon (black), mountain type medium horizon (red), mountain type lower horizon (green) and the sub mountain type (blue).

The Fig. 3 below shows the altitudinal distribution of these forest types. The sub-mountain type (A) starts from 1250 m to 1500 m level; it is followed by the mountain lower horizon (B) between 1500 m and 1800 m altitude. The mountain type medium horizon (C) is between 1850 and 2400 m and finally, the mountain type upper horizon (D) between 2400 and 2600 m altitude.

Table 1 summarizes all species which characterize each forest type along the elevational gradient.

In fact, some species are faithful to their own forest type. In this case, their probability of fidelity (A) is 1. Other species can be found in all plots that compose the forest type, and then their occurrence probability (B) is 1. For example:

**Table 1.** Indicator species for different forest types.

| Num | Species | Probability | | Indival (IndVal.g) | | Morphologic type | Dissemination model |
|---|---|---|---|---|---|---|---|
| | | A (Fidelity) | B (Occurrence) | Indival | p > 5% | | |
| | *28 indicator species of sub mountain type 1250 to 1500 m level* | | | | | | |
| 1 | *Pycnanthus angolensis* | *1.0000* | *1.0000* | *1.000* | *0.0009 **** | A | Sarco |
| 2 | *Trichilia welwichii* | *0.9577* | *1.0000* | *0.979* | *0.0009 **** | Arb | Ballo |
| 3 | *Ficus urceolaris* | *0.8511* | *1.0000* | *0.923* | *0.0009 **** | A | Sarco |
| 4 | *Erythrococa welwitchii* | *1.0000* | *0.8333* | *0.913* | *0.0009 **** | Arb | Ballo |
| 5 | *Sterculia tragacantha* | *1.0000* | *0.8333* | *0.913* | *0.0009 **** | Arb | Sarco |
| 6 | *Tarenna soyauxii* | *1.0000* | *0.8333* | *0.913* | *0.0009 **** | Arb | Sarco |
| 7 | *Pseudospondias microcarpa* | *0.9568* | *0.8333* | *0.893* | *0.0009 **** | A | Sarco |
| 8 | *Monodora myristica* | *0.9322* | *0.8333* | *0.881* | *0.0009 **** | A | Sarco |
| 9 | *Celtis soyauxii* | *1.0000* | *0.8333* | *0.913* | *0.0029 *** | Arb | Sarco |
| 10 | *Erythrina mildbraedii* | *1.0000* | *0.6667* | *0.816* | *0.0039 *** | A | Ballo |
| 11 | *Leptonychia bampsii* | *1.0000* | *0.6667* | *0.816* | *0.0059 *** | A | Sarco |
| 12 | *Phyllanthus muellerianus* | *1.0000* | *0.6667* | *0.816* | *0.0059 *** | Arb | Ballo |
| 13 | *Vepris orophila* | *1.0000* | *0.6667* | *0.816* | *0.0059 *** | Arb | Sarco |
| 14 | *Markhamia lutea* | *0.9882* | *0.6667* | *0.812* | *0.0049 *** | Arb | Ballo |
| 15 | *Teclea nobilis* | *0.8750* | *0.6667* | *0.764* | *0.0099 *** | A | Sarco |
| 16 | *Drypetes spinosodentata* | *1.0000* | *0.5000* | *0.707* | *0.0079 *** | A | Sarco |
| 17 | *Garcinia volkensii* | *1.0000* | *0.5000* | *0.707* | *0.0090 *** | A | Sarco |
| 18 | *Pentaclethra macrophylla* | *1.0000* | *0.5000* | *0.707* | *0.0079 *** | A | Ballo |
| 19 | *Trema orientalis* | *0.8400* | *0.6667* | *0.748* | *0.010989 ** | Arb | Sarco |
| 20 | *Diospyros troupinii* | *1.0000* | *0.5000* | *0.707* | *0.011988 ** | Arb | Sarco |
| 21 | *Ficus spbunya2* | *1.0000* | *0.5000* | *0.707* | *0.0139 ** | A | Sarco |
| 22 | *Rauwolfia vomitoria* | *1.0000* | *0.5000* | *0.707* | *0.0109 ** | Arb | Sarco |
| 23 | *Ricidendron heudelotii* | *1.0000* | *0.5000* | *0.707* | *0.0169 ** | A | Sarco |
