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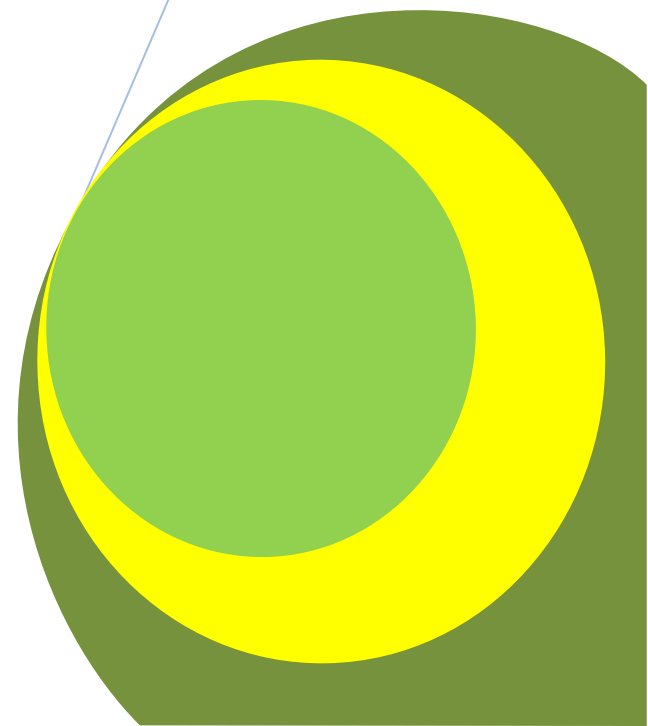
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Floristic Patterns and Impact of Edaphic Heterogeneity on Species Assemblages within Woody Forests Layers in Semi-deciduous Forests from the Congo Basin

By

**Amani A. Christian
Jean Lejoly**



Research Article

Floristic Patterns and Impact of Edaphic Heterogeneity on Species Assemblages within Woody Forests Layers in Semi-deciduous Forests from the Congo Basin

Amani A. Christian*¹, Jean Lejoly²

¹Center for International Forestry Research; 25, av. Greuilleas, Goma, D.R.Congo.

²Herbarium de l'Université Libre de Bruxelles, Belgium.

²Email : jlejoly@ulb.ac.be

*Corresponding Author's Email: c.amani@cgiar.org; Tel: +243 9 97 42 33 00

ABSTRACT

Knowledge of floristic composition and structure of forests is useful in identifying important elements of plant diversity, protecting threatened and economic species. Investigations into floristic composition and structure of forests are essential in understanding the forest ecosystem dynamics and conservation.

Using 1-ha plots established in 3 sites harboring semi-deciduous forests in the Congo Basin, we defined floristic patterns of the vegetation within forest layers. To account for common and rare species, we considered the diversity indices of orders 0, 1 (exponential of the Shannon index) and 2 (inverse of Simpson index). We used the Chao 1 index for diversity of order 0. The jackknife and minimum variance unbiased estimator (MVUE) were considered to estimate diversity of orders 1 and 2. We also assessed the way substrate differentiation affects species assemblages in these forests. Results showed that floristic patterns (species composition and species diversity) vary from a forest layer to another. Three main groups of species assemblages were defined in the overstorey. It has been observed that soil features (clay and sandy substrates) influence species occurrences in these semi-deciduous forests.

Keywords: ecological guild, floristic pattern, plant community, species diversity.

1. INTRODUCTION

Recent considerations report that many tropical forests are now persisting as fragments. Therefore, there is a growing interest in quantifying habitat characteristics such as forest structure, floristic composition and plant species richness in intact, degraded and fragmented forests (Myers et al., 2000). Prioritizing conservation efforts must rely on a sound knowledge of the different vegetation units that exist in the area of concern.

Floristic inventory and diversity studies help us understand the species composition and diversity status of forests, which also offer vital information for forest conservation. Quantitative inventories, moreover, help identify species that are in different stages of vulnerability as well as the various factors that influence the existing vegetation in any region (Jayakumar et al., 2009). Botanical assessments, based on floristic composition and structural patterns of the vegetation are particularly necessary to apprehend the extent of plant biodiversity in forest ecosystems.

Historically, vegetation studies of the Congolese forests include a number of classical contributions (Lebrun, 1936; Louis, 1947; Léonard, 1950; Lebrun and Gilbert, 1954; Germain and Evrard, 1956; Gérard, 1960; Evrard, 1968; Schmitz, 1988) but most of them only focused on describing plant associations in monodominant forests. Little is known about floristic parameters in mixed and more complex forests.

More recently, a number of quantitative floristic inventories have been assembled within the Congo Basin (Lejoly, 1994; Lejoly et al., 1994; Lejoly, 1995a; Lejoly 1995b) but very few have focused on floristic patterns in different forest layers (Senterre, 2005; Nshimba, 2008). Yet a better understanding of a multi-layered plant ecosystem requires each forest layer to be considered separately from others since they both belong to different ecological guilds. As reported by Decocq (2002), stratification of the vegetation (which express its vertical dimension) is one of the spatial dimensions to be considered following an existing hypothesis which considers that there is a

clear lack of coupling between forest layers (tree, shrub and herb layers) because of differential response to the underlying influence of environmental controls.

