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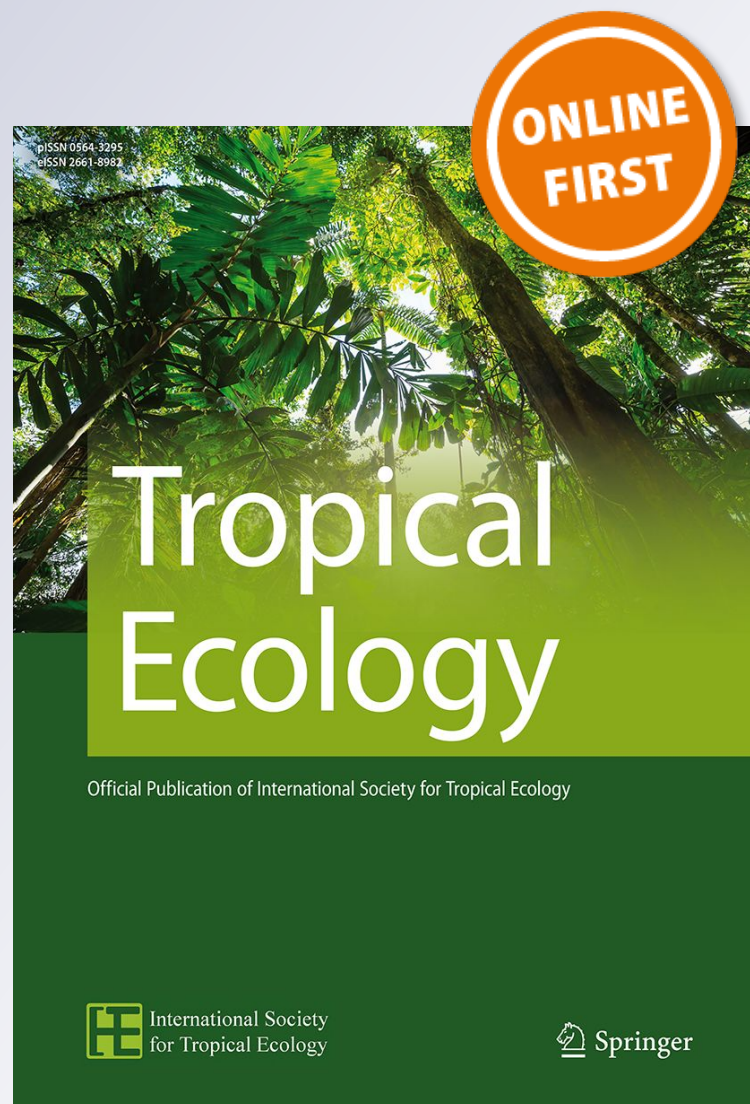
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The effect of elevation on species richness in tropical forests depends on the considered lifeform: results from an East African mountain forest

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Abstract

Elevation gradients in tropical forests have been studied but the analysis of patterns displayed by species richness and elevation have received little attention. We examined whether the effect of elevation on species richness varies according to forest lifeforms and the main plant families in the Kahuzi-Biega National Park, within the Albertine Rift. We established 20 1-ha plots from 810 to 2760 m asl. Inside each plot, species inventories were carried out within three nested sub-plots: the tree lifeform (i.e. species with a dbh ≥ 10 cm), the shrub lifeform (dbh < 10 cm) and the herbaceous lifeform. For trees and shrubs (woody lifeforms) abundance data (i.e. number of individuals per species) were taken into account whereas the herbaceous lifeform was surveyed using presence–absence data. We plotted species counts vs elevation for each of the ten richest families per forest lifeform and resorted to Poisson regression models to assess the statistical meanings of the displayed results. Hurdle models (truncated Poisson regression) were used to account for overdispersion in the data. For woody lifeforms, we observed a monotonic decrease of species richness, while species richness appeared to be increasing with elevation for the herbaceous lifeform. Woody lifeforms displayed various vegetation patterns according to the considered families, therefore, contrasting with the general pattern observed in the herbaceous lifeform. These findings suggest the existence of specific eco-physiological properties pertaining to each forest lifeform and the existence of family-specific elevation patterns of species richness.

Keywords Elevation gradients · Species richness · Tree lifeform · Shrub lifeform · Herbaceous lifeform · Kahuzi-Biega national park

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Introduction

Mountain ecosystems account for approximately one-fifth of the Earth's land surface (Tse-ring et al. 2010; Price et al. 2011) and tropical mountain forests represent about 11% of tropical forests over the world (Doumenge et al. 1995). Species richness is particularly high in these ecosystems and they are often biodiversity hotspots (Bussmann 2001; Plumtre et al. 2003; Tse-ring et al. 2010; Price et al. 2011; Admassu et al. 2016). In these mountain ecosystems, elevation strongly influences the distribution of their biodiversity (Doumenge 1998; Eilu et al. 2004; Hemp 2009; Pickering and Green 2009; Chain-Guadarrama et al. 2012). Indeed, elevation regulates several abiotic factors that control the observed vegetation patterns and the ecology of mountain forests. Climatic variables such as temperature or atmospheric pressure decrease with increasing elevation while radiation under cloudless sky and fraction of UV-B

radiation at any given total solar radiation increase (Körner 2007; Chain-Guadarrama et al. 2012). Other factors such as light availability (in terms of diffuse transmittance), cloudiness and humidity (Lebrun and Gilbert 1954; Körner 2007; Unger et al. 2013), soil depth (Doležal and Šrůtek 2002) and soil parameters (e.g. organic matter, total nitrogen, water content, available nitrogen and C/N ratio) increase, whereas pH, N mineralization and nitrification tend to decrease or present an intermediate maximum with increasing elevation, depending on the climatic context and elevational range (Zhang et al. 2012). Furthermore, the orographic characteristics differently affect precipitation in mountain ecosystems, resulting into local variations in species composition.