| 24 | *Ficus arcuatone* | *0.9492* | *0.5000* | *0.689* | *0.0119 ** | Arb | Sarco |
| 25 | *Milletia ferruginea* | *0.9474* | *0.5000* | *0.688* | *0.0349 ** | A | Ballo |
| 26 | *Spathodea campanulata* | *0.9231* | *0.5000* | *0.679* | *0.0269 ** | A | Ballo |
| 27 | *Grewia malacocarpoides* | *0.8800* | *0.5000* | *0.663* | *0.0449 ** | Arb | Sarco |
| 28 | *Baphiopsis parciflora* | *0.8929* | *0.5000* | *0.668* | *0.0449 ** | A | Ballo |
| | *15 indicator species of mountain type lower horizon 1500 to 1800 m level* | | | | | | |
| 1 | *Lebrunia buchaie* | *0.8933* | *1.0000* | *0.945* | *0.0009**** | A | Sarco |
| 2 | *Drypetes dinklagei* | *0.8618* | *1.0000* | *0.928* | *0.0009 **** | Arb | Sarco |
| 3 | *Grewia mildbraedii* | *0.7860* | *1.0000* | *0.887* | *0.0009 **** | A | Sarco |
| 4 | *Vitex rubro.aurantia* | *0.7834* | *1.0000* | *0.885* | *0.0009 **** | Arb, A | Sarco |
| 5 | *Cleistanthus polystachyus* | *0.9744* | *0.8333* | *0.901* | *0.00297 *** | A | Sarco |
| 6 | *Manilkara multinervis* | *0.7961* | *1.0000* | *0.892* | *0.0029 *** | Arb | Sarco |
| 7 | *Leplaea mayumbensis* | *0.7803* | *1.0000* | *0.883* | *0.0019 *** | A | Ballo |
| 8 | *Carapa grandiflora* | *0.7545* | *1.0000* | *0.869* | *0.0030 *** | A | Ballo |
| 9 | *Fagara gilletii* | *0.7241* | *1.0000* | *0.851* | *0.0030 *** | A | Sarco |
| 10 | *Diospyros sp.* | *1.0000* | *0.6667* | *0.816* | *0.0050 *** | Arb | Sarco |
| 11 | *Garcinia punctanta* | *1.0000* | *0.6667* | *0.816* | *0.0060 *** | A | Sarco |
| 12 | *Monanthotaxis poggei* | *1.0000* | *0.6667* | *0.816* | *0.0060 *** | Arb | Sarco |
| 13 | *Anthocleista grandiflora* | *0.9897* | *0.6667* | *0.812* | *0.0050 *** | A, Arb | Sarco |
| 14 | *Alchornea laxiflora* | *0.9615* | *0.6667* | *0.801* | *0.0050 *** | Arb | Ballo |
| 15 | *Ocotea usambarensis* | *0.7000* | *0.8333* | *0.764* | *0.0198 ** | A | Sarco |
| | *5 indicator species of mountain type medium horizon 1800 to2400 m* | | | | | | |
| *1* | *Maesa lanceolata* | *0.8708* | *0.7857* | *0.827* | *0.016 ** | *Arb* | *Sarco* |
| *2* | *Lindackeria kivuensis* | *0.9383* | *0.6429* | *0.777* | *0.014 ** | *Arb* | *Ballo* |
| *3* | *Allophyllus kiwuensis* | *1.0000* | *0.5714* | *0.756* | *0.026 ** | *A* | *Sarco* |
| *4* | *Bridelia micranta* | *1.0000* | *0.5000* | *0.707* | *0.030 ** | *A* | *Ballo* |
| *5* | *Dombea goetzenii* | *1.0000* | *0.4286* | *0.655* | *0.042 ** | *A* | *Ballo* |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | *8 indicator species of mountain type upper horizon 2400 m to 2600 m* | | | | | | |
| *1* | *Agauria salicifolia* | *1.0000* | *1.0000* | *1.000* | *0.0009 **** | Arb | Ballo |
| *2* | *Hagenia abyssinica* | *0.9922* | *1.0000* | *0.996* | *0.0009 **** | Arb, A | Ptéro |
| *3* | *Nuxia floribunda* | *0.9837* | *1.0000* | *0.992* | *0.0009 **** | A | Ballo |
| *4* | *Rapanea melanophloeus* | *0.9314* | *1.0000* | *0.965* | *0.0009 **** | A | Sarco |
| *5* | *Nuxia congesta* | *0.8297* | *0.7500* | *0.789* | *0.0229 ** | A | Ballo |
| *6* | *Ficalhoa aurifolia* | *1.0000* | *0.5000* | *0.707* | *0.0159 ** | A | Ballo |
| *7* | *Myrica salicifolia* | *1.0000* | *0.5000* | *0.707* | *0.0159 ** | A | Sarco |
| *8* | *Hypericum revoluta* | *0.9937* | *0.5000* | *0.705* | *0.0179 ** | Arb | *Ballo* |