The objective of this study is twofold. We first describe the floristic patterns of the vegetation considering separately the forest layers in order to express the contribution of each forest layer to forest structure. We also examined plant assemblages existing in the overstorey and analyzed whether the observed plant groups partition themselves following a given environmental factor (soil texture, in this case).

2. METHODS

2.1 Study sites

Sampling vegetation plots were established within primary forests located in 3 sites: Yoko (0°17'34.9"N; 25°18'27.4"E), Biaro (0°14'47"N; 25°19'44.05"E) and Yangambi (0°51'01.62"N; 24°31'43.53"E). These sites are home to semi-deciduous forests characterized, in many areas, by two *Fabaceae* species, *Scorodophloeus zenkeri* and *Prioria oxyphylla* in the overstorey. They are both located around the town of Kisangani. Ten kilometers separate Yoko from Biaro (southwards) and Yangambi is located at more than 100 kilometers, further west.

The mean elevation of the region is 435 m above sea level and the climate is of the kind Af in the Köppen classification. The annual rainfall ranges from 1417mm to 1915 mm (mean: 1728 mm) with mean monthly temperatures varying from 23.7°C to 26.2 °C. Throughout the year, the region is marked by a long rainy season interrupted by two small dry seasons, the first going from December to January whereas the second one extends from June to August (Nshimba 2008). The soil can be subdivided into two main categories: the ferrallitic and the recent soils (Kombele 2004). The ferrallitic soils are those generally covering the plateaus with small rates in exchangeable bases (< 3 meq/100 g). They are acidic soils (pH < 6) and appear to be red or yellow in colors. Ferrallitic soils are the dominant group in the region (van Engelen et al., 2006) and are particularly marked by xanthic ferralsols (Beernaert, 2003).

2.2 Botanical composition survey and soil analysis

Plants inventories and data collection were performed within 1-ha plots. Our investigations were carried out on the four forest layers, defining the overstorey (layers A and Ad) and the understorey (layers ar). By layer A, we consider all trees beyond 20 m in height and for the layer Ad, trees ranging between 6 meters and 20 meters. For the shrubs (layer ar), their height varies from 1.5 meter to 6 meters. The sampling efforts varied from a stratum to another. Trees belonging to the stratum A (canopy trees) were inventoried along a 200 m transect line by 25 m from each side of the main line. For stratum Ad, inventories were performed within a 2000 m² surface (5 m from each side of the main transect line), whereas for stratum ar plants were counted within a 500 m² surface (i.e. 200 m by 2.5 m placed on only one side of the main transect line).

Most of the species were identified in the field. Trees were determined by slashing the bark and then looking for diagnostic features like color, smell, and exudates among others. Plant samples were collected during the study and species that could not directly be determined were collected and identified in herbaria (BR, BRLU) and using standard available reference text-books such as Tailfer (1989), Vivien and Faure (1995) and Lebrun and Stock (1991-1997). The floristic data included the number of individuals of each woody species per plot. For each individual more than 1.30 m, the trunk diameter (at breast height, dbh) was measured and used to determine the diametric structure of the forest.

In each of the plots, soil samples were collected for textural and chemical (pH, conductivity, organic matter, phosphorus) analyses. Soil samples were collected at a depth of 0-10 cm. They were air-dried, cleaned of stones and roots fragments and then passed successively through 20- and 2-mm sieves. Soil organic matter, pH, phosphorus concentration and electrical conductivity were determined. Percentages of sand, clay and silt were measured by classic granulometric analyses using sedimentation columns in accordance with the Stokes' law. The percentage of organic matter was measured by weighing a soil sample from a drying oven (105°C) as well as before and after calcinations in a muffle furnace (450°C), and then by measuring the masses difference. Phosphorus concentration (µg/ml) was measured by the Ølsen method (Ølsen et al., 1954). Initially, 1 g of soil was weighed to which 20 ml of bicarbonate (extractor) were added. pH and conductivity (µSiemens/cm) were determined following the saturated paste method.

2.3 Data analysis

2.3.1 Floristic composition

Relative density of species and families were assessed for each species and family (relative diversity). We also considered the relative frequency of species in the forest layers. These floristic parameters are defined as follows:

- Relative density = (number of individuals of a species x 100)/ total number of individuals of all species.
- Relative frequency = (number of plots containing a species x 100)/ sum of frequencies of all species.
- Relative diversity = (number of species of a family X 100)/total number of species of all families.

The Shannon-Weiner's index, as well as the Simpson 1-D and Fisher alpha indices were used for species diversity measures within the plots. Shannon index is calculated as:

$$H = - \sum_{i=1}^S p_i \ln p_i$$

where: P_i = fraction of the entire population made up of species i ; S = numbers of species encountered and \sum = sum from species 1 to species S .