Facing all these factors driven by elevation, species from different taxa, families or lifeforms respond specifically according to their eco-physiological properties and sensitivity (Grime 1977, 1979; Kessler 2000; Pausas and Austin 2001; Chawla et al. 2008). For example, several studies have found that, among functional traits, solar radiation tolerance is one of the explanatory factors shaping diversity patterns in forest understory layers (Grytnes 2000, Willinghöfe et al. 2012, Nanda et al. 2018).

Some studies found that the relationship between tree species richness (for species with at least 10 cm of diameter at breast height) and elevation is unimodal, displaying a peak around 1000 m asl (Pierlot 1966; Doumenge 1998; Bhattarai and Vetaas 2006; Lee et al. 2013), while others reported that tree species richness declines monotonically with increasing elevation (Stevens 1992; Zhao et al. 2004; Kraft et al. 2011; Zhu et al. 2015). Most of these studies were performed in the temperate zone and few data are available on elevational gradients in tropical Africa (Pierlot 1966; Imani et al. 2016; Cirimwami et al. 2017). In the East African Mountains, when considering wide elevational gradients, patterns of tree species richness tend to present a maximum in the lower elevations of montane forests (Pierlot 1966; Doumenge 1998; Schmitt et al. 2010).

Although the relationship between species richness and elevation has been shown to be a function of the vegetation lifeform studied (Zhao et al. 2004; Grytnes et al. 2006; Gairola et al. 2008; Akhtar and Bergmeier 2015; Zhang et al. 2016), variation of plant species richness in tropical mountain forests has been mainly studied focusing on trees with dbh \geq 10 cm (Pierlot 1966; Hsieh et al. 1998; Imani et al. 2016; Cirimwami et al. 2017; Gonmadje et al. 2017) albeit the fact that the floristic richness of tropical forests is highly related to other lifeforms such as shrubs, lianas and herbaceous species (Gentry 1988; Bussmann 2001; Tchouto et al. 2006). Along large gradients, shrubs' species richness tends to be negatively correlated with elevation, at least in the temperate zone (Akhtar and Bergmeier 2015). Conversely, in tropical environments, species richness of herbaceous lifeform was found to increase along small elevational gradients

(Poulsen and Pendry 1995; Salinas and Casas 2007; Nanda et al. 2018) as well as along large elevational gradients on Mount Kilimandjaro (Hemp 2006). This tendency is confirmed by a transcontinental (America, Africa and South East Asia) study that showed that species richness of understory herbs in tropical forests is positively correlated with increasing elevation (Cicuzza et al. 2013). The elevation patterns of diversity for herbaceous lifeforms are explained by light availability as most of them are shade intolerant (Pierlot 1966; Grytnes 2000; Jiang et al. 2016).

The relationship between elevation and species richness may also vary according to the considered family (Kessler 2000; Lomolino 2001; Salas-Morales and Meave 2012). In many studies in which different families' species richness were plotted according to elevation, a wide variety of patterns was observed (Kessler 2000, 2002; Delnatte 2010; Salas-Morales and Meave 2012). The main explanations of the existence of this wide variety of patterns are eco-physiological properties of families and their functional traits. Furthermore, the elevational patterns of species richness within different families *per* lifeform (herbs to trees) may clearly differ from that of the whole plant community (Chawla et al. 2008; Salas-Morales and Meave 2012).

Few studies compared the elevational variation in diversity and composition of various plant lifeforms, from herbs to trees in mountains of tropical Africa (Woldu et al. 1989; Hemp 2006; Fischer et al. 2011). However, this information is nevertheless key for conservation as well as REDD+ strategies in a context of climate change (Foster 2001; Malhi et al. 2010; Malhi and Marthews 2013). The importance of such studies for REDD+ strategies is due to the fact that several components of REDD+ (e.g. the measure of Above Ground Biomass) are influenced by the species richness of studied sites (Gonmadje et al. 2017; Imani et al. 2017).

In this study, we focused on how species richness of three lifeforms (tree, shrub and herbaceous) varies with elevation—810 to 2760 m asl—in the Kahuzi-Biega National Park (KBNP), East of the Democratic Republic of the Congo (DRC). We hypothesized that (1) the relationship between species richness and elevation depends on the studied lifeform (more precisely, we postulated that (1.a) tree and shrub species richness decrease with increasing elevation and that (1.b) herbaceous species richness increases with increasing elevation), and (2) the elevational pattern of families' species richness changes from a family to another.