Legend: = Ballo = Ballochories; Sarco = Sarcochories; Ptero = Pterochories; A = Tree; Arb = Shrub.

The sub-mountain type 1250 to 1500 m: 57% of indicator species are faithful to this type: *Pycnanthus angolensis, Erythrococa welwitchii, Sterculia tragacantha, Tarenna soyauxii, Monodora myristica, Celtis soyauxii, Erythrina mildbraedii, Leptonychia bampsii, Phyllanthus muellerianus, Vepris orophila, Drypetes spinosodentata, Garcinia volkensii, Pentaclethra macrophylla, Diospyros troupinii, Ficus sp., Rauwolfia vomitoria, Ricidendron heudelotii.* Of these species, some are characteristic of undergrowth and other from tree strata. In the undergrowth, we note: *Erythrococa welwitchii, Sterculia tragacantha, Tarenna soyauxii, Celtis soyauxii, Phyllanthus muellerianus, Vepris orophila, Drypetes spinosodentata.* Only 11% of indicator species are presents in all plots of this forest type.

**Table 2.** Altitudinal distribution of some species in mountain forest.

| Num | Species | Probability | | Indival (IndVal.g) | | Morphologic type | Dissemination model | Num |
|---|---|---|---|---|---|---|---|---|
| | | A (Fidelity) | B (Occurrence) | Indival | p > 5% | | | |
| | *Indicators Species between 1250 and 1800 m altitude* | | | | | | | |
| *1* | *Polyscias kivuensis* | *1.0000* | *1.0000* | *1.000* | *0.0009 **** | A | Ballo | FS |
| *2* | *Bakerisideroxylon sp* | *1.0000* | *0.9167* | *0.957* | *0.0009 **** | A | Ballo | FP |
| *3* | *Musanga cecropioides* | *0.9820* | *0.9167* | *0.949* | *0.0009 **** | A | Sarco | FS |
| *4* | *Dacryodes edulis* | *1.0000* | *0.8333* | *0.913* | *0.0009 **** | A | Ballo | FS |
| *5* | *Lovoa trichilioides* | *1.0000* | *0.8333* | *0.913* | *0.0009 **** | A | Ballo | FP |
| *6* | *Trilepisium madagascariens* | *1.0000* | *0.8333* | *0.913* | *0.0009 **** | A | Sarco | FP, FS |
| *7* | *Piptadeniastrum africanum* | *0.8537* | *0.9167* | *0.885* | *0.0009 **** | A | Ballo | FP |
| *8* | *Tetrorchidium didymostemon* | *1.0000* | *0.7500* | *0.866* | *0.0039 *** | A | Sarco | FS, FP |
| *9* | *Cynometra alexadrii* | *1.0000* | *0.5833* | *0.764* | *0.0069 *** | A | Ballo | FP |
| *10* | *Lindackeria dentata* | *1.0000* | *0.5000* | *0.707* | *0.0209 ** | Arb | Ballo | FS,FP |
| *11* | *Macaranga monandra* | *1.0000* | *0.5000* | *0.707* | *0.017982 ** | A | Ballo | FS |
| | *Indicators Species between 1800 and 2400 m altitude* | | | | | | | |
| 1 | *Macaranga neomilbraediana* | *0.9663* | *1.0000* | *0.983* | *0.0009 **** | A | Ballo | FP,FS |
| 2 | *Polyscias fulvae* | *1.0000* | *0.9444* | *0.972* | *0.0009 **** | A | Sarco | FS |
| | *Indicators Species between 1500 and 2400 m altitude* | | | | | | | |
| 1 | *Sapium ellipticum* | *0.9447* | *0.9000* | *0.922* | *0.02597 ** | A | Sarco | FS |
| 2 | *Tabernaemontana johnstonii* | *0.9681* | *0.8000* | *0.880* | *0.00599 *** | A, Arb | Sarco | FS |
| 3 | *Diospyros polystemone* | *1.0000* | *0.6500* | *0.806* | *0.01399 ** | A | Sarco | FP |
| 4 | *Parinari excelsa* | *0.9879* | *0.6500* | *0.801* | *0.01998 ** | A | Sarco | FP |
| 5 | *Chrysophyllum gorungosanum* | *0.9835* | *0.6000* | *0.768* | *0.04795 ** | A | Sarco | FP |
| | *Indicators Species between 1250 and 2400 m altitude* | | | | | | | |
| 1 | *Strombosia scheffleri* | *1.0000* | *0.8846* | *0.941* | *0.003 *** | A | Sarco | FP |
| | *Indicators Species between 1500 and 2600 m altitude* | | | | | | | |
| 1 | *Syzygium guineense* | *0.9957* | *0.8750* | *0.933* | *0.003 *** | A | Sarco | FP |

Legend: = Ballo = Ballochories; Sarco = Sarcochories; Ptero = Pterochories; A = Tree; Arb = Shrub; FP= primary forest; FS= Secondary forest

The analysis of diaspores dissemination shows a dominance of Sarcochories species (68%), which have fleshy diaspores that can be transported over long distances, especially by birds. Others species ejected themselves their diaspores (Ballochores).

The mountain type lower horizon, 1500 to 1800 m: 20% of indicator species are faithful to this forest type: *Diospyros sp., Garcinia punctanta, Monanthotaxis poggei*. The species of undergrowth are *Drypetes dinklagei, Manilkara multinervis, Diospyros sp., Alchornea laxiflora*. In fact, 53% of indicator species are presents in all plots of the forest type.

Depending on dissemination model, 80% of indicators species are Sarcochores and 20% Ballochores.