Simpson's Index (D) measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species)

$$D = 1 - \frac{\sum_{i=1}^S n_i(n_i - 1)}{N(N - 1)},$$

where S is the number of species, N is the total percentage cover or total number of organisms and n is the percentage cover of a species or number of organisms of a species. In this form, D ranges from 1 to 0, with 1 representing infinite diversity and 0 representing no diversity. We considered the Simpson's Index of Diversity $1 - D$ which represents the probability that two individuals randomly selected from a sample will belong to different species. Fisher's alpha is defined by the formula $S = a \ln(1 + n/a)$ where S is number of taxa, n is number of individuals and a is the Fisher's alpha. These diversity indices were computed using PAST (Hammer and Ryan, 2008) and BiodivR 1.0 (Hardy, 2005) softwares.

To account for common and rare species, we considered the diversity indices of orders 0, 1 (exponential of the Shannon index) and 2 (inverse of Simpson index). The diversity of order zero is completely insensitive to species frequencies and is better known as species richness (Jost, 2006). We used the Chao 1 index for diversity of order 0. This approach uses the numbers of singletons and doubletons to estimate the number of missing species because missing species information is mostly concentrated on those low frequency counts. The jackknife and minimum variance unbiased estimator (MVUE) were considered to estimate diversity of orders 1 and 2. These estimators were computed using the SPADE package (Chao and Shen, 2003).

Finally, we used a Correspondence Analysis to visualize the defined plant assemblages of the overstorey along axes, as well as a Canonical Correspondence Analysis to combine floristic patterns and environmental features in these groups. These multivariate analyzes were performed through CANOCO (ter Braak and Smilauer, 1998).

3. RESULTS

3.1 Floristic composition

3.1.1 Relative diversity of families in forest layers

Based on their relative diversities, 4 families (with more than 5 species) are the most representative of the upper arborescent layer. These are respectively *Fabaceae* (38 species), *Meliaceae* (13), *Sapotaceae* (9) and *Oleaceae* (6). *Rubiaceae* and *Annonaceae* are the dominant families in the lower arborescent layer with 40 and 13 species.

The other important families are *Euphorbiaceae* (13), *Malvaceae* (12), *Ebenaceae* (9), *Clusiaceae* (7) and *Apocynaceae* (7). Eight families rank ahead in the shrub layer: *Rubiaceae* (29 species), *Malvaceae* (10), *Euphorbiaceae* (9), *Phyllanthaceae* (8), *Anacardiaceae* (8), *Annonaceae* (7), *Ochnaceae* (6) and *Salicaceae* (6).

3.1.2 Relative density of species in forest layers

In the upper arborescent layer, *Scorodophloeus zenkeri* (*Fabaceae*) appears to be the most dominant species (Figure 1), followed by *Petersianthus macrocarpus* (*Lecythidaceae*), *Julbernardia seretii* (*Fabaceae*), *Polyalthia suaveolens* (*Annonaceae*), *Trilepisium madagascariensis* (*Moraceae*) and *Cynometra hankei* (*Fabaceae*).

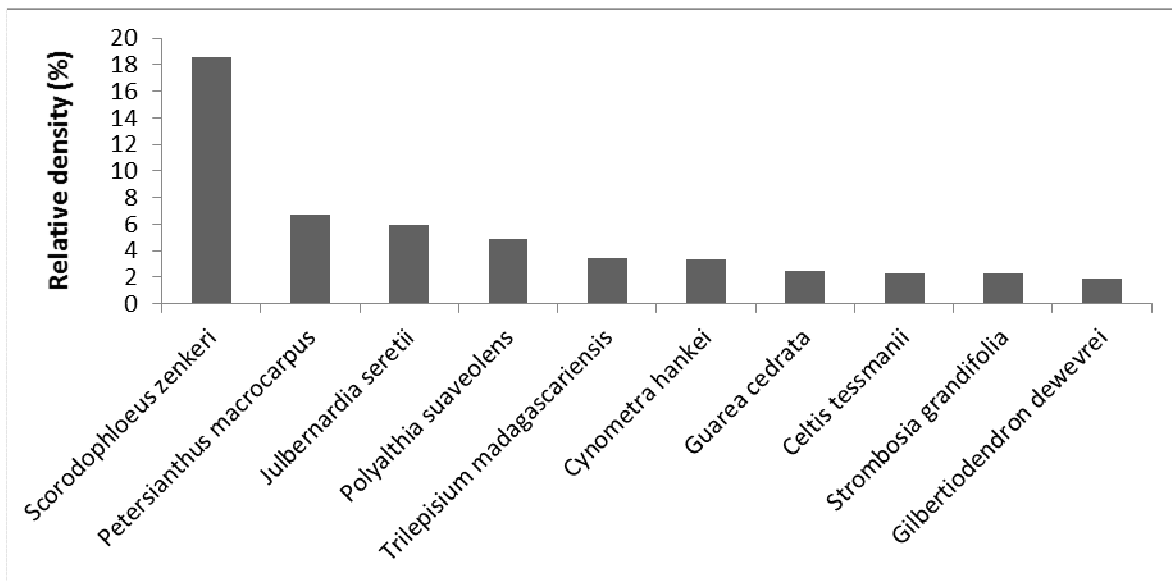


Figure 1: Ten Dominant Species in the Upper Forest Layer.