Methods

Site

This study was conducted in the mountain forests of the Kahuzi-Biega National Park (KBNP), located in the

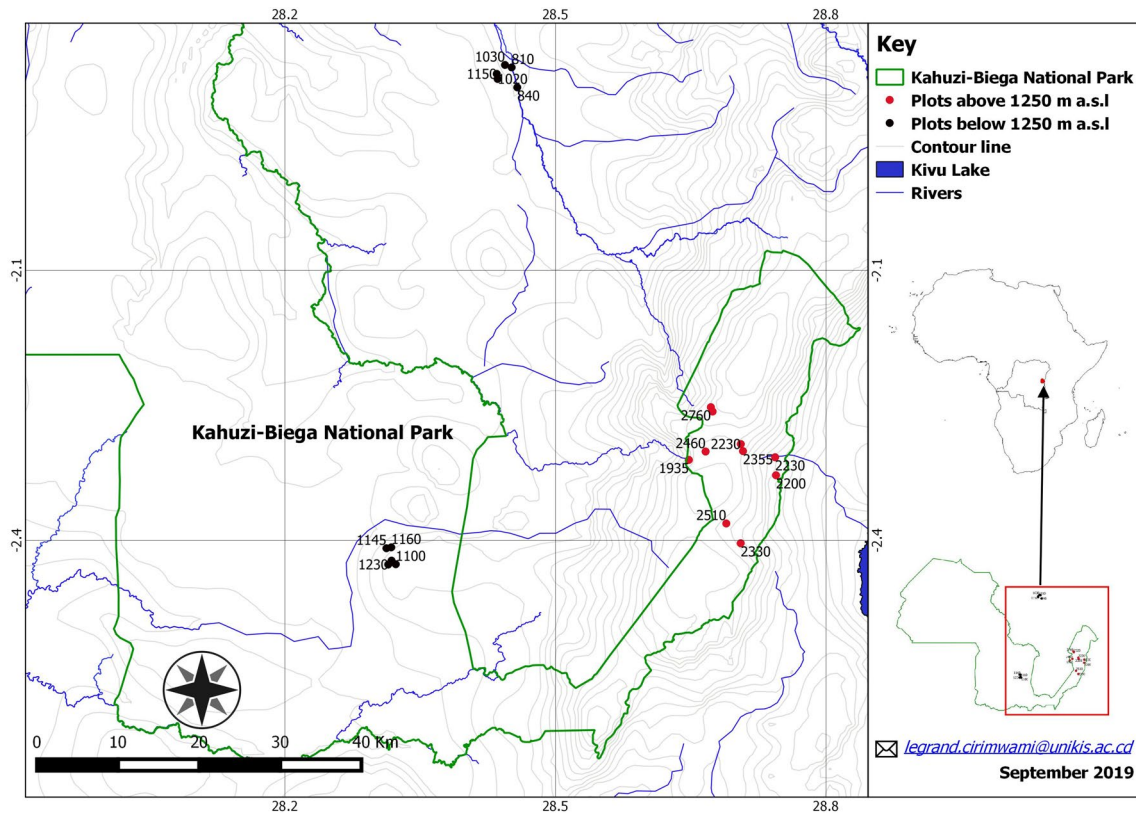


Fig. 1 Plots established in the East African Mitumba mountains in the Democratic Republic of the Congo

Eastern part of the Democratic Republic of the Congo. The study site is located between $1^{\circ}5' S$ and $3^{\circ} S$ of latitude and between $27^{\circ} E$ and $29^{\circ} E$ of longitude (Fig. 1). The KBNP is part of the Mitumba Mountains, along the Western Rift, which are characterized by high species richness and many endemic species (Plumptre et al. 2003; Admassu et al. 2016). In this park, the elevation stretches from 650 to 3315 m asl (Fischer 1996). This large elevational gradient and the mountainous topography entails a great variation in the climatic parameters, in particular temperature and rainfall (Fischer 1993; Mangambu 2013). In the lowland (600–1250 m asl) mean precipitation is 2646 mm and the temperature varies from 15 to 25 °C (Fischer 1993) while in the highland (1250–3315 m asl) mean precipitation is 1900 mm and the temperature varies from 15 to 21 °C (Fischer 1993; Biedinger and Fischer 1996). The lowland area is characterized by equatorial climate of Af type, following Köppen classification and is part of the Guineo-Congolian region, whereas the highland area belongs to the Afromontane center of endemism (White 1983). The KBNP consists of five major types of vegetation including equatorial rainforest (650–1250 m asl), transitional sub-montane rainforest (1250–1700 m asl), montane rainforest (1700–2400 m asl), bamboo vegetation (2400–2600 m asl) and a subalpine vegetation from

2600 to 3315 m asl (Fischer 1993; Mangambu 2013; Imani et al. 2016).

Plot design, data collection and species identification

Nested plots were used in a multilayered sampling approach. We established 20 plots between 810 and 2760 m asl (Fig. 1) in less disturbed forests. Five of the ten plots below 1250 m asl were established in the Irangi forest reserve, out of the park's borders (Fig. 1), which has the same climate and ecological conditions as the park's lowland area. The relocation of these plots was due to insecurity prevailing in some corners of the KBNP. Three lifeforms were taken into account during the sampling process: tree, shrub and herbaceous. Plot sizes differed according to the considered lifeform, as suggested by previous studies (Kessler and Bach 1999; ter Steege et al. 2000; Senterre 2005; Amani 2011). The minimum suitable inventory area is usually determined using species area curves (Brinkmann et al. 2009). Many researchers used different plots sizes according to each lifeform (Table 1) as suggested in multilayer-based studies, each lifeform possessing its minimum suitable area (Gillet 2000).