**Table 3.** Diversity measures for each inventory plot with its mean altitude.

| Altitude | Number Family | Number Genus | Number Species | Abundance | Simpson | Ficher's Alpha | Shannon index H | Evenness Pièlou |
|---|---|---|---|---|---|---|---|---|
| 1260 | 29 | 49 | 50 | 410 | 0,85 | 14,93 | 2,81 | 0,72 |
| 1300 | 33 | 59 | 60 | 416 | 0,95 | 19,24 | 3,42 | 0,84 |
| 1350 | 24 | 40 | 46 | 429 | 0,94 | 13,06 | 3,19 | 0,83 |
| 1385 | 25 | 40 | 45 | 442 | 0,93 | 12,53 | 3,05 | 0,8 |
| 1420 | 27 | 46 | 51 | 465 | 0,93 | 14,61 | 3,11 | 0,79 |
| 1527 | 32 | 61 | 68 | 468 | 0,96 | 21,87 | 3,55 | 0,84 |
| 1570 | 30 | 54 | 58 | 404 | 0,95 | 18,56 | 3,49 | 0,86 |
| 1615 | 35 | 59 | 63 | 521 | 0,96 | 18,75 | 3,61 | 0,87 |
| 1680 | 26 | 43 | 50 | 555 | 0,91 | 12,96 | 2,96 | 0,76 |
| 1702 | 28 | 47 | 50 | 517 | 0,94 | 13,66 | 3,13 | 0,8 |
| 1750 | 30 | 49 | 53 | 543 | 0,94 | 14,53 | 3,29 | 0,83 |
| 1803 | 27 | 46 | 48 | 527 | 0,94 | 12,84 | 3,2 | 0,83 |
| 1840 | 17 | 21 | 22 | 322 | 0,91 | 5,35 | 2,67 | 0,86 |
| 1934 | 27 | 37 | 37 | 1018 | 0,91 | 7,53 | 2,76 | 0,76 |
| 1980 | 26 | 40 | 42 | 391 | 0,94 | 11,93 | 3,17 | 0,85 |
| 2020 | 22 | 31 | 31 | 327 | 0,94 | 8,41 | 3,08 | 0,9 |
| 2096 | 16 | 22 | 23 | 534 | 0,87 | 4,89 | 2,41 | 0,77 |
| 2100 | 11 | 12 | 12 | 340 | 0,81 | 2,42 | 1,93 | 0,78 |
| 2145 | 14 | 15 | 15 | 582 | 0,69 | 2,81 | 1,51 | 0,56 |
| 2150 | 20 | 28 | 31 | 740 | 0,88 | 6,54 | 2,6 | 0,76 |
| 2170 | 29 | 46 | 49 | 466 | 0,96 | 13,81 | 3,51 | 0,9 |
| 2240 | 18 | 26 | 26 | 602 | 0,89 | 5,53 | 2,49 | 0,77 |
| 2290 | 13 | 17 | 17 | 361 | 0,84 | 3,7 | 2,17 | 0,77 |
| 2326 | 17 | 23 | 23 | 763 | 0,86 | 4,51 | 2,27 | 0,72 |
| 2340 | 25 | 30 | 31 | 609 | 0,85 | 6,62 | 2,4 | 0,71 |
| 2370 | 17 | 21 | 21 | 595 | 0,72 | 4,24 | 1,84 | 0,6 |
| 2400 | 9 | 10 | 10 | 652 | 0,61 | 1,68 | 1,21 | 0,52 |
| 2435 | 7 | 7 | 8 | 301 | 0,72 | 1,51 | 1,54 | 0,74 |
| 2500 | 15 | 18 | 19 | 1206 | 0,81 | 3,2 | 1,97 | 0,67 |
| 2590 | 13 | 16 | 18 | 1318 | 0,89 | 2,95 | 2,4 | 0,83 |
| Moyenne | 22 | 34 | 36 | 561 | 0,9 | 9,5 | 2,7 | 0,8 |
| Ecart-type | 7,7 | 15,9 | 17,5 | 243,2 | 0,1 | 6,0 | 0,7 | 0,1 |

The mountain type medium horizon, 1800 to 2400 m: 60% of species is faithful to this forest type: *Allophyllus kiwuensis, Bridelia micrantha, Dombea goetzenii*. In the undergrowth strata we note: *Maesa lanceolata* and *Lindackeria kivuensis*. Concerning to the occurrence probability no characteristic species is present in all plots. Furthermore, 60% of species ejected theirs diaspores themselves.

The mountain type upper horizon, 2400 to 2600 m: it is noted that 37% of characteristics species are faithful to this forest type: *Agauria salicifolia, Ficalhoa aurifolia* and *Myrica salicifolia*. In the undergrowth, we note the presence of *Hypericum revoluta* and rarely *Agauria salicifolia*.

The probability of occurrence shows that 30% of species are present in all sites of the forest type. Analysis of dissemination mode highlights the dominance of species which ejected themselves theirs diaspores (Ballochores: 63%), followed by fleshy diaspores (Sarcochores: 25%) and species with wing-like appendages (Pterochores).

In the mountain forest of KBNP and its surroundings, some species may have high plasticity in their altitudinal distribution and the others being confined only to a certain altitude level. The table below summarizes this situation:

**Table 4.** Axis contribution to the principal component analysis.

| Axis | Eigenvalue | % of variance | % cumulative variance |
|---|---|---|---|
| Comp1 | 6,77 | 75,26 | 75,26 |
| Comp2 | 1,04 | 11,55 | 80,80 |
| Comp3 | 0,87 | 9,66 | 96,46 |
| Comp4 | 0,21 | 2,35 | 98,81 |

*Change in floristic diversity along the altitudinal gradient*

Table 3 summarizes the change in diversity along altitude. We inventoried 561 ± 243 individuals, 36 ± 17 specific taxa, 34 genera and 22 ± 16 ± 8 families across a plot.

The floristic diversity has been studied and based on the abundance, species richness, number of genera, family and through diversity indices like Simpson, Shannon Fischer Alpha and Pielou evenness.

The correlation analysis reveals that Simpson (r - 0.59; p value <0, 001), Fischer (r - 0.83; p value <0, 001) Shannon (r - 0.72; p value <0, 001) and Pielou (r - 0.44; p value 0.01) have a negative linear relationship with altitude elevation.

The diversity decreases with the increasing of altitude. The number of individuals increases as the altitude (Fig. 4).

Indeed, the abundance is positively associated with elevation, although there is considerable variability. Multiple regression reduced to the significant variables (abundance and richness) confirms this variance (F = 10.43, Df = 29, $R^2$ = 0.799, adjusted $R^2$ = 0.72, p-value <0.001, Table 5).

**Table 5.** Relationship between altitude, richness and abundance.

| Explicative variables | Coefficient | Er-T coefficient | Test | pvalue |
|---|---|---|---|---|
| Constant | 2285,85 | 142,14 | 16,08 | <0,0001*** |
| Richness | -16,80 | 2,27 | -7,39 | <0 ,0001*** |
| Abundance | 0,46 | 0,16 | 2,84 | 0,008** |

When considering forest types, the number of individuals per hectare is variable (Df = 3; F = 3, 48; p 0,029) between plots. The mountain type upper horizon has more individuals per hectare than other types (Fig. 5).