The lower arborescent layer (Figure 2) is dominated by *Staudtia stipitata* (*Myristicaceae*), *Aidia micrantha* (*Rubiaceae*), *Drypetes likwa* (*Putranjivaceae*), *Annonidium mannii* (*Annonaceae*), *Diospyros boala* (*Ebenaceae*) and *Cola griseiflora* (*Malvaceae*).

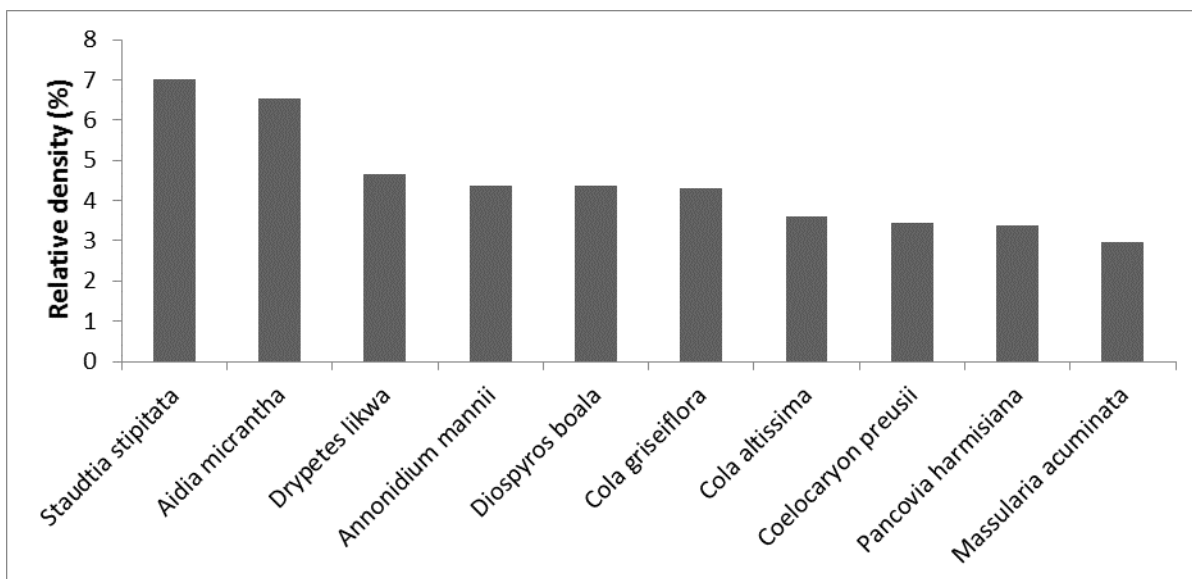


Figure 2: Ten Species Characterizing the Lower Arborescent Forest Layer.

Within the understorey, the shrub layer (ar) is almost exclusively dominated by *Scaphopetalum thonneri* considered in its high relative density (47.21%). 10 other species are well represented in this layer (Figure 3): *Rinorea obliquifolia* (2.96%), *Pancovia laurentii* (2.84%), *Microdesmis yafungana* (2.77%), *Euphorbiaceae sp. 1* (2.56%), *Alchornea floribunda* (2.39%), *Deinbolia acuminata* (2.30%), *Cola bruneelii* (2.25%), *Campylospermum claessensii* (2.22%), *Alsodeiopsis poggei* (2.07%) and *Myrianthus preusii* (1.80%). These species account for 71.37% of the total species in the layer ar.