In this study, the sampling design consisted of nested plots comprising the tree, the shrub and the herbaceous

Table 1 Plot sizes and lifeforms (tree, shrub and herbaceous) as *per* previously published data

Authors	Year	Plot size for tree lifeform	Plot size for shrub lifeform	Plot size for herbaceous lifeform
Poulsen and Pendry	1995	2500 m ²	–	100 m ²
Sundarapandian and Swamy	2000	100 m ²	100 m ²	1 m ²
Ojeda et al.	2000	50 m*	50 m*	0.25 m ²
Wang et al.	2002	100 m ²	100 m ²	1 m ²
Sánchez-González and Lopez-Mata	2005	1000 m ²	250 m ²	9 m ²
Poulsen et al.	2005	10,000 m ²	–	2500 m ²
Tchouto et al.	2006	1000 m ²	1000 m ²	25 m ²
Gairola et al.	2008	100 m ²	100 m ²	1 m ²
Brinkmann et al.	2009	600 m ²	600 m ²	100 m ²
Senterre et al.	2009	500 m ²	200 m ²	200 m ²
Nanda et al.	2018	100 m ²	25 m ²	1 m ²

The author's name(s) are provided, as well as the year of publication

*Transect line

lifeforms. Species with at least 10 cm dbh (tree lifeform) were inventoried within 1-ha plots (50 m × 200 m). The other woody species belonging to the shrub lifeform (dbh < 10 cm ≥ 1 cm) were surveyed into 0.1-ha sub-plots (5 m × 200 m) whereas for the herbaceous lifeform species were inventoried within 0.01-ha sub-plots (10 m × 10 m). For tree and shrub lifeforms, the number of individuals per species was considered (abundance data) whereas for the herbaceous lifeform, only species occurrences (presence–absence data) were taken into account. At the best possible, all species were identified directly in the field or afterwards by comparing the collected samples with specimens available in local herbaria.

Data analysis

Analyses of species richness were performed for each lifeform. We analyzed the relationship between the number of species and elevation using Poisson regression models, given that our dataset consists of count data, or hurdle models (truncated Poisson regression) when the dataset is full of many zeros (0) thanks to the glmmTMB package implemented into the R software (Brooks et al. 2017; R Core Team 2018). This allowed us to account for potential overdispersion cases, frequently observed when dealing with count data.

For families (following APG IV), we only considered the top-10 ones, i.e. families with the highest number of species. For tree and shrub lifeforms, we tested for the relationship between their species richness and elevation, on one side, and abundances and elevation, on the other. For the herbaceous lifeform we only considered the species richness and elevation.

Results

Overview of species richness

The whole dataset was made up of 20 plots (for tree lifeform) and another 40 plots representing 20 sub-plots accounting for the shrub lifeform and 20 sub-plots pertaining to the herbaceous lifeform. In the tree lifeform, a total of 241 species belonging to 59 families were collected. 256 species (70 families) were recorded in the shrub lifeform whereas the herbaceous lifeform accounted for 123 species split into 48 families.

Families' species richness

The ten richest families are represented for all studied lifeforms by decreasing species richness (Table 2). Seven of the top-10 families (Fabaceae, Rubiaceae, Meliaceae, Apocynaceae, Euphorbiaceae, Annonaceae and Clusiaceae) appear to be well represented in the woody lifeforms. These families become outnumbered in the herbaceous lifeform except for the Rubiaceae family, which is ranked second. In the studied area, these findings suggested that 15% of all species were from the Rubiaceae family. Despite the presence of some tree ferns in the woody lifeforms (tree and shrub lifeforms), it was only in the herbaceous lifeform that a fern family appears among the top-10 families.

Relationship between species richness and elevation

The relationship between species richness and elevation depended on the lifeform studied (Fig. 2). Species richness decreases with increasing elevation for woody lifeforms (tree

Table 2 Species number in the richest families (top-10) within the three lifeforms (tree, shrub and herbaceous)

Tree lifeform	S	%	Shrub lifeform	S	%	Herbaceous lifeform	S	%
Fabaceae	26	10.8	Rubiaceae	58	22.7	Asteraceae	10	8.1
Rubiaceae	23	9.5	Fabaceae	16	6.3	Rubiaceae	10	8.1
Meliaceae	16	6.6	Euphorbiaceae	12	4.7	Acanthaceae	8	6.5
Apocynaceae	14	5.8	Apocynaceae	10	3.9	Balsaminaceae	7	5.7
Euphorbiaceae	14	5.8	Meliaceae	10	3.9	Aspleniaceae*	6	5.7
Phyllanthaceae	10	4.1	Asteraceae	9	3.5	Zingiberaceae	6	4.9
Sapotaceae	9	3.7	Malvaceae	8	3.1	Commelinaceae	5	4.1
Annonaceae	8	3.3	Annonaceae	6	2.3	Marantaceae	5	4.1
Clusiaceae	8	3.3	Celastraceae	6	2.3	Poaceae	5	4.1
Moraceae	8	3.3	Clusiaceae	5	2.0	Piperaceae	4	3.3
Other families (49)	105	43.6	Other families (60)	116	45.3	Other families (38)	57	46.3