Species richness decreases with the increasing of altitude. The sub-mountain types have more species per hectare than other types (Fig. 6) (Df = 3, F = 28.08, p <0.001).

The most diversified families according to the importance of individual number of individuals and species are *Euphorbiaceae* (20, 24%), *Meliaceae* (6,16%), *Moraceae* (5,89%), *Monimiaceae* (5,86%), *Myrsinaceae* (4,97%), *Fabaceae* (4,72%), *Rubiaceae* (4,17%) and *Sapindaceae* (4,1%).

## Discussion

*Forest types along the altitude gradient*

*Ecological significance of species combination* *(regrouping) along an altitudinal gradient*

Altitude is one of the important factors that determine the combination of plant communities in mountain forests (Körner, 2007; Jump *et al.*, 2009) but this can vary from one area to another so that Senterre (2005) believes that no generalized model can exist. Our results show that woody composition changes with elevation in the area of Kahuzi-Biega National Park and its surroundings, which were seen elsewhere in the Tanzanian and Kenyan mountains in the Rift (Lovett *et al.*, 2006; Medley and Maingi, 2014) or in other areas like Reunion island (Tassin *et al.*, 2004), Amazonian forests (Terborgh and Andresen, 1998) or Asia (Lee *et al.*, 2014). The theory of ecological discontinuity that allowing disappearance and appearance of species along a gradient remains an open debate in ecology (Hardy *et al.*, 2004; Fayolle *et al.,* 2014). Each region having its particularities (Cuello, 2002; Karger *et al.,* 2011). However, the more pronounced is the gradient, which allows multiple combinations of vegetation, especially in mountain areas, most species richness becomes important and the difference between groups pronounced (Tassin *et al.*, 2004). Our results showed that the floristic composition in forest types is greatly different when their altitudes are far removed.

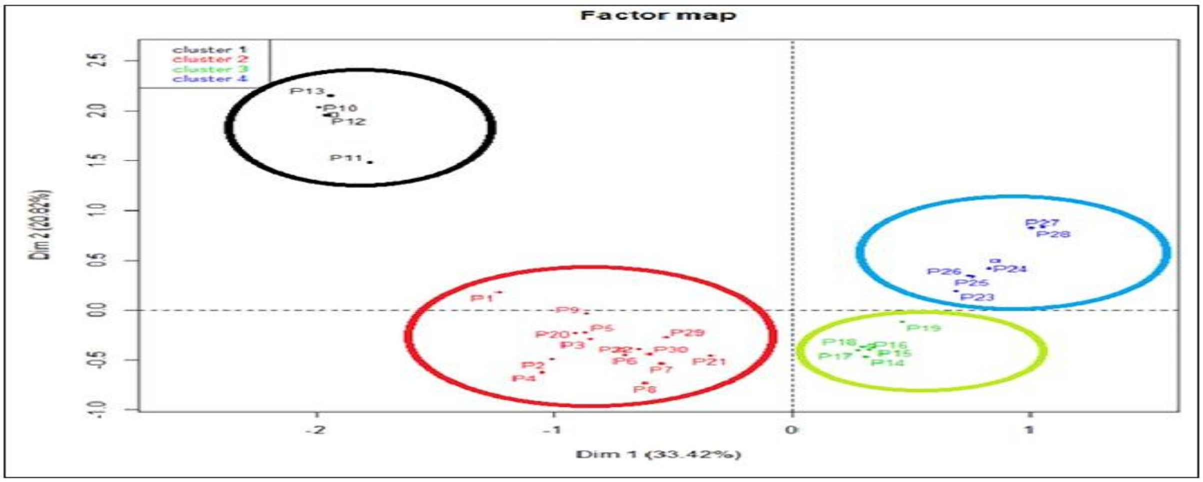

**Fig. 2.** Distinction of forest types along the altitudinal gradient. Hierarchical clustering analysis (HCS) combined to a correspondence analysis of (CA). The 53% cumulative percentage on the axes is not that of a classic AFC but the values of the inertia of Ward approach of the hierarchical clustering analysis

In the mountains of KBNP and its surroundings, no specific forest typology to mountain formations has been made until today. However, comments made by some authors locate these forests between 1350 and 2400 m (Fischer, 1996) or between 1250 and 2600 m when considering mixed forest with Bambous community after 2400m (Mangambu, 2013).

These authors confirm that the mountain forest in this region begins by a sub-mountain forest, or transition forest between 1200 and 1700m. In other way, for improved forest typology, consider the tree woody species (Senterre, 2005). It is the reasons why we present in this study our results with a specific typology of mountain forests of KBNP and its surroundings, based on woody species.

Indeed, these forests begin with a sub-mountain or transition forest between 1250 and 1500 m then we have mountain type with three different horizons along the altitudinal gradient.

The lower horizon between 1500 and 1800 meters is followed by the medium horizon, very wider, 1800 and 2400 m and finally comes the upper horizon, restricted, between 2400 and 2600 m in which it possible to see Bamboos communities in some area of the park. However, the species combination in Albertine Rift mountain varies according to the zones (Bussmann, 2006).