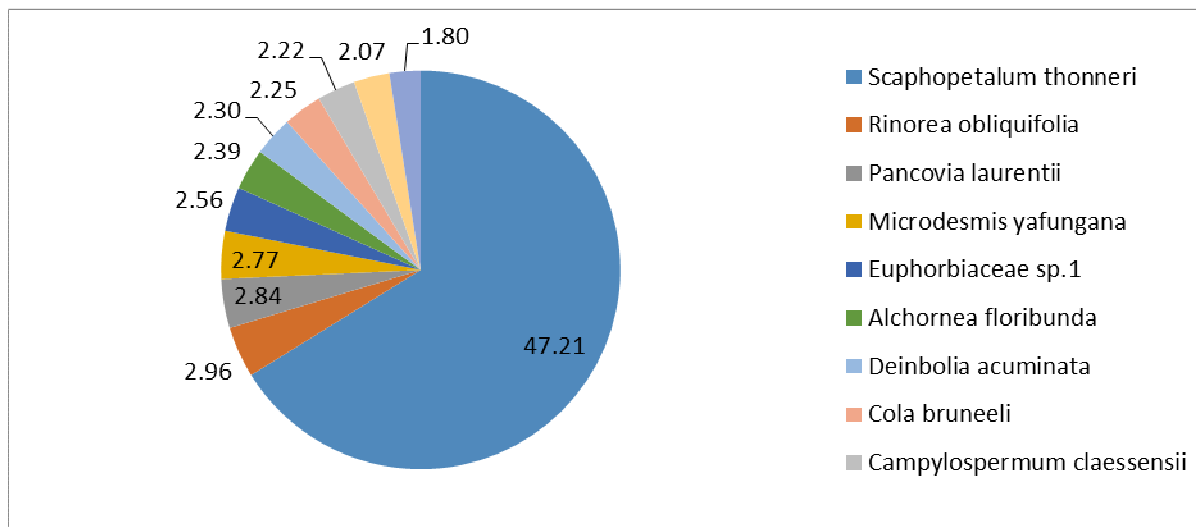


Figure 3: Eleven Most Frequent Species in the Understorey (layer ar).

3.2 Species richness and diversity

The number of species and individuals varied within the forest layers (Table 1). Mean values of these observations are showed in the Figure 4. While the lower arborescent layer holds the great number of species, the greatest number of individuals was observed in the understorey (230 individuals/0.05 ha in average). Based on the number of species and individuals, the upper arborescent layer (A) is less diversified.

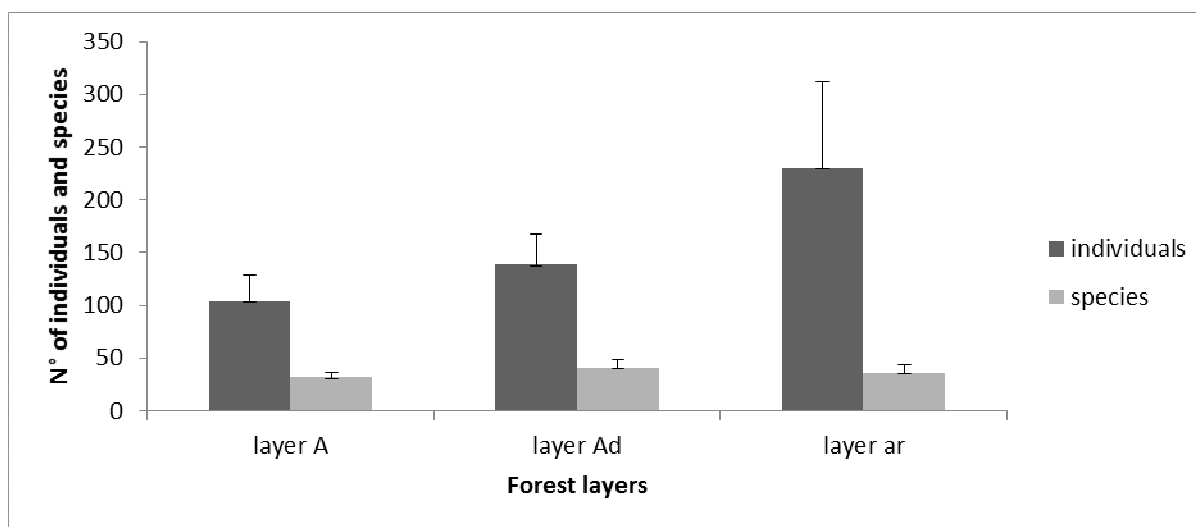


Figure 4: Variations Between the Number of Species and the Number of Individuals in the Woody Forest Layers. Mean values are given and the vertical lines stand for standard deviations.

In table 1, differences in diversity indices among the woody forest layers are indicated. Both the considered diversity indices (Shannon H, Simpson 1-D and Fisher alpha) are higher in the lower arborescent forest layer.

Table 1: Species Diversity in the Woody Forest Layers.

Species richness	Forest layers		
	Layer A	Layer Ad	Layer ar
Shannon H	2.86 (0.32)	3.28 (0.22)	2.33 (0.49)
Fisher alpha	16.64 (4.67)	20.52 (4.90)	12.77 (4.05)
Simpson 1-D	0.89 (0.06)	0.94 (0.02)	0.75 (0.14)
True diversity of order 0 (Chao 1)	37.2 (17.4)	44.3 (28.6)	52 (33.4)
True diversity of order 1 (Jackknife)	25.99 (4.48)	25.43 (4.94)	18.22 (4.76)
True diversity of order 2 (MVUE)	27.08 (0.22)	30.60 (0.43)	9.22 (0.39)

* Mean values are given and standard deviations are shown in parenthesis.

A comparison of diversity within these 3 woody forest layers, using the Shannon index, showed a significant difference, the layer Ad being the most diversified than the 2 others ($p < 0.001$).

3.3 Plant assemblages in the overstorey

Results are summarized by the Correspondence Analysis in the Figure 5. Three main plant assemblages were identified. At the first subdivision, one group immediately distinguished itself from others giving rise to an intermediary group which later partitioned into two other groups. On a total of 242 species included in the dataset, 61 species (25.21%) are found in the first group whereas the second identified group accounted for 64 species and the third group 36 species. 64 species were common to all the plots. Finally, 17 belong to an intermediary group, from species resulting from the second partition of the dataset.