S species richness representing the number of species belonging to the family

*A fern family

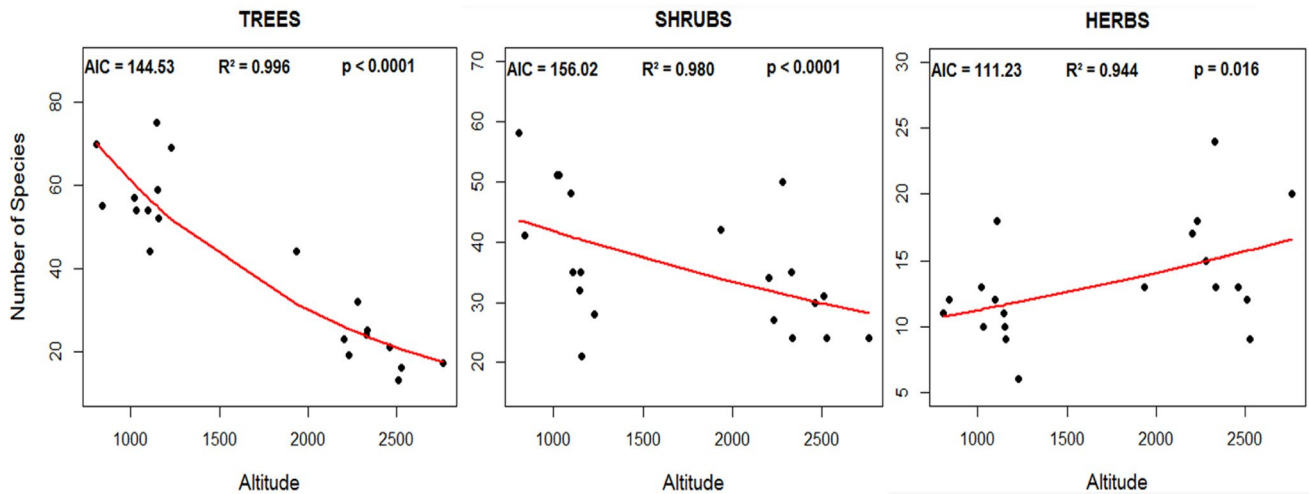


Fig. 2 Relationships between the number of species and elevation. The trend in woody lifeforms differs from that displayed by the herbaceous lifeform

and shrub lifeform). Conversely, species richness in the herbaceous lifeform increases with elevation.

Relationship between species richness within richest families and elevation

We found that 36/59, 25/70 and 16/48 families expressed a significant relationship between their species richness and elevation, respectively, in tree, shrub and herbaceous lifeforms. Among these families with a significant correlation, 75% were found to be negatively correlated to elevation in the tree lifeform while 60% of their counterparts in the shrub lifeform followed suit and only 25% in the herbaceous lifeform (see Online appendix 1).

(a) Tree lifeform

Species richness and abundance of the ten richest families vary significantly with elevation in the tree lifeform (Fig. 3). (i) Both species richness and abundance decrease with increasing elevation for Phyllanthaceae, Annonaceae and Moraceae ($P < 0.05$). (ii) For Euphorbiaceae and Apocynaceae families, the number of species decreases while the number of individuals increases with increasing elevation ($P < 0.05$). (iii) For the remaining families, either the number of species or the number of individuals increases or decreases with increasing elevation ($P < 0.05$).

(b) Shrub lifeform

The various trends displayed by the considered families are summarized in Fig. 4.

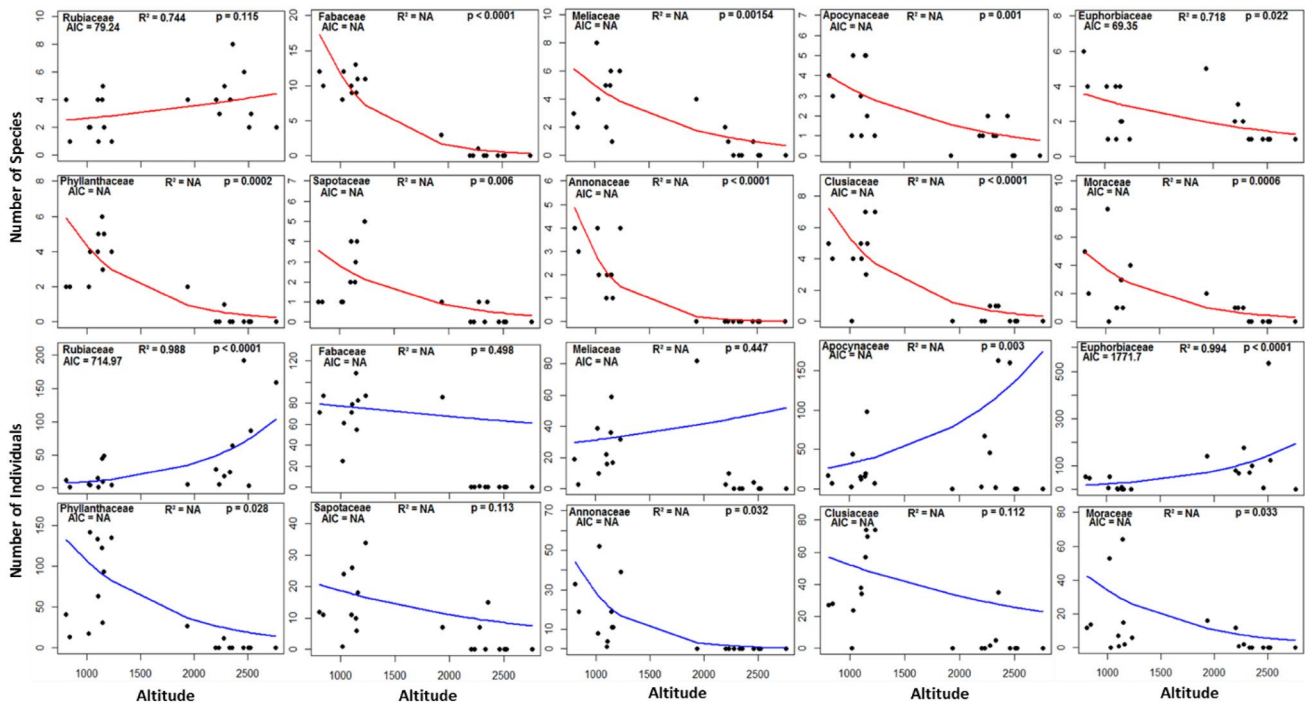


Fig. 3 Relationship between species richness (red), abundance (blue) and elevation in the ten richest families of the tree lifeform. We used Poisson regression only for Rubiaceae and Euphorbiaceae. For other families, we used hurdle models (truncated Poisson regression)