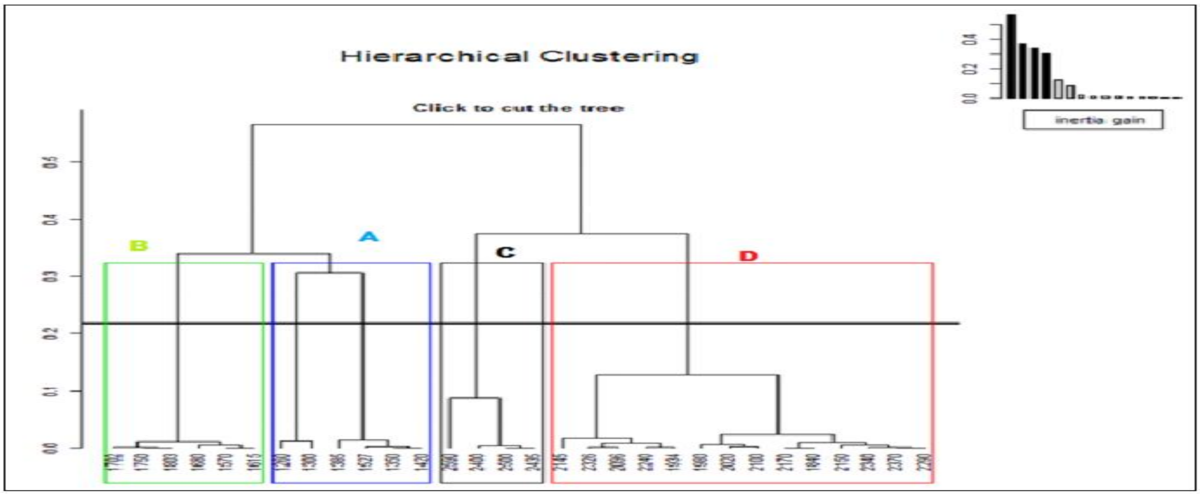

**Fig. 3.** Communities similarity according to the altitudinal gradient. A (sub-mountain), B (lower mountain horizon), C (upper mountain horizon), D (medium mountain horizon).

*Altitudinal range of species and trend of the individual size in relation to forests type*

The species trait is the specific factor that could enable it to have a high plasticity and colonize large areas. So why some species are restricted to a particular area while others are widely spread on forest land. In our study, out of all 212 species recorded, the sub-mountain type (1250 to 1500 m) has itself 123 (58% of richness) with 28 indicators species, 57% are found exclusively on this type. The mountain type lower horizon (1500 to 1800) have 100 species (47%), with 15 indicators species which only 20% characterize exclusively this range. The mountain type medium horizon (1800 to 2400 m) has 91 species (43%) and includes 5 indicators species of which 60% own at this range. Finally, mountain type upper horizon (2400 to 2600 m) with only 28 species (13%), with 8 indicators and 37% specifics to this forest type. Despite this numerical decrease in species richness, along altitude range, some species disappear while others appear. For example, between 2400-2600 m, there are three new species *Agauria salicifolia, Myrica salicifolia* and *Erica arborea* that are not found in the lower forest types; 16 species are

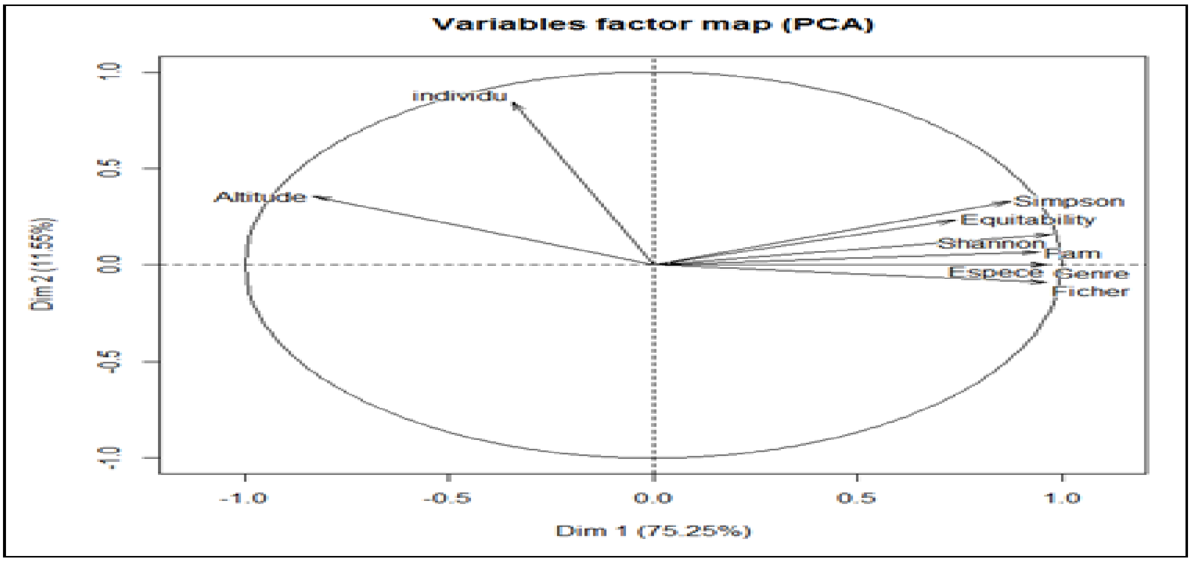

**Fig. 4.** Analysis of the relationship between diversity indices and altitude using a principal component analysis (PCA).

found only among 1250-1500 and 3 respectively between 1500-1800 m and 1800-2400 m. Thus, variability in tree species composition becomes important when altitudes are becoming increasingly remote. This confirms the hypotheses that high altitudes areas are populated by endogenous and specific species (Tassin *et al.*, 2004) reason why they remain fragile and have priority for conservation (Plumptre *et al.*, 2009).