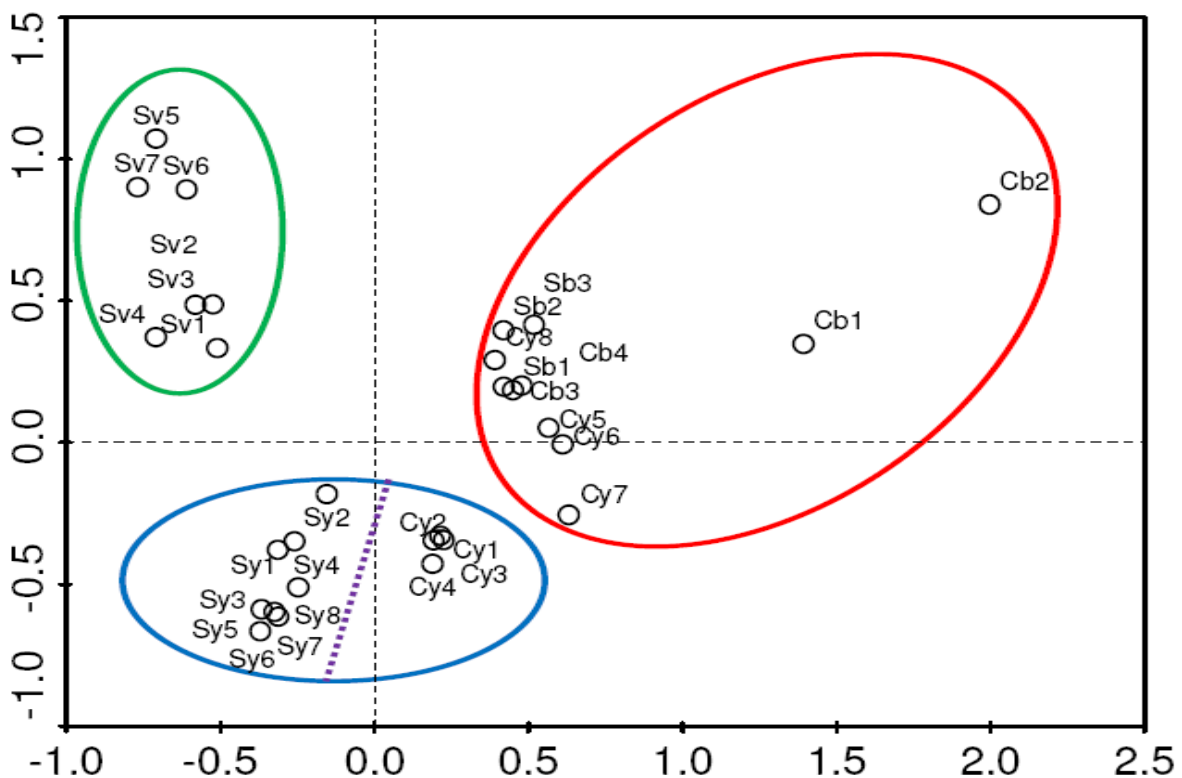


Figure 5: Correspondence Analysis Showing The Main Plant Assemblages Observed In The Overstorey And Displaying Three Main Groups.

Results are based on species composing the overstorey (upper and lower arborescent layers). Red: plots belonging to Group 1; Blue: plots belonging to Group 2 (within this group, the dashed line separates sandy and clay plots in Yoko); Green: plots belonging to the Group 3. The first and second axes account for 26.2% (total inertia: 2.307). Sy and Cy: plots established on sandy and clay soils in Yoko; Sb and Cb: plots established on sandy and clay plots in Biaro; Sv: plots established on sandy substrates in Yangambi.

These three main plant assemblages defining the overstorey are defined as follows (environmental factors explaining them are shown in Figure 6):

1) **Group 1:** This group is mainly related to clay substrates but with species particularly responding to the percentage of silt, soil acidity (pH) and the percentage of organic matter. Important species of this group include: *Pseudospondias microcarpa*, *Hannoa klaineana*, *Grewia trinervia*, *Trichilia gilgiana*, *Alstonia boonei*, etc. This group is based on 11 plots located in Yoko and Biaro.

2) **Group 2:** This group is composed of 12 plots established in Yoko and subdivided into 2 sub-groups according to their locations on sandy or clay substrates. Characteristic species of this subdivision are: *Cleistanthus mildbraedii*, *Julbernardia seretii*, *Anthonotha fragrans*, *Cola griseiflora*, *Diogoia zenkeri*, *Grewia pinnatifida*, *Gilbertiodendron dewevrei*, etc.

3) **Group 3:** In this group are found species inventoried within the 7 plots exclusively located in Yangambi. They are related to sandy soils but particularly distinguish themselves by the rate of phosphorus concentration and higher litter depths. Characteristic species are: *Cola altissima*, *Synsepalum subcordatum*, *Erythrophleum suaveolens*, *Pancovia laurentii*, *Dialium excelsum*, *Vitex welwitschii*, *Carapa procera*, etc.