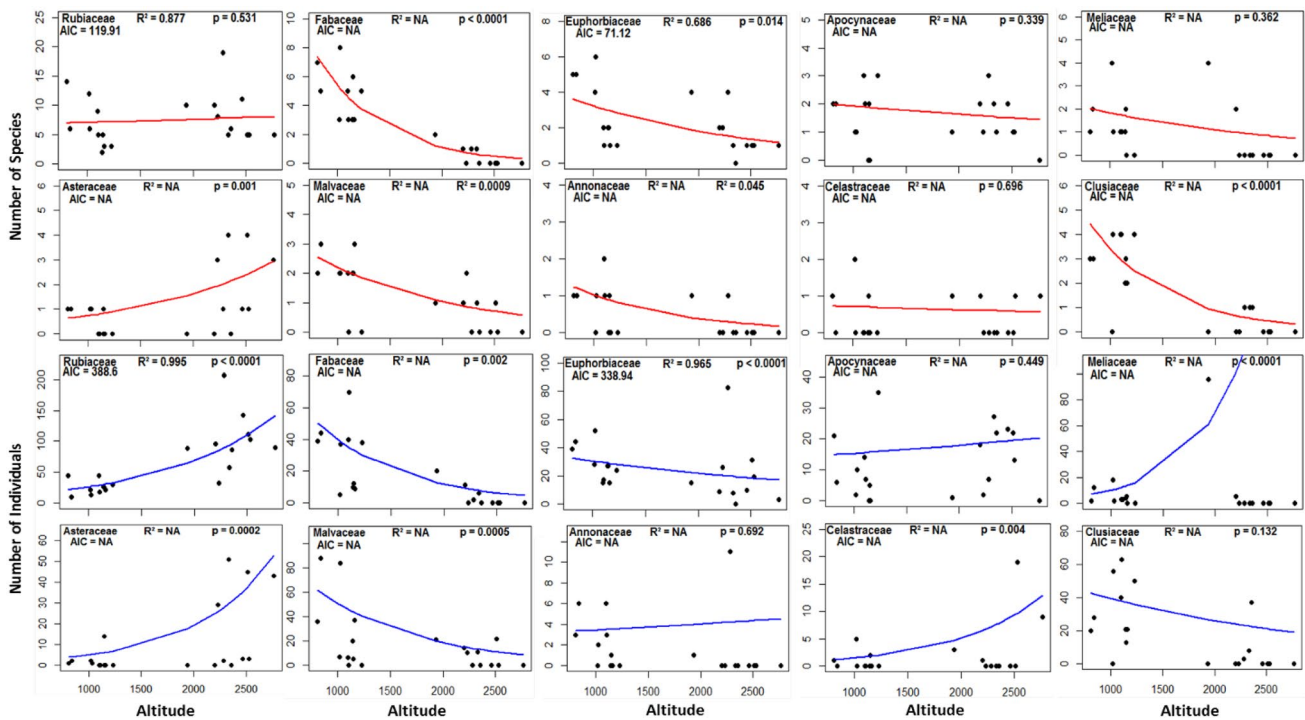


Fig. 4 Relationship between species richness (red), abundance (blue) and elevation in the ten richest families of the shrub lifeform. Poisson regression was used for Rubiaceae and Euphorbiaceae, whereas the remaining families were submitted to hurdle models (truncated Poisson regression)

Three main patterns appear: (i) species richness and abundance decrease with increasing elevation for Fabaceae, Euphorbiaceae and Malvaceae; (ii) for the Asteraceae family both the number of species and the number of individuals increases with increasing elevation; (iii) as in the tree lifeform, for the rest of families, either the number of species or the number of individuals increases or decreases with increasing elevation ($P < 0.05$) or both are not influenced by elevation (e.g. Apocynaceae: $P > 0.05$).

(c) Herbaceous lifeform

When the relationship between species richness and elevation for the selected families (top-10) is considered in the herbaceous lifeform, three trends were observed (Fig. 5).

(i) The first trend consists of families for which the number of species decreases with elevation: Rubiaceae, Zingiberaceae, Commelinaceae and Marantaceae ($P < 0.05$). (ii) The second trend is made up of families which number of species increases: Asteraceae and Aspleniaceae ($P < 0.05$). (iii) The other families appeared not to be influenced by elevation ($P > 0.05$).

Discussion

The elevational pattern of species richness depends on the studied taxon

The elevational gradient in species richness has received considerable attention over the last decades in studies focusing on various taxa (birds, mammals, bats, galls, ferns, vascular plants, rattan, etc.) (Rahbek 1995; Lara et al. 2002; Grytnes and Vetaas 2002; Hodkinson 2005; McCain 2005;

Siebert 2005; Kebede et al. 2013; Mangambu et al. 2013). The main conclusion was that there is no general pattern along elevational gradients, although some patterns (unimodal hump-shaped and monotonic decrease) prevail. This is because there is a multitude of rules driving the general ecology of forest ecosystems (Lawton 1999) and the existence of a wide variety of strategies and ways developed by species to adapt to environmental stresses (Grime 1977, 1979).