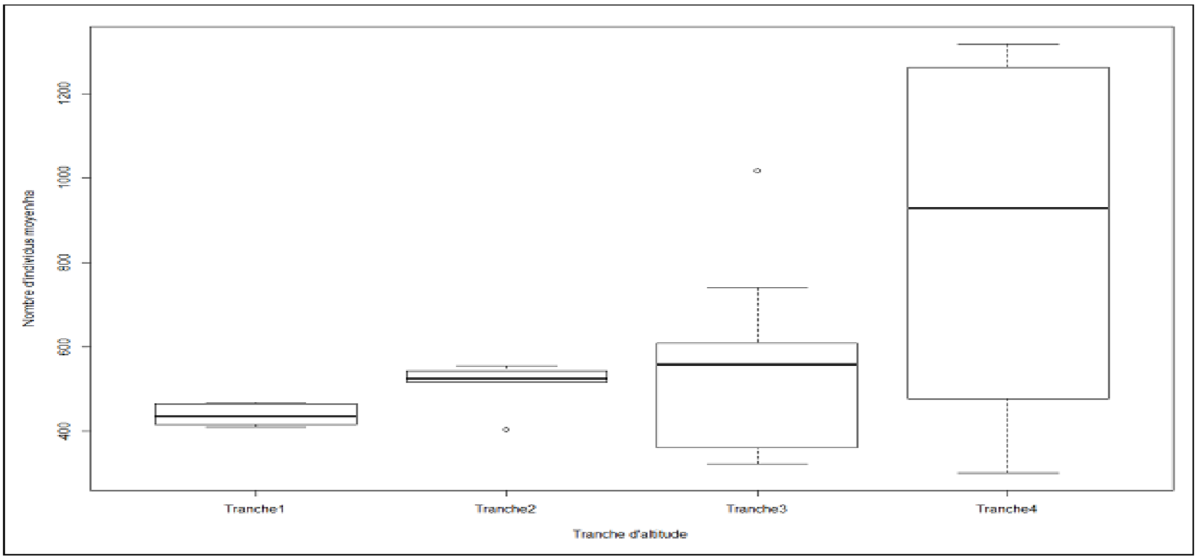

**Fig. 5.** Abundance variability according altitude. The dark black bar in the middle shows the average while the clear black bars and the x indicate the lower and upper values.Tranche1= Sub-mountain type, Tranche2= Mountain type lower horizon, Tranche3= Mountain type medium horizon and Tranche4= Mountain type upper horizon.

Furthermore, our results showed a strong similarity between plots along same altitudinal range except for the tranche 1800-2400 m which shows the variability in abundance and floristic composition whether is primary or secondary forest. In mountain regions, the species composition is influenced by slope position (Senterre, 2005). In the case of KBNP mountain forest, we observe that rainfall on the eastern slope is not the same as the West slope of Kahuzi and Biega Mounts and it influences the composition of vegetation between 1900 and 2600 m of altitude (Pierlot, 1966; Fischer, 1996). This is confirmed by our results in terms of woody species distribution among the range 1800-2400 m.

In other way, distribution of individuals in a forest area depends, in partly, on dissemination model of species concerned (Habiyaremye, 1995; Kumba *et al.*, 2013). Between 1800-2400 levels, dissemination is provided by the plant itself (Ballochores) to 60% and 80% between 2400-2600. Some study confirms that local environmental conditions can effect on seed weight of tropical plants(Opler *et al.*, 1980). This condition, can explain a restricted distribution of species that characterize high altitudes. It will, for these areas, to wait for some animals to come allow wider dissemination after dark fruits that can be driven by secondary dispersion (consumption of fallen fruits, hanging, hunting,...) (Basabose, 2002). A pressure to animal population in this part of forest of KBNP could influence partially on floristic composition. However, the dissemination mode is not the only factor, Soil and climate sometimes correlated with altitude, can also influence the distribution of species (Toledo *et al.*, 2012).

Nonetheless, some species have a large distribution throughout the mountain forest; they are present in all forest types in mature as secondary forest. For every elevation levels, the presence and abundance of pioneer species such as *Macaranga neomilbraediana, Trilepisium madagascariens, Tetrorchidium didymostemon, Lindackeria dentata,* vary according to several parameters including disturbance intensity and in some cases being good indicators of secondary formations. These opportunistic species are related to natural disturbances and they have relatively low abundance in the undisturbed natural formations. Their abundance will also be a function of altitudinal gradients.