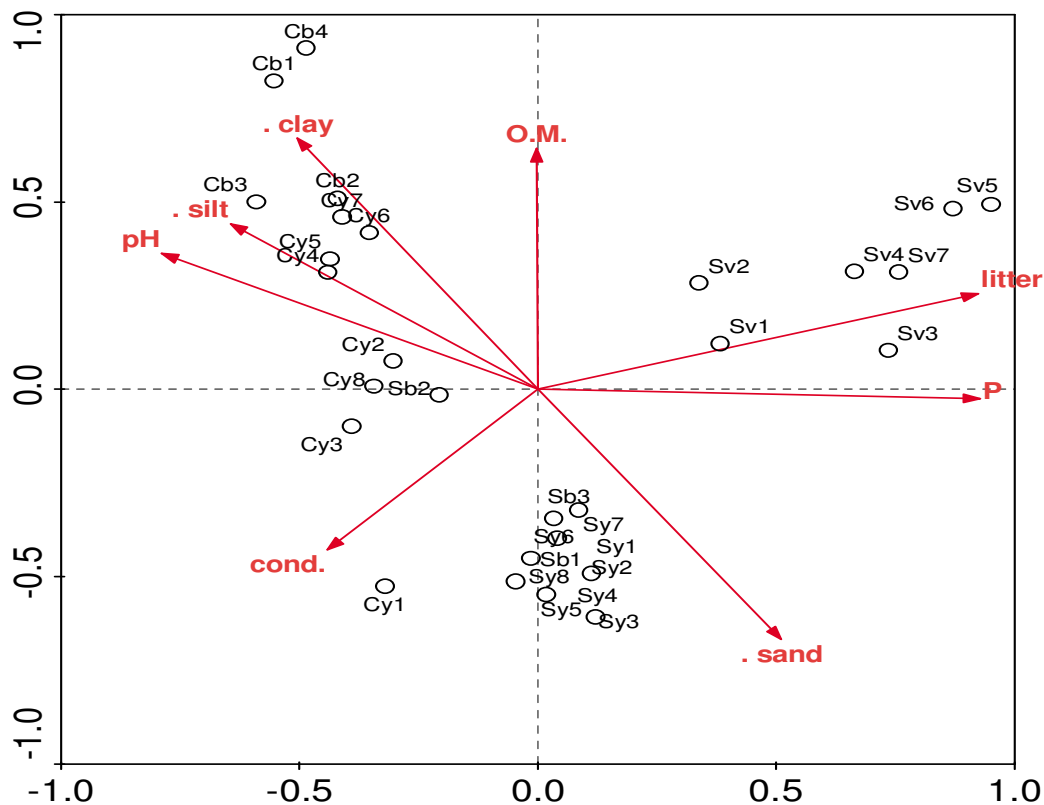


Figure 6: CCA Expressing the Relation Between Plots and Edaphic Variables in the 3 Groups Showed in Figure 5.

The first 2 axes represent 52 % (total inertia: 2.307). Sy and Cy: plots established on sandy and clay soils in Yoko; Sb and Cb: plots established on sandy and clay plots in Biaro; Sv: plots established on sandy substrates in Yangambi.

4. DISCUSSION

4.1 Floristic patterns and species diversity

4.1.1 Comparison with other floristic studies within the tropics

The most frequent families in our forests are also the most frequent in tropical rain forests in different tropical areas. In seasonally deciduous forest on limestone outcrops in Central Brazil, Felfili et al. (2007) also found that *Fabaceae* (*Leguminosae*) was the most dominant family. *Fabaceae* (*Leguminosae*) and *Euphorbiaceae* were among the 10 leading families in the Krau Wildlife Reserve, Malaysia (Nizam et al., 2006) and are also dominant in the Peruvian Amazon (Nebel et al., 2001), in the Eastern Ghats, India, (Jayakumar et al., 2009) and in Chiapetta seasonal forest, Brazil (Benvenuti-Ferreira and Coelho, 2009). Floristic studies conducted in Africa reveal similar results. In a tropical moist semi-deciduous forest from Ghana, Pappoe et al. (2010) found that the most significant families, in terms of the numbers of genera and species, were the *Meliaceae*, *Malvaceae* (*Sterculioideae*), *Fabaceae* (*Mimosoideae*), *Moraceae* and *Annonaceae*. Nshimba (2008) reports the same finding within the Mbiye Island (D.R. Congo).

The general arrangement of all species was found to show high density at lower DBH classes. In the Krau Wildlife Reserve, Malaysia, Nizam et al. (2006) noted that tree communities in the study plot were dominated by small size of trees whereby 1072 individuals was found with diameter of 5.0-14.9 cm and only thirty individuals in the largest diameter class of 55.0 cm and above. Similar observations are reported by many other authors (Prader, 2008; Giriraj et al., 2008; Addo-Fordjour et al., 2009; Christo et al., 2009; Hédli et al., 2009; Krishnamurthy et al., 2010; Pappoe et al., 2010; Woldemichael et al., 2010).