The elevational pattern of species richness depends on the studied lifeform

Recently, various studies were conducted—especially on plants—to assess how species richness of different lifeforms is influenced by elevation (Akhtar and Bergmeier 2015; Zhang et al. 2016; Xu et al. 2017). In some rare cases, researchers found the same relationship between elevation and species richness (unimodal or monotonic) for all the studied lifeforms (Sánchez-González and López-Mata 2005; Hemp 2006; Hrivnák et al. 2014; Xu et al. 2017) but, more often, this relationship differs between the lifeforms (Zhao et al. 2004; Grytnes et al. 2006; Ren et al. 2006; Gairola et al. 2008; Akhtar and Bergmeier 2015; Zhang et al. 2016; Nanda et al. 2018). Some of these works have been performed in small elevation gradients and most of them in temperate climates. Here, we showed that, in a wide elevation gradient in tropical Africa, the relationship between species richness and elevation varies from a vegetation lifeform to another. The species richness for trees and shrubs are negatively correlated with elevation between 810 and 2760 m asl in a tropical African mountain, displaying a monotonic decrease with increasing elevation. This decrease of species richness is certainly due to eco-physiological constraints

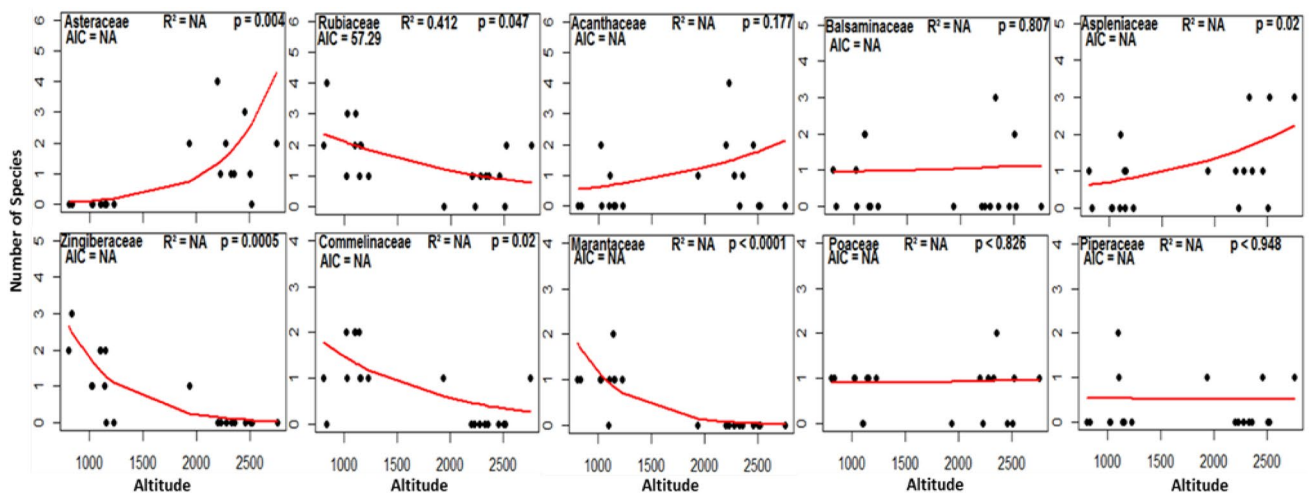


Fig. 5 Relationship between species richness and elevation in the ten richest families of the herbaceous lifeform. We used Poisson regression only for Rubiaceae and hurdle models (truncated Poisson regression) for the rest of families

at higher elevation, such as the drop-in temperatures or in CO₂ pressure, which may affect photosynthetic capacity, net primary productivity and living structure maintenance (Körner 2007; Ren et al. 2006; Chawla et al. 2008; Malhi and Marthews 2013). When climbing up, these environmental factors exert more pressure on tree lifeform than on shrub lifeform (Grime 1977, 1979), which may explain the stronger decreasing slope of tree species richness compared to the shrub one (see Fig. 2).

Contrary to what is observed in the woody lifeforms, herbaceous species richness is positively correlated with elevation, depicting a monotonic increase. The existence of these two opposite trends—trees and shrubs richness decreasing, and herbs increasing—suggests that the relation between elevation and species richness from different lifeforms is strongly influenced by environmental factors, both physical and biological.

Why does herbaceous species richness increase with increasing elevation?

Our results have pointed out that species richness in the herbaceous lifeform increases with elevation, as it was also reported in other studies (Salinas and Casas 2007; Chawla et al. 2008; Ciczuzza et al. 2013; Malik and Nautiyal 2016). The same trend was found on the Mount Kilimanjaro in a study conducted on trees, shrubs, lianas, herbs and epiphytes (Hemp 2006). Poulsen et al. (2005) divided the ground herbs in angiosperms and ferns in their study conducted in the Albertine Rift. They found that species richness of herb ferns increases with altitude, while the species richness of angiosperm herbs decreases, probably due to the separation between ferns and angiosperms herbs. Herbaceous species contribute to the general architecture of the overall species richness in many forest ecosystems but they are the most represented at higher elevations (Gentry and Dodson 1987; Gentry 1988; Bussmann 2001; Malik and Nautiyal 2016). Given their particular traits and their ability to withstand environmental conditions at higher altitudes, herbaceous communities are an important component of highland ecosystems (Gilliam and Roberts 2003; Gilliam 2007). Therefore, some montane forests and several ecosystems are made especially of an herbaceous lifeform while shrub and tree lifeforms are less represented (Schoonmaker and Mckee 1988; Pickering and Butler 2009; Bao et al. 2017).