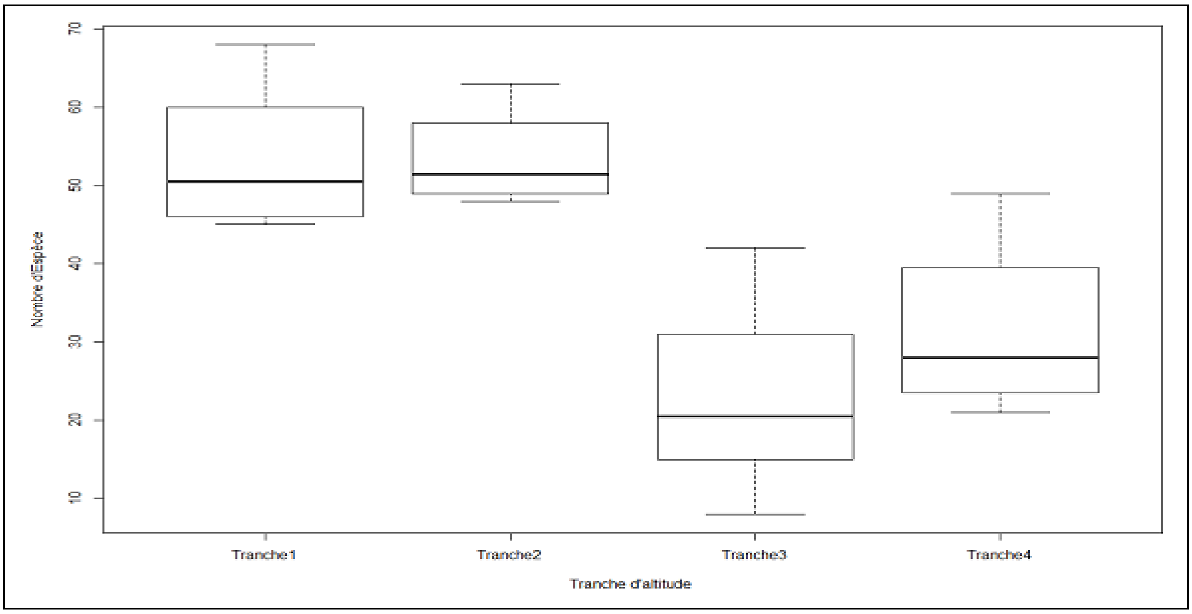

**Fig. 6.** Richness variability along altitude gradient. The dark black bar in the middle shows the average while the clear black bars and the x indicates the lower and upper values.Tranche1= Sub-mountain type, Tranche2= Mountain type lower horizon, Tranche3= Mountain type medium horizon and Tranche4= Mountain type upper horizon.

*Woody diversity decreases with increasing altitude*

Mountain forests in the Albertine rift is diversified (Plumptre *et al.*, 2007). We inventoried 561 ± 243 individuals, 36 ± 17 species with DBH ≥ 10 cm per hectare. In the same forest types in Tanzania Lovett *et al.,* (2006) inventoried 700 to 1,000 stems per hectare for the same diameter but Cizungu (2015) recorded 839 ± 154 individuals for DBH ≥ 6cm at Nyungwe in Rwanda and Masumbuko *et al.*, (2012) observed 568 individuals DBH ≥ 5 cm in the high altitude of the KBNP. The average is the same but the variability observed can be explained by different methodological approaches.

The results showed, as in many cases, a decline of diversity (Simpson, Fischer alpha, Pielou evenness, richness) with increase in altitude (Bruun *et al.*, 2006; Delnatte, 2010). Only the abundance increases with elevation. Other researches shown that there is not a linear variation between altitude and diversity (Lovett *et al.*, 2006; Ren *et al.*, 2006). The authors justify this loss of diversity by the island biogeographic theory of mountain suggesting that isolated nature of mountain forests prevents the frequent migration of species and the low balance provides limited support species (Lieberman *et al.*, 1996; Givnish, 1999). We observed the same situation in this study; there are more species in lowland than upper altitude but against more individuals in altitude. The altitude affects the trees growth; having fewer large trees for the highest areas could allow the release of space and therefore the proliferation of individuals at the expense of species immigration limitation (Vazquez and Givnish, 1998; Givnish, 1999). In the context of KBNP, search on some taxonomic groups confirm the altitude effect on diversity. The richness of Rubiaceae decreases with altitude (Mwanga Mwanga *et al.*, 2014); that of wood-destroying fungi increases to around 2300 m before decreasing to 2600 m (Balezi, 2013). In the same case, Mangambu *et al.*, (2013) noted the decrease in the diversity of ferns with increase of the altitude. This author demonstrated that factors such as temperature, slope, substrates and altitude, it is the latter which greatly influences the wealth of ferns.

## Conclusion

Species distribution and forest typology of mountain forest in the Congolese Albertine Rift precisely in the Kahuzi Biega National Park and its surroundings was investigated in this work using a hierarchical cluster associated with a correspondence analysis.

Woody diversity was assessed using the diversity indices. The objective of this study was to distinguish the different forest types in the mountain forests in Kahuzi Biega National Park and its surroundings and to show that these types differ more strongly when their altitudes are remote. In total 16 797 individuals Dbh ≥ 10 cm, were surveyed in 30 ha. These individuals are grouped into 212 specific taxa, 161 genera and 66 families.

Four forest types were identified along the altitudinal gradient. These types are Sub-mountain (1250-1500m), lower mountain horizon (1500-1800m), medium mountain horizon (1800-2400m) and mountain top horizon (2400-2600m). Each forest group is characterized by a specific number of indicator species.

The lower elevation (1250-1800m) has more indicator species than the upper one due to mountain effect which limits the distribution of species. The altitude between 1800-2400 m presents peculiarities in the distribution and abundance following specific trait each species and the location of the plot to the East or West slope in the Park. The mode of dissemination by sarcochorie is predominant in the lower altitudes (1250-1800) while in the higher elevations is the ballochorie which becomes increasingly predominant for species.

Woody diversity generally decreases with elevation. While species richness decreases with increasing altitude, the abundance is positively correlated with this one increasing. This is due to the small size of trees in high altitude, freeing up space for the benefit of other individuals on plot scale. To improve a better understanding of the ecosystem functioning in this mountain forest and make a more effective management system. It is important to study the variability of the vegetation structure in connection with this forest typology.

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