Using the Shannon index to test for diversity, our plant communities express some differences compared to some other tropical ecosystems. Shannon index was 2.86, 3.28 and 2.33 in the upper arborescent layer, lower arborescent layer and shrub layer, respectively.

In their floristic inventory of woody plants in Doon Valley (India), Seema et al. (2010) found that species diversity was 2.82 for trees and 3.52 for shrub. It varied from 1.80 to 3.11 and 1.79 to 2.68 for tree and shrub layers in the Similipal Biosphere Reserve (India) as reported by Mishra et al. (2008) and averaged 3.43 in Ghana (Pappoe et al., 2010). In the Kalimantan forest (Indonesia) dominated by dipterocarp species, Dubiharta (2010) found that Shannon diversity index was 3.54 for trees. Some other surveys report higher diversity values.

In tropical dry deciduous forest of Eastern Ghats, (India), Sudhakar et al. (2008) show that Shannon index (H) ranges from 4.11 to 4.89 whereas in Western Ghats (India), the observed values are 4.89 (Giriraj et al., 2008) and 4.86 (Pascal and Péliissier, 1996). Nizam et al. (2006) report a considerable high value (H = 5.74) in the Krau Wildlife Reserve (Malaysia) whereas Prader (2008) mentions the value H = 5.693 for all individuals dbh \geq 10 cm in lowland rain forests of the Piedras Blancas National Park (Costa-Rica).

4.1.2 Ecological significance of the floristic patterns

The fact that many families are common to the different ecosystems compared above is not surprising since they both belong to the same biome, the tropical rain forest.

Species diversity reflects differences when comparing our communities with some others, particularly from Asian and American tropical areas. Evidence from literature is that, within the tropical world, the richest communities occur on the eastern flanks of the Andes, in Peru and Ecuador (Gentry, 1988; Valencia et al., 1994). Very high diversities have also been recorded from SE Asian localities, whereas diversities of African forests are all much lower (Richards, 1973). Morley (2000) points out the fact that because of high diversities in tropical lowland forests, representatives of many taxa (families and genera) tend to occur together and that sympatry (same geographic distribution) can be observed within some families with many closely related species occurring in the same plot.

In the Americas, Mori (1989) reported 199 species in 11 genera for the family *Lecythidaceae* alone. In our case, though the figures are not identical, the most dominant families in the upper forest layer for example are the *Fabaceae* and *Meliaceae*, respectively with 38 species in 27 genera and 13 species in 9 genera.

One among the many ecological hypotheses put forward to explain the high diversity in tropical forests is the prevalence of specialized habitats. Furthermore, because species are distributed among different vegetation layers this results into much diversified niches, though in practice such layers are rarely well defined (Whitmore, 1998).

We defined four forest layers in our case and although we did not focus on the species distribution, it was almost evident that, in some sites, some species reflected a gregarious occurrence. This is the case of *Scorodophloeus zenkeri* and *Scaphopetalum thonneri*, respectively in the upper arborescent layer and in the shrub layer.

However, the dominance of the *Fabaceae* family (particularly the subfamily *Faboideae*) can also raise interesting questions about nitrogen uptake within these semi-deciduous forests. It is a common knowledge that

species from this group (*Faboideae*) are nitrogen-fixing thanks to their symbiosis with some bacteria. Nitrogen supply exerts strong control over the composition, diversity and productivity of many ecosystems (Reed et al., 2008).

4.1.3. Information species assemblages

Apart from soil texture, many factors actually act in shaping plant communities within the semi-deciduous forests under study. We showed that some of the observed plant assemblages correspond to a given type of soil while others contain species from plots established on different substrates. One of the cases is illustrated by species belonging to the first group, with plots on sandy soils in Biaro and those established on clay soils in Yoko. This situation is also visible in the second group which contains both species from sandy and clay plots in Yoko albeit further divisions clearly distinguish these two substrates. There is also a certain influence of soil chemical properties on these communities. More interesting is the influence of distance expressed by the demarcation of plots established in Yangambi which form a separated group from those located on similar substrates (based on their texture) in Yoko and Biaro. Therefore, if evidence of deterministic factors on these communities exists, there is also evidence of stochastic forces.

5. CONCLUSION

This study was mainly focused on floristic and structural patterns of the semi-deciduous forests within the Central Congo Basin. We mentioned vegetation features in each of the woody forest layers taken into account and which define both the overstorey and the understorey. If the *Fabaceae* family has appeared to be the most dominant in the upper arborescent layer, species belonging to the *Rubiaceae* family form the major group of plants occurring in the lower arborescent layer. The understorey (shrub layer) particularizes itself by the almost exclusive presence of the species *Scaphopetalum thonneri*. It has been observed that soil features play a major role in shaping these plant communities, more specifically in the overstorey where species partition themselves according to sandy and clayey soils.

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