It is known that species belonging to a given lifeform/guild use similar resources and respond to the environment and environmental stresses in similar ways; they have comparable strategies (Grime 1977, 1979; Pausas and Austin 2001). Thus, the herbaceous species could respond differently to most of environmental factors such as temperature, rainfall, light availability, cloudiness, humidity caused by the change in elevation compared to the way other lifeforms

could respond (Grime 1979; Körner and Diemer 1987; Gilliam and Roberts 2003; McCain and Grytnes 2010). In the mountain forests of Eastern DRC, light availability at the soil level increases with elevation (Lebrun and Gilbert 1954) as this was also confirmed by Körner and Diemer (1987) in Innsbruck and Glungezer. The fact that several herbaceous species are shade intolerant (Pierlot 1966; Grytnes 2000) explains their increase in species richness in high elevations where light availability increases even if other factors related to soil, climate, topography, density of herbivores, etc. may also influence their elevational distribution patterns of diversity (Körner and Diemer 1987; Poulsen and Pendry 1995; Jiang et al. 2016). Therefore, the diversity pattern of herbs along the elevation gradient may be shaped by the interaction between altitude and canopy density which controls light availability in the understory (Zhang et al. 2016). Herb lifeforms benefit both from fewer competition with woody lifeforms and also from more available light (Körner 2007).

The elevational patterns of species richness are family-specific

Families' species richness is not necessarily following the trend drawn by the lifeform to which the species belong. Some families followed the general lifeform's trend while others displayed a totally different trend (see Online appendix 1). These various trends suggest the existence of family-specific sensitivity to changes driven by elevation, a variety of eco-physiological properties of each family and family trait-based responses (Kessler 2000; Chawla et al. 2008; Delnatte 2010).

For trees and shrubs, the amount of families decreasing in species richness was higher than that of families increasing along the elevational gradient but the opposite is observed in the herbaceous lifeform (Online appendix 1). For example, woody families such as Myricaceae, Ericaceae, Monimiaceae, Myrsinaceae, Theaceae and Podocarpaceae (see appendix 1) are positively correlated with elevation (Fischer 1993; Doumenge 1995; Hemp 2006). This also is partially the case for Rubiaceae, which shows in both woody lifeforms a slight increase of species as well as an increase in abundance following elevation, especially in the shrub lifeform. Rubiaceae is among the most common families in the understory of tropical lowland forests (Mwanga Mwanga et al. 2013) but it appears to be even more important in the highland forests above 2000 m asl (Gentry 1988).

Families such as Phyllanthaceae and Pandanaceae which gather many species from the *Uapaca* and *Pandanus* genus, characteristics of riverside forests (Cirimwami 2013), decrease with increasing elevation. The families such as Fabaceae, Meliaceae or Annonaceae are megathermal families typical of lowland tropical

rainforests (Richardson et al. 2004; Kumar et al. 2014; Noumi 2015; Koenen et al. 2015). Fabaceae is recognized as one of the richest families in African lowlands (Amani 2011; Gonmadje et al. 2011; Noumi 2015).

In the herbaceous lifeform, species pertaining to Marantaceae and Zingiberaceae families decrease also significantly with elevation; they are mostly restricted to lower elevations in understory or clearings, and on river sides. They are also megathermal families, being mostly confined to the tropics (Troupin 1987; Kahindo 2011). On other cases, the increasing trend of species richness within many families could be related to two parameters, their microthermal character and their appetite for light. The fact that forests at higher elevations had high light availability may favour them (Pierlot 1966). For example, Asteraceae species and many fern species from families such as Aspleniaceae, Dennstaedtiaceae, Lycopodiaceae, etc. are hardly found at lower elevations (often in illuminated environments) but they are more diverse in tropical mountains and temperate environments. Their strong presence in mountains can also be explained by the structure of their flowers looking like a daisy (Poulsen et al. 2005; Glimm-Lacy and Kaufman 2006) which could enable them to be easily dispersed by mountain winds.

Conclusion

This research aimed to assess the elevational patterns of species richness with respect to main forest lifeforms and a number of selected families in an East African Mountain forest in the Democratic Republic of the Congo. The results indicated that lifeforms made up of species with more similar adaptive strategies have the same trend when plotted according to elevation. Tree and shrub species richness decreased with increasing elevation probably due to changes driven by environmental factors such as lowering temperatures. On the opposite, herbaceous species richness displayed a positive and strong correlation with elevation. Nevertheless, within this broad pattern, families react differently to the elevational gradient, both in terms of species richness and abundance. This must be due to eco-physiological properties, sensitivity and traits of each family.

Thus, studies of biodiversity based on different lifeforms and most represented taxa (families, genus, etc.) with similar ecological properties or structures would advance our understanding of montane forests ecology in the face of climate change and human-driven disturbances. Unfortunately, we still know little of the eco-physiology of the main plant families in these tropical forests and their adaptability to environmental changes. This knowledge is nevertheless important for predicting tropical forests' evolution in the face of the

above-mentioned pressures and adapted management and conservation strategies.